MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1896–97.—PART III.

SECT. I.—MINUTES OF PROCEEDINGS.

9 February, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President, in the Chair.

(*Paper No. 3025.*)

"Cold Storage at the London and India Docks."

By HAY FREDERICK DONALDSON, M. Inst. C.E.

THE Australasian colonies, with their large surplus production, have not been slow, particularly since the low shipping rates of recent years have ruled, to take advantage of the increased demand for fresh meat which began to be felt fifteen or twenty years ago. Live bullocks have for many years been imported for killing, and this trade has recently increased largely, but beasts so imported must be slaughtered within fourteen days of arrival, and special lairages and slaughter-houses have been provided at convenient places, notably at Deptford on the Thames, and at Birkenhead on the Mersey. Beef, preserved during transit by chilling, or by retention at a temperature between 31° F. and 33° F., has also been imported, chiefly from America, and a fairly large quantity has been shipped from Australia and New Zealand in a frozen state. It is generally considered, however, that the texture of beef is injuriously affected by this process; but this deterioration seems to occur more from the thawing before use than from the freezing, as meat specially treated during the thawing period appears to sustain no loss of "bloom" or deterioration. Nevertheless, the bulk of the frozen-meat trade has been represented by carcases of sheep and lambs frozen perfectly hard.

Imported live-stock has to be rapidly dealt with in large quantities for quick despatch to the various centres of consumption, and special contrivances have to be adopted to extract the natural heat from the freshly-killed animals. Cooling chambers and machinery are therefore provided at the two places mentioned, where the Author is informed a temperature between 28° F. and 33° F. gives the requisite results in the best manner, the period occupied being between twelve and eighteen hours. At Deptford the dry-air system was adopted, the machines being constructed by Messrs. Haslam, of Derby, of the same type and general design as those to be referred to later at the Victoria Docks. Experiments have recently been undertaken at this place with ammonia freezers used to cool brine, through which the air circulating round the chambers is passed. These means have been adopted to enable the cold to be conveyed a considerable distance. At Birkenhead, the Linde process is employed. Although its working has not come under the Author's personal supervision, he has been enabled through the courtesy of the Engineer-in-Chief of the Mersey Docks and Harbour Board, and of Mr. T. B. Lightfoot, to obtain information as to the leading features of the system. It is a combination of the ammonia engine with brine coolers, which however are not conveyed into the chambers, but are placed in cooling-boxes supplied with an artificial-rain apparatus, through which atmospheric air is passed and so cooled. The air is then pumped into the chambers in which refrigeration takes place. This combination of systems enables the machinery to be placed in the basement, and the cooling-boxes at the top; so that the difficulty in working the cold-air system is obviated, because the cold air has merely to be pumped into the chambers, and gravitates from one chamber to another. The experiments with the machinery at the Corporation lairages at Deptford, referred to, embody somewhat the same principle.

For the transport of live beasts, comparatively slight preparations are necessary; but for the importation of mutton or beef in a frozen or chilled state, special provisions are required at the port of shipment, on board ship, and at the end of the voyage. These provisions consist of: (1) slaughter-houses, insulated chambers, and refrigerating machinery, at or near the port of shipment; (2) insulated chambers on board ship, and refrigerating engines for the preservation of the meat in transit, in many cases across the tropics; and (3) suitable insulated chambers, with the requisite cooling-machinery, and appliances for dealing with the receipt and delivery of meat whether frozen or chilled at the port of discharge.

The experimental stage of the frozen-meat trade with the colonies may be considered to have commenced in 1881, and by 1886 or 1887 it showed signs of becoming firmly established. The London and St. Katharine Dock Company were among the first to recognise the new trade, and constructed chambers for the receipt of frozen meat in vaults at the Victoria Dock in 1881; and the East and West India Docks Company followed the example by constructing wooden chambers at their South West-India Dock. The bulk of the trade has, however, been dealt with at the Royal Victoria Dock. The first store, owing to the system being entirely experimental both as to machinery and insulation, gave considerable trouble in working, due, no doubt, in a measure to the fact that the chambers were in vaults partially below the level of the water in the dock, which caused dampness. In the insulation of these chambers the thickness of insulating material was less than has since been found most suitable, and improvements in the machinery have given much better results. The gradual increase in the imports led the London and St. Katharine Dock Company in 1887 to extend their accommodation, and to discontinue the use of the original vault store; and a new store, with a capacity of 78,515 cubic feet, was erected in a more suitable position inside a wooden shed, which was at the time available. Further extensions have since been carried out by the London and India Docks Joint Committee, which came into existence in 1889, in the Victoria Docks, all the stores being contiguous. The storage-capacity at this dock has now attained 926,604 cubic feet, sufficient for 264,744 carcases of sheep, allowing 3·5 cubic feet per sheep, including gangways. The store at the South West-India Dock, already referred to, was built in 1884, and contains approximately 50,000 cubic feet. It is a wooden store similar to those at the Royal Victoria Dock, and has been regularly in use since its construction. In 1894 the increase in the bulk of imports pointed to the fact that further accommodation was necessary to meet the requirements of this still growing trade; and, after careful consideration, the London and India Docks Joint Committee decided to increase the storage-capacity at the Victoria Dock, and to erect another store at the West India Dock, in the centre of the north quay of the import dock (to accommodate vessels using this dock through the new entrance which had recently been constructed at the Blackwall end), and this store, of a capacity of 378,613 cubic feet, was completed in August, 1895. In 1894 also, the Joint Committee's clients pressed upon them the advisability of having a distributing store close by the Central Meat-Market at West Smithfield, and, a suitable site having been procured, the erection of the building, with a capacity of 365,717 cubic feet, was commenced at the end of 1894, and was finished early in 1896.

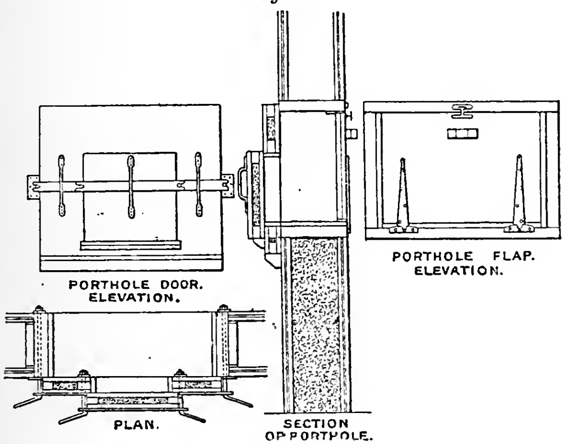
Fig. 1, Plate 1, is a key plan of the Victoria Dock Stores. They consist of two floors, Figs. 2, each about 10 feet high, so arranged as to have chambers on each side of the engine-room, which is placed in the middle. One end of the buildings abuts on the quay on which the meat is discharged from vessels. They are further supplied on each side with platforms generally used for receiving meat from the quay, and for the discharge into railway wagons of meat for despatch to the various centres of consumption. The rails upon which the meat-trucks run are in connection with all the railway systems in the country, so that meat can be loaded into the trucks of any railway company which chooses to send its own trucks for the purpose. The end remote from the water-side is provided with a platform for the delivery of meat into carts for transport into the meat market or for delivery by road. The side platforms are also supplied with small lifts by which the upper chambers are charged, curved rails being fitted at the top to automatically discharge the load when the ram of the lift has arrived at the end of its stroke.

The flooring of the ground floor is a few inches only above the normal level of the ground- or rail-level. Entrance to the chambers is obtained through small doors about 4 feet 6 inches above the latter, opening into lobbies at the level of the ground floor. From the lobbies, ordinary insulated doors open into the chambers, and by these means the rise of temperature through the opening of the doors to the outer air is reduced to a minimum; the coldest air remaining in the trough or tray, between the sill-level of the entrance door and the ground-level. The lobbies are so arranged that two chambers can be entered from one outer door. All the doors are fastened by butterfly bolts which tend to draw the shutting faces tightly to one another and so prevent leakage. These doors are only used for the entry of those employed into the chambers.

The meat is received and delivered through portholes, about 4 feet 6 inches above the ground-level and 1 foot 6 inches above the platform-level, made of two sizes, one inside the other, as shown in *Figs. 3*, the larger orifices being used for quarters of beef, and the smaller for frozen sheep. These ports are not hinged to the sides, but are made so that they can be lifted down and give clear entry or exit, without danger of the "shirts" or coverings of the carcases catching against the hinges, &c. They are supplied with a strip of blanket flannel round the edge, and, at each side, have a cockspur and hinged bolt, so that they can be screwed tight. These ports, as well as the doors, are constructed of two layers of matched-boarding, with brown paper and silicate cotton in the annular spaces, in much the same way as is hereafter mentioned in describing the main insulation of the walls, though the insulating material is thinner and of a different type.

All the buildings at the Victoria Dock are carried upon piles, spaced in the most convenient manner, the caps of which in turn carry the uprights for the chambers. The surface of the ground is covered to a varying thickness with 8 to 1 concrete, upon which is a layer of asphalt to prevent damp from rising. On the top of this asphalt, one layer of matched-boarding is laid and well tarred, and upon this two layers of stout brown-paper are placed; a second layer of matched-boarding and floor-joists are then set, having a scantling of 3 inches by 11 inches, spaced 1 foot 9 inches apart with binder-joists 11 inches by 4 inches. Both

Figs. 3.

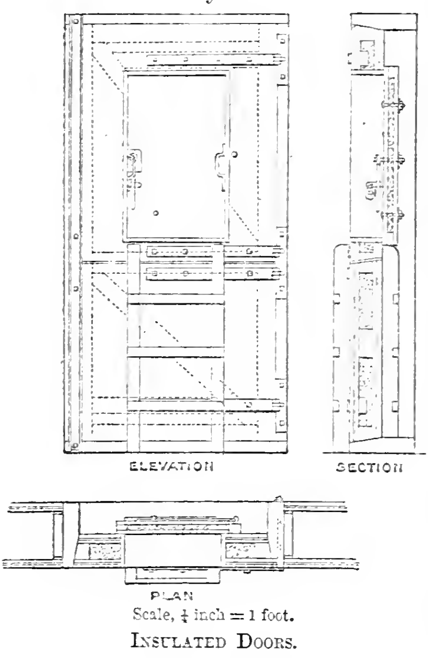


Scale, ¼ inch = 1 foot.

Insulated Portholes and Porthole-Doors.

the bearing-edges of these floor-joists are protected by strips of hair felt ¼ inch thick, and the space between the joists is filled with flake charcoal, the whole being covered with 1¼ inch tongued and grooved floor-boards. The walls are constructed in a similar manner, of studding 7 inches by 2½ inches and 3 inches by 11 inches, spaced according to the weight which has to be carried on the upper floor, and with two layers of brown-paper between each pair of tongued and grooved matched-boarding. Direct contact of wood with wood is prevented by strips of felt, in the same way as in the floors. The space is filled with charcoal as already described. The ceilings and upper floors are dealt with in the same way, and are protected outside by weather-boarding, or, where exposed to the weather, by corrugated iron. The roof also is covered with the latter material, having an ample air-space between it and the insulation. The end at which deliveries into carts are made is protected by a cantilever lean-to roof without front supports, and a similar type of cover is adopted at the side to allow railway-trucks to be loaded without exposure to the weather. The charcoal insulation is packed to a consistency of as nearly as possible 11 lbs. per cubic foot; but as this material is of a nature which does not lend itself to packing upwards or laterally, the lower sides of beams, transoms, sills, &c., are rammed full with silicate cotton to make the insulation complete over all parts of the chambers. The doors, *Figs. 4*, as already mentioned, are insulated, but silicate cotton only is used, as the shaking which results from opening and closing would soon bring the charcoal into such a compact mass as to leave spaces at the top, and make the packing tighter than is found most efficient. The general construction aimed at is shown in *Figs. 3* and *4*.

Figs. 4.

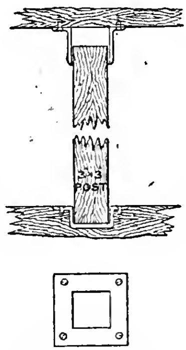


Scale, ¼ inch = 1 foot.

INSULATED DOORS.

The cold dry-air system being adopted at this dock, air-trunks are required for conveying the cold air from the engines into the chambers, and *vice versa*. These are ordinary timber trunks supplied at intervals in suitable places with sliding ports, so that the cold may be regulated, by opening or closing them more or less. In the more recent chambers, various small additions have been made, notably in the construction of movable bins to admit of parcels of meat bearing one mark being kept together, and so occupy as small floor-area as possible. These bins, *Figs. 5*, consist of small castings fixed into the floor and ceiling, with sufficient space to allow a 3-inch square post to be lifted up through the upper and dropped into the lower recess, and so obtain lateral support which enables carcases of sheep to be piled from floor to ceiling, even though the parcel may be a small one. All surfaces which are liable to wear from the passage of frozen carcases over them, are protected by ironbark timber, which has been found the most durable material in such places. This applies to the ports, to the sills of the doors, and to the shoots by which the meat stored in the upper chambers is delivered on to the various platforms. The upper chambers, as already mentioned, are served by a sufficient number of small direct-acting lifts, so arranged as to tip their cargo upon a table, from which it is passed by hand into the upper chambers. The chambers are lighted throughout with bulkhead electric glow-lamps, fixed in the ceilings, which answer their purpose well.

Figs. 5.



Scale, ¾ inch = 1 foot.

MEAT-BIN DIVISION.

The Author has carried out experiments with various classes of insulating material. A number of tin boxes, provided with drain-pipes, were made as nearly as possible alike, and embedded in the insulating material under test. Some four or five experiments were carried on at the same time to judge of the different materials when the conditions were identical. In these boxes were placed blocks of ice of as nearly as possible the same weight, and it was observed which class of insulating material retained the largest blocks of ice at the end of given periods. The results are given in the following Tables :—

EXPERIMENT No. 1.

—	Thickness of Insulating Material.	Original Weight of Ice.	Weight after Twenty-four Hours.	Weight after Seventy-two Hours.	Loss after Seventy-two Hours.
	Inches.	Ozs.	Ozs.	Ozs.	Per cent.
Peat (compressed and set in fossil meal)	9	95	81	59	37·89
Charcoal	11	96½	79½	56	41·97
Silicate cotton	4½	92½	73½	40½	56·21
Magnesia and asbestos fibre .	4½	93	73	40½	56·45

NOTE.—The Author thought it undesirable to consider further compressed peat set in fossil meal, as he found by experiment its powers of absorption of moisture to be so great as to constitute in his opinion a source of danger.

Experiment No. 2.

—	Thickness of Insulating Material.	Original Weight of Ice.	Weight after			Loss after Ninety-six Hours.
			Twenty-four Hours.	Forty-eight Hours.	Ninety-six Hours.	
	Inches.	Ozs.	Ozs.	Ozs.	Ozs.	Per cent.
Silicate cotton . .	6	104	88¾	76¾	58½	43·75
Sawdust	9	103½	86½	71	48	53·62
Peat	9	104	77½	56	26¼	74·75
Charcoal	9	104	88¾	78½	60½	41·82

Experiment No. 3.

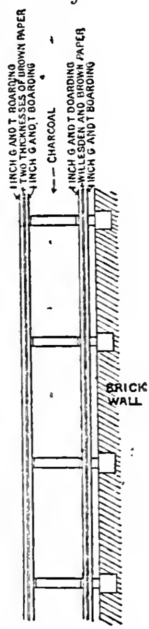
—	Thickness of Insulating Material.	Original Weight of Ice.	Weight after		Loss after Seventy-two Hours.
			Twenty-four Hours.	Seventy-two Hours.	
	Inches.	Ozs.	Ozs.	Ozs.	Per cent.
Silicate cotton	9	92	83½	72½	21·19
Charcoal	11	92	82¾	70½	23·36

Experiment No. 4.

—	Thickness of Insulating Material.	Original Weight of Ice.	Weight after		Loss after Ninety-six Hours.
			Twenty-four Hours.	Ninety-six Hours.	
	Inches.	Ozs.	Ozs.	Ozs.	Per cent.
Silicate cotton (loosely packed)	9	110	103	84¼	23·41
" "	9	110	101¾	80¾	26·59
Charcoal	11	110	100½	79	28·18
Vegetable silica	11	110	101½	76¾	30·22
Diatomite	11	110	99	73¾	32·95

It was not possible, owing to local circumstances, to build the new stores at West India Dock and West Smithfield of timber throughout, as at the Victoria Dock; and therefore the brick building which encloses them has been specially dealt with to meet the different circumstances. Where the insulation has been placed close to the wall it has appeared desirable to the Author to arrange as far as possible for ventilation for the outside skins of matched-boarding; and in carrying up the building, air-bricks have been provided at about every 5 feet in all directions, and the insulation has, by distance-pieces, *Fig. 6*, been kept away from the wall some 2½ inches to 4 inches, to allow of the free circulation of air, and also, in the event of slight leakage of cold through the insulation, to prevent sweating from the wall, which would materially shorten the life and render the insulation rapidly inefficient. In the West India Dock the whole of the store is placed upon a newly-constructed upper floor of the warehouse, the brick-structure being built upon the old walls, and where possible, the old floor-joists have been utilized.

Fig. 6.

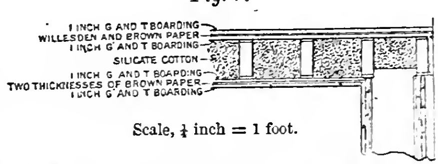


Scale, ¼ in.=1 ft.
INSULATION NEXT THE WALLS.

As a result of the experiments referred to, the Author thought it better to use silicate cotton in the floors and ceilings, *Fig. 7*. For some time this alteration has been found to give quite as good results as though charcoal was used throughout; but it has not been found to stand the shake and jar of the working on the floors so well as charcoal. It must not, however, be forgotten that it has been placed in a somewhat exceptional position, which has rendered its use difficult, especially as the Author endeavoured to get the silicate cotton lightly packed in the way the best experimental results were obtained. When in situations where there is no spring in floors, it has been found at least as efficient as charcoal.

The boilers and machinery, Figs. 9, 10, 11, Plate 1, and Fig. 14, Plate 2, are placed upon the ground level in an annexe at the back; and all the storage is upon one floor, supplied with gangways or passages for general use in discharging meat to railway trucks or carts by means of shoots and lifts at the back. The Author has introduced, with satisfactory results, a stage along the quay in front of

Fig. 7.



Scale, ¼ inch = 1 foot.

INSULATION IN FLOORS AND CEILINGS.

this store, at such a height as to require a minimum consumption of hydraulic power in the cranes discharging vessels; the lift over the combing being of the requisite height to deposit the slings direct upon the upper floor of the staging, where the meat is sorted and passed down shoots arranged at angles between 17° and 20°, over which the carcases travel by gravitation directly into the chambers. At the ends of the shoots are receiving-tables supplied with spring buffers by which any heavy carcases which may attain too great speed are stopped without damage to the meat. This method has proved to entail considerably less handling of the meat than any previous means adopted at the docks. The section through the centre of the building shows the general position and arrangement, in addition to the platform at the back. Lifts are adopted by which the meat in trucks can be lowered on to the platform and loaded into carts or trucks. This delivery platform is protected by a specially-designed roof to admit of the meat being loaded into carts or trucks without interference from the weather. A new system of sidings to give accommodation and access to all the railway systems, similar to that at the Victoria Dock, has recently been laid down. The chambers are furnished inside with movable bins in a manner similar to that already referred to at the Victoria Dock, and have been found to greatly facilitate the sorting of the various parcels of meat which have to be dealt with. There is a large chamber over the engine-room at a somewhat greater distance from the quay; this has, up to the present time, been worked experimentally by extending the shoot from the quay platform down the passage way, to enable carcases to travel by gravitation to the utmost extent possible, and from the point at which they naturally stop they are carried and passed by hand through the port provided for the purpose. A reverse shoot for delivery from this passage on to the quay-level for barges, &c., has also been supplied.

The West Smithfield store does not call for lengthy remark, as the general principles adopted are much the same as at the West India Dock stores; but, owing to the value of the land, it has been necessary to carry the building to a greater height in order to attain the requisite amount of storage. It has therefore been designed to consist of a basement, ground floor, and four floors above, Figs. 12, Plate 1. About half the basement is occupied by boilers, engines, and other machinery, Figs. 16, Plate 2, and is about 10 feet high in the clear. The ground floor is supplied along the front with provision for offices or shops, and has also an area into which the carts for conveying the meat from the docks or for delivery are drawn, and backed against a platform for rapid discharge. This floor has been arranged to be about 15 feet in the clear, one object being to admit the carts, and another to give sufficient height for hanging sides of beef, if required, in the large chamber on the south side. Provision has also been made for a chamber on each floor for the storage of butter, milk, eggs, cheese, and such produce separate from meat. The distribution into the various chambers on receipt of cartloads of meat, and the arrangements for deliveries, have been specially provided for by lifts working to each floor. The insulation is practically the same as that of the West India Dock store, but to meet the requirements of the ventilation at the back of the insulation, special shafts have been built into the walls to ensure a free current of air from top to bottom of the building. The great weight which has to be carried by the lower floor-supports of this building necessitated the introduction of iron columns which are not adopted elsewhere; but these are protected by insulating material specially arranged round them to prevent, as far as possible, any rapid variation in temperature to the detriment of the cast-iron of which the columns are made. On each floor of the building provision is made for a lobby or sorting-chamber in connection with lifts, which are arranged for the receipt and delivery of meat.

Machinery.—The Joint Committee has now in use refrigerating engines of three separate types. At the Victoria Dock, three pairs of Haslam dry-air machines are used, two having a capacity of 170,000 cubic feet per hour, and one of 120,000 cubic feet per hour. At the West India Dock, the type adopted has been the De la Vergne ammonia machine, with brine-conveyors in the chambers, also constructed by Messrs. Haslam of Derby. And at West Smithfield, the Hall carbonic-anhydride system was chosen. This installation is also supplied with brine-coolers in the chambers. At the South West-India Dock, the original store, already referred to as being built by the East and West India Dock Company in 1884, is worked with a pair of Haslam dry-air machines, of design similar in all essential points to those at the Victoria Docks, and supplied with steam from a pair of multitubular boilers. The dimensions of compressor-cylinders are 1 foot 9 inches in diameter by 2 feet stroke, and are therefore of smaller capacity than the machines hereafter described in detail. The general principle in each case is the same, in that the reduction in temperature is obtained by compressing air or gas, and cooling the reduced bulk, which is then expanded and consequently causes a great fall in temperature. Under certain conditions, each type has its own special advantages as well as disadvantages. For instance, with the cold-air type of machine it is necessary that the chambers to be cooled should be approximately upon the same level as the engine, because any attempt to lift cold air through a considerable height would at once cause the temperature of the air to rise, and consequent loss of efficiency in obtaining the refrigerating results required. It also necessitates the use of a large quantity of water for cooling purposes at a fairly low temperature, and can, therefore, only be economically applied when this commodity is procurable in practically unlimited quantities free of cost; and further, the horse-power required to do a given amount of work is much larger than with either of the other two types under review.

On the other hand, the advantages obtained are no doubt great, and the constant change of air in the chambers cannot fail to be good for the preservation of meat, more especially in cases, as must sometimes occur, of a carcase being introduced into the chamber in a slightly tainted condition. Again, the method of distributing the cold air through trunks has the effect of retaining the bulk of the snow in the snow-boxes and air-trunks; so that a minimum amount of snow reaches the chambers, and there is consequently less trouble in retaining an unaltered distribution of cold than with some other systems. In the case of ammonia engines, with brine-conveyors, as at the West India Dock, among the disadvantages may be mentioned, that there is a possible danger to the attendants from any failure or breakage of pipe or connection, which, with the best machines, may be a remote contingency, but is one which has been known to occur. In considering the selection of the most suitable machine, this should not be overlooked, and it was the Author's objection to the ammonia-conveyors in the chambers which led him to recommend the substitution of brine-conveyors. Again, the space occupied by the vertical compressor, which is no doubt the best type, is—in places where the price of land is a matter of importance—a point which must receive careful consideration. The formation of snow on the conveyor-pipes is also, no doubt, a great objection to this type of machine, as the pipes require periodical cleaning, and form a source of expense when the work has to be done, and of loss of efficiency when the pipes become thickly coated with snow, as they do after the system has been at work for some time. On the other hand, among the advantages may be mentioned that the brine can be circulated high above the position of the engine, whilst five, six, or more floors, can be as well cooled as when all the chambers are on the same level; and further, the power required is not great for the work to be done, and is very much less than with the cold-air type. Moreover, in no part of the machine need the pressure become really excessive, as it should not exceed from 100 lbs. to 120 lbs. per square inch. If the machine and all its adjuncts are properly constructed, the loss of ammonia in ordinary working should not be great, and consequently the addition of more ammonia should not be frequently required. The disadvantages in the carbonic-anhydride type are in some cases the same as in the ammonia type, because in both cases the cold is conveyed in pipes through the chambers, using brine as the vehicle; and the formation of snow on these pipes, as already mentioned, is objectionable. These machines, too, develop a considerable pressure in working, amounting to as much as 1,100 lbs. and 1,200 lbs. per square inch; and it further appears that additions of new carbonic-acid gas have to be fairly constantly made, although the prime cost of this gas, as compared with ammonia, weight for weight, is negligible. On the other hand, it is stated that a whole charge of anhydride carbonic-acid gas can be discharged into the engine-room without suffocating or injuring the attendants in charge. In both the ammonia-anhydride and carbonic-acid machines, the use of brine for conveying the cold into the chambers necessitates considerable attention in watching its specific gravity, which must not be allowed to fall materially below 1·20, and should be tested frequently to retain it as far as possible uniformly at 1·25.

The cold-air engines in use at the Victoria Dock, Figs. 13, Plate 2, may shortly be described as follows, taking the 170,000 cubic feet machine as an example. The steam-engine is of the ordinary horizontal, steam-jacketed compound, surface-condensing type, having a high-pressure cylinder 20 inches in diameter, and a low-pressure cylinder 31·4 inches in diameter, both with a stroke of 36 inches. They are set side by side, and actuate an ordinary crank-shaft carrying heavy fly-wheels. The pistons are of ordinary type, and their rods extend at both ends, one end actuating the fly-wheels, and the other being directly connected to the compressor-pistons. The compressor-cylinders, $25\frac{1}{4}$ inches in diameter, with a 3-foot stroke, are set on the bed-plate tandem to the steam-cylinders, and are water-jacketed for cooling purposes. The water for this purpose is circulated by suitable pumps from the coolers, hereafter described. These cylinders are fitted at each end with air-chests connecting the two ends; and into these the cold air returning from the chambers is drawn, being passed thence into the compression-cylinders by the reciprocating motion of the pistons through suction-valves in groups of four at each end of the cylinders. The compressors act upon the volume of air thus admitted, and apply a pressure of about 50 lbs. per square inch; the air then passes through suitable delivery-valves in groups of five at each end of each cylinder, the area of the five delivery-valves being equal to that of the four suction-valves. After being compressed and its temperature consequently considerably raised, the reduced volume of air has to be cooled, and this is effected by coolers arranged at the end of and apart from the engines. These coolers are similar to the ordinary surface-condenser for a steam-engine, and each contains about 1,000 tubes, round which the cold water (in this case pumped direct from the dock) is circulated, and is subsequently passed through the compressor-jackets, and thence through the engine-condenser before being returned to the dock. The circulating water is, as a rule, under a pressure of between 10 lbs. and 15 lbs. per square inch.

The process of drying the cold air is essential to this system of working. This is effected by passing it between drying-pipes, arranged in the return air-trunks, containing the cool air on its way back to be re-compressed after use in the chambers. By this means the out-going air in its compressed state is exposed to a large cooling surface, and its temperature falls considerably and causes condensation; so that the moisture in the compressed air liquefies, and the water so formed is collected in a trap and drained off at the bottom—the dried air being drawn into the chests of the expansion cylinders, where heat is further extracted by expansion. In this case the expansion-cylinders consist of two ordinary cylinders 19½ inches in diameter, with 36-inch stroke, fitted with expansion-slides, valves, &c., the cut-off of which regulates the pressure at which the machine is required to work. They have the same stroke as the compression- and steam-cylinders, but are of less volume than the former, being in this case in the ratio of 1 to 1·67. The pistons and valve-rods are directly connected with the pistons of the compression- and steam-cylinders and steam-valve rods respectively, so that all work directly in conjunction with one another, and thus the work given out in the expansion-cylinders is used again in doing useful work in the compression-cylinders. The expanded air is exhausted in a similar way to that in a steam-engine, and enters the snow-box, being at this point at its lowest temperature, averaging

65° below zero F., or 395° absolute temperature. The air is distributed through the refrigerator-chambers by rectangular shafts or trunks fixed in the centre of the top of each chamber, measuring 2 feet by 1 foot 10 inches, outside, and are constructed of wood. The distribution of air is further regulated by means of flaps or trap-doors at intervals along these trunks, which can be opened, shut, or partially opened at will, according to the temperature required in each chamber, which is usually between 18° and 22° F. The return air-trunks are placed at the sides of each chamber close to the ceiling, and measure 15 inches by 15 inches outside. These are also fitted with traps to regulate the outflow of the air, which, after passing through the drying-pipes, again enters the compression-cylinders. When the engine is running at its normal speed, the air passes through a complete cycle every two hours. The aggregate indicated HP. in the engine-room for cooling purposes is about 287. The steam for the cold-air engines, of which there are in all three pairs, is supplied from a battery of six boilers of the Galloway type. Only five of these, however, are usually under steam at the same time, and they also supply steam for the engines for the electric lighting of Albert Dock.

The de la Vergne compressors, Fig. 14, Plate 2, at the West India Dock consist of two sets of engines in duplicate, one being sufficient for the whole of the work required. They are horizontal tandem condensing-engines, driving one ammonia-compressor, 11 inches in diameter, which is placed vertically at right-angles to the axis of the engine, and supported on cast-iron A-columns, the connecting-rods of the pumps being worked directly from the crank. The cylinders of the engine are 11 inches and 18 inches in diameter, and the stroke of the engine and pumps is 28 inches. The high-pressure engines are fitted with an expansion-valve, and the packing-rings are of the Ramsbottom type. Each engine is provided with a governor. The slide-valves are of ordinary construction driven by eccentrics fixed upon the crank-shaft with a rocking shaft and levers between to secure a direct lead. The surface-condenser, circulating-pump, air-pump and feed-pump, together with their driving-engine, form a compact group on one bedplate, and are separate from the engine and pump already referred to. The pumps are driven by a connecting-rod from the engine-crank, and the circulating-pump is double-acting. The piston of the air-pump is fitted with a Ramsbottom ring, and the feed-pump plungers are brass-lined. The engine-room also contains the ammonia-cylinders, and the cooler is supplied with all the requisite pressure and vacuum-gauges, which are brought to a convenient point on the end wall. The ammonia-condenser is placed in a half-floor above the boiler-room, and is supplied with water pumped from and returned to the dock after use; and every advantage is taken of the atmospheric temperature in order to obtain the most efficient condensation possible by this means. The steam is supplied by three boilers of the Galloway type, which also supply power for the electric-light engines in the neighbourhood of this installation.

In the ammonia process of refrigeration, the gas is drawn from the cooler and is compressed to 90 lbs. or 150 lbs. per square inch, according to the temperature of the condensing water. After compression, it is passed into an oil-separating cylinder, and thence to a nest of condenser-coils exposed to atmospheric air with a constant stream of water flowing over them, in which course it is liquefied. It then flows into a storage-tube or cylinder about 12 feet long by 12 inches in diameter, whence it passes through the expansion-cock into the cooler where the brine is cooled by the evaporation of the ammonia. The cooler contains coils of pipes confining the brine, which acts as the cooling medium, and is circulated by means of pumps through chambers containing about 11 miles of piping. The aggregate indicated HP. in the engine-room for one pair of engines with appurtenances is about $70\frac{1}{2}$.

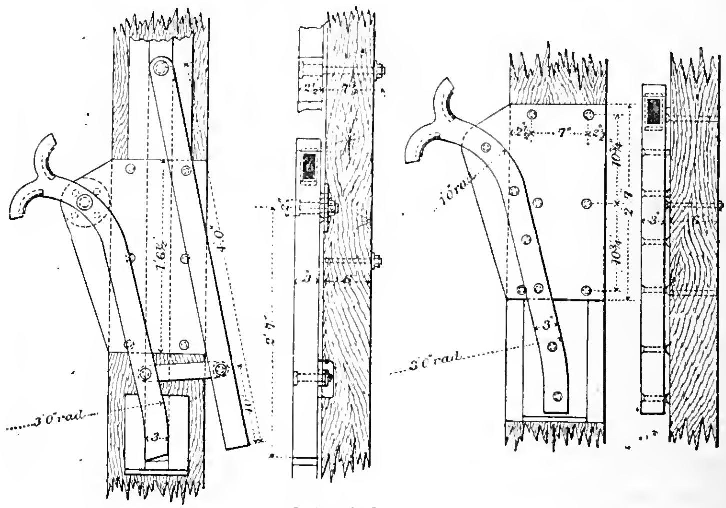
The carbonic-anhydride machines, Figs. 15 and 16, Plate 2, supplied by Messrs. J. and E. Hall for the West Smithfield cold store, are two in number, and are each of sufficient power and capacity to cool the whole store; the plant therefore is entirely in duplicate. The engines, Figs. 15, are of the compound tandem jet-condensing type with cylinders 10 inches by 17 inches in diameter and 21 inches stroke, driving a compressor $5\frac{1}{2}$ inches in diameter and 21 inches stroke, the ram of which is connected with the high-pressure tail-rod. They are fitted with variable expansion-valves and are provided with heavy fly-wheels. The pistons are of the Ramsbottom type, the high-pressure piston being a solid block with four steel springs. The low-pressure piston is fitted with two common springs with a cast-iron T division-piece. The bed-plates, cylinders, and fly-wheels are of cast-iron, and the piston-rods, valve-rods, connecting-rods and crank-shafts are of steel. The condenser is situated directly beneath the crank-shaft, and the air- and circulating-pumps are worked by eccentrics fixed on the crank-shafts, which are constructed on the bucket-and-trunk principle, and are double-acting. The main bearings are fitted with brass bushes lined with Babbitt metal. The compressor is a solid steel forging with the various chambers drilled out of the solid, and gun-metal screwed glands are provided. The gas after compression is passed into a condenser, consisting of a cylinder 9 feet 6 inches high by 6 feet 6 inches diameter, in which the compressed gas is cooled and condensed by passing through pipes surrounded by water; the contents then pass into the evaporator 10 feet high by 7 feet diameter, where expansion takes place. The coils in which this is effected are surrounded by brine which gives up its heat, and forms the reservoir from which the cooled brine is pumped through pipes having an aggregate length of 14 miles in the chambers. The indicated HP. for one pair of engines, with appurtenances for refrigeration purposes, is about 74.

At the Victoria Dock the other machinery consists solely of lifts for serving the upper floors. These are of the ordinary direct-acting type, but tipped automatically at the end of the stroke, so as to discharge the loads on to a table from which they are removed into the various chambers by men in attendance. Light for the chambers is obtained from the Joint Committee's central electric-lighting station at the Victoria Dock.

At the West India Dock, four hydraulic lifts, supported on one side only in the form of a bracket, comprise all the machinery which has been found necessary for the delivery. The bulk of the work of transporting frozen carcases is carried out by gravitation. Electric light for this store is obtained from special engines and dynamos in an adjoining room, in communication with the main engine-room, and receiving steam from the same boilers. The dynamos were supplied by Messrs. Crompton and Company, and are directly attached to Belliss high-speed engines.

At the West Smithfield store, owing to the height of the building and other causes, a somewhat more extended use of machinery is required. Electric light is supplied from Siemens dynamos attached direct to Belliss high-speed engines, and for the receipt and discharge of meat there are four lifts. Two of these are of ordinary type supplied by Messrs. R. Waygood and Company. They are capable of carrying passengers, but are particularly adapted to the delivery of meat in trucks. The receipt of meat is dealt with by two specially-constructed lifts, Figs. 17, Plate 2, designed by the Author; so arranged that carcases of meat are loaded at the receiving platform, where the attendant in charge is already informed by the tallyman as to the chamber into which the various loads are to go. By levers, he throws the points, *Figs. 18* and *19*, over to the floor on which the carcases have to be discharged, and starts the lift; after which he need only let the lift run its course; as, when it reaches the point at which the turn-out has been prepared, an automatic cut-off in connection with the lever comes into play, and the machine is stopped at the exact place at which the best result in discharging is to be obtained. In practice, however, the driver generally slackens the speed of travel just before reaching the point of

Figs. 18. *Figs. 19.*



Scale, ½ inch = 1 foot.

TIPPING-LIFT SWITCHES.

discharge, so as to avoid the jar which results from the automatic cut-off due to the high speed at which these lifts travel.[1] The meat so discharged on to a table overhead, naturally falls away by gravitation, and passes along shoots directly into the chamber for which it is intended; so that from the time the meat is placed upon the lift at the bottom, it only requires to be directed into its proper shoot from the receiving-table, and has not, of necessity, to be again lifted until it reaches the chamber in which it has to be stored. There are three Lancashire

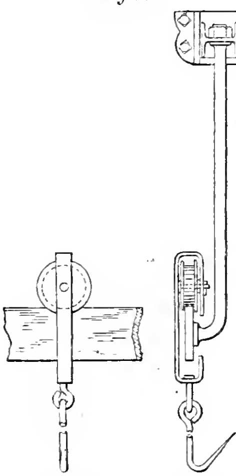
[1] A model of two floors fitted with this arrangement was exhibited.

boilers at this station, which supply steam not only to the refrigerating engines but also to the electric-light and other auxiliary engines. The installation is further supplied with two large tanks on the roof of the building, having a capacity of 20,615 gallons and 8,928 gallons respectively, the larger one being used for cooling water for the gas-condensers, and the smaller for the cooling water of the steam-condensers. These tanks are supplied with an arrangement of pipes and Körting nozzles for spraying and cooling the water for repeated use. The circulation of the water in the tanks is effected, in the larger by centrifugal-pumps driven off a countershaft by the main refrigerating-engines, and in the smaller from the steam-condensers by an ordinary direct-acting pump.

The chambers are supplied with suitable thermometers, but the registration of temperature necessitates the engine-driver or other attendant visiting each chamber, and this, for many reasons, is objectionable. It has been the Author's desire to discover some economical and reliable arrangement to enable the readings of each chamber to be taken in the engine-room. It is true that with the brine-conveyors a general idea of all the chambers can be obtained at the West India Dock by reading the delivery and return temperatures of the brine; and this is possible more closely at West Smithfield, where, though the delivery is by a large main, each chamber has its own separate return, so that with practice the temperature of a chamber can be approximately gauged. But even this is hardly as near as could be wished, and after several trials the Author has come to the conclusion that the arrangement which gives the results he has wanted has been a system of electric temperature tell-tales, designed by Mr. C. E. Vernon, one of his assistants, which have been applied at West Smithfield, and the use of which (if they continue to work satisfactorily) the Author hopes to see extended to other stores.

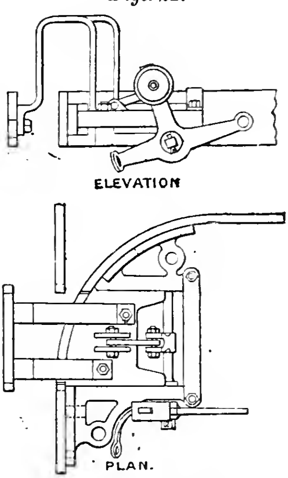
Each chamber is supplied with a small box containing a metal spring (a compound coil of steel and brass), one end of which is securely fastened to a backboard with a variable fulcrum, while the other end plays loose, varying its position according to the expansion and contraction of the metals of which it is constructed. At the loose end an electrical contact is provided, and is brought into play by a specially constructed small magnet, which becomes operative as soon as the circuit is completed by pressing the button in the engine-room. Over the arc, through which this loose end travels according to the temperature, six points, in the case of West Smithfield, are so placed as to coincide with the actual temperatures. However many chambers there may be, all that is required for the communication is a six-wire cable

Figs. 20.



Scale, ¾ inch=1 foot.
MEAT-HOOK RUNNERS.

Figs. 21.



Scale, ¾ inch=1 foot.
MEAT-RUNNER SWITCHES.

carried to the engine-room, coinciding with the six points referred to. Each chamber needs a magnet-wire and a return-wire. The average requirements for indication at West Smithfield are considered to be between 16° and 26°, and it is found sufficient to take indications for 16°, 18°, 20°, 22°, 24°, and 26° F.; the apparatus, however, can be calibrated to register any temperature required, by an adjusting screw. The individual wires in the six-wire main are carried to their respective drop-disks on the indicator-board in the engine-room, which carries six drop-disks; and the two other wires referred to are also connected with the push button of each chamber. The circuit is completed by pressing any of these buttons, and the indicator drops at the degree at which the temperature of the chamber (to which the button pressed refers) stands. If, however, the temperature is between any of the numbers shown on the indicator board, say at 19°, for which there is no disk, both 18° and 20° will fall, thus showing the temperature is between those two degrees, and for practical purposes this is sufficiently accurate. If the temperature coincides with any of the degrees shown on the indicator-board, that figure will fall on pressing the button. Although the apparatus has only been at work for a comparatively short time, it seems to give simple and more reliable working than any other apparatus which the Author has tried.

The arrangements for hanging chilled meat are shown in *Figs. 20*, and the points and crossings in *Figs. 21*.

Trials.

The Author has made two or three trial runs of six hours each at the Victoria Dock, North Quay, West India Dock, and West Smithfield, to obtain comparative results as to ordinary working expenses; and would append the full data to this Paper, but for the fact that the conditions ruling at each place vary so much that erroneous deductions might readily be made if submitted exactly in the form taken. It may be of interest to mention some of the divergent conditions which render it almost impossible to give comparative results. As to coal consumption, the requirements of each place necessitate, or at least render desirable, the use of coal of different qualities, and therefore of varying prices. Again, the working staff at each place varies according to the local requirements, and is more or less numerous according to the circumstances prevailing at each place; if, however, the actual requirements of each type of engine only were provided for, it is probable that the variations in these charges would be considerable. Besides these points, there are others much more difficult of adjustment, such as the proportion of empty and occupied space at each store; the relative temperatures of the meat at the beginning of a trial as compared with the working temperature of the store; and the relation of the working temperature in force at each store to the outside temperature.

If one set of chambers is less filled than another, and if all communication with the outside temperature is kept effectually cut off, it will probably be admitted that the former chamber will be more rapidly cooled than one stored with a larger quantity of meat, the specific heat of atmospheric air being much less than that of animal tissue. Such a case would manifestly give results which would be entirely misleading when dealing with the question of cost of working. Again, though the quantity of meat stored in two sets of chambers of about the same capacity may be identical, the actual temperature of the meat in each case at the commencement of a trial run becomes an important factor in dealing with the recorded results. Let it be assumed that in one set of chambers the stock of meat has for a week or so remained unchanged, and that the average temperature in the chamber has been maintained during a lengthened period without change at, say, 19° F. The meat will have assumed that temperature, and therefore, during the trial run, the machinery has only to maintain it. Let it be assumed that in the other set of chambers, though the normal chamber-temperature has been maintained at an average of 19°

during the same period, but that the stock of meat has varied from day to day by large deliveries and corresponding receipts; that the meat received has been kept at an average temperature of 22°; and that in course of transit a considerable portion of each carcase has risen in temperature to 28°. It is clear that in this second case the refrigerating machinery has to do more work to retain the desired temperature at the suggested 19°, and that, consequently, very erroneous results may be obtained unless these matters are taken into account. The error may be the other way —that meat which has been kept uniformly at a temperature of 19° may be housed with the carcases about that temperature in chambers of which the normal thermometer-readings are, say, 21°, and in such a case the error would be in favour of the machinery. The third point dealing with the relative working temperatures is one which does not call for many words; for it is evident that there will be less work on an engine which is required to maintain a temperature of 21°, than on one which has to maintain 16°.

The Author has endeavoured, with the data obtained at the various trials, to make allowances for all elements, and has taken as his basis cubic-foot-degrees (that is to say, the number of degrees the temperature was lowered in each case multiplied by the contents in cubic feet of the chambers operated upon; and he finds that there is little difference in the actual cost of working the three types of machines, which comes out between 4*d.* and $4\frac{1}{2}$*d.* per 10,000 cubic-foot-degrees. It was not possible to make the trials upon identical lines throughout, as such a state of things could only be obtained by having no meat in the chambers, which the exigencies of business would not allow. In the descriptions of each machine, the I.HP. of each is mentioned, and it is instructive to note so wide a difference in the horse-power, the working-expenses being so nearly approximate, after making allowances for the above-named difficulties and treating all machines upon the same basis with regard to the cost of water used for cooling purposes.

The various stores at the Victoria Dock were built by the Joint Committee's staff, without contractors; but the stores at the West India Dock and West Smithfield were built under contracts entrusted to Messrs. Dove Brothers, and Messrs. J. Mowlem and Company, respectively. The Author desires to record here his thanks to those of his staff who have from time to time been entrusted with matters relating to the several stores described.

The Paper is accompanied by nineteen drawings, from which Plates 1 and 2, and the *Figs.* in the text have been prepared.

Discussion.

Mr. J. Wolfe Barry, C.B., President, was sure that the members would all recognize from the Author's interesting Paper that an important trade had grown up and had become flourishing within a comparatively few years. It was a trade of the greatest interest to everybody in the United Kingdom, as well as to their brethren in the Colonies. It was also of much importance from the point of view of the British producer, who would have to take the facts that were set out in the Paper very seriously into his consideration. He could imagine that the Colonial Secretary might view the work of the Author with the greatest admiration, and that the Minister of Agriculture would look at it with very different feelings. However that might be, the members could all see that the works which had been described were not only of a most extensive nature, but that every detail connected with them appeared to have been carried out with the utmost care, and with much scientific precision. He was certain he was speaking the sentiments of the members in saying that they were very grateful for the Paper, and admired the talent which had produced such interesting buildings, and such carefully-designed machinery. They were also obliged to the Author for the fine set of diagrams which he had prepared to illustrate his Paper. Mr. Wolfe Barry.

Mr. Donaldson desired to state that the work at the Victoria Dock had been commenced by his predecessor Mr. Robert Carr, to whom the credit of the initial stage was largely due, and many of the results of whose labours the present works had embodied. The duty obtained with the automatic lift, a model of which was on the table, showed that it would do about three times as much work in a given time as the ordinary box type of lift, with one-third the number of men. With the ordinary type it was necessary to have trucks, and men to manipulate them, with separate lift-drivers for each lift. At present one man worked the whole from the ground floor. The carcases had not to be touched, except to guide them into separate shoots leading into the chamber. Mr. Donaldson.

Mr. Montague Nelson observed that one of the chief objects of Companies working refrigerating processes had been to place their machinery as near to the flocks of sheep as possible, and as far from the port as the risk of having sheep thawed before they Mr. Nelson.

Mr. Nelson. could be placed on board ship would allow. It was well known that driving sheep long distances produced a state of fever which was very detrimental to the meat; it was therefore desirable that they should be killed as near the pastures as possible. In Australia it was found that refrigerating machinery could be erected 200 miles, or 300 miles, from the port of shipment; and there was no difficulty in carrying frozen bodies by railway that distance in properly insulated trucks. In an insulated air-tight truck, with only 3 inches or 4 inches of insulation, packed full of frozen meat at a temperature of 15° or 20° F., absolutely excluding air and heat, the temperature would not rise for a very long time, and it could be taken with perfect safety 200 miles or 300 miles. That was very important, and had a bearing also on the trade in London. The Colonial Consignment and Distributing Company had refrigerating stores on the Thames, opposite the Temple Gardens, where frozen sheep were taken up the lift at the rate of about one thousand per hour. The lift was not exactly like the one described, but it raised the sheep very rapidly from the lighters to the floor where they entered the chambers, and proved very effective. As to the advisability of bringing sheep from the ships in lighters, say from the Albert or the Tilbury docks, so far up the Thames as between the Blackfriars and Waterloo bridges, when it was remembered that in Australia they were taken 200 miles or 300 miles by rail it would appear that in a properly constructed lighter, with the heat and air excluded, 10 miles, 20 miles, or 30 miles up the Thames was a comparatively trifling consideration. It was, as stated in the Paper, generally considered that the texture of beef was injuriously affected by freezing, but he did not think it was so. In experiments on the subject,[1] Dr. Rideal had been unable to discover that the meat was injured in any way by the process of freezing. In the early days of the frozen-meat trade it had been said that the cells of the meat were burst by the freezing, just as water-pipes were burst by the winter's frost, and that when the meat was thawed the cells were burst and the juice ran out, so that the meat was spoiled. On making careful enquiries and experiments, he had found in the first place there were no cells to burst. Meat consisted of bundles of fibres, with juice between them; but there were no cells. He might be permitted to give the results of a few experiments that he had made in connection with his process for defrosting meat. He believed that the popular error

[1] *The Hospital*, vol. xxi. pp. 265, 283, 314.

Mr. Nelson.

on the subject had arisen from the fact that, when frozen beef was brought into the outside atmosphere at a temperature of perhaps 50°, 60°, or 70° F., the condensation of moisture of the atmosphere on it was very great. It became wet, and when it was cut in slices it was colder inside than out; there was condensation on the cut parts, and the water mixed slightly with the juice of the meat and ran away, giving the impression that all the juice was running out of the meat. It was simply the moisture of the atmosphere condensed upon the meat, just as water was condensed on any cold body. It had occurred to him that to remedy the evil the beef should be heated to the temperature of the outside atmosphere without allowing the deposit of moisture upon it, in a warm dry atmosphere. It was easy to obtain the warm atmosphere, but the question was how to get it dry. He had come to the conclusion that the simplest way was to freeze the moisture out of it. He had fitted up a small room with ammonia pipes running along one side and steam-pipes along the floor. The meat was hung in the room, and all the moisture in the atmosphere was immediately frozen as snow on the cold pipes. The room was heated gradually to about 60°, and the result was that the beef was defrosted without any deposit of moisture upon it. In one of his experiments, carried out in a room holding about ten quarters of beef, the temperature was raised to about 60°, but notwithstanding that, and even when it was raised to 90°, the pipes remained with about $\frac{1}{2}$ inch of snow on them, derived from the moisture from the atmosphere. After he had thawed the ten quarters of beef he had weighed the moisture, thawing off the snow, and found that there was 160 lbs. of water on the pipes. Probably that amount of water would have been deposited on the meat by any other process; and that, he believed, was the cause of the disrepute into which frozen beef had fallen. By the application of the defrosting process no one could tell from the appearance of the meat, or its taste, or anything else, that it was not ordinary fresh-killed meat. The first frozen meat had been brought from Australia in 1880. From that time to the end of 1896 37 millions of sheep and lambs had been imported into Great Britain. The number imported in 1880 was only 400, while in 1896 the number was $5\frac{3}{4}$ millions, besides 250,000 cwt. of beef. That was independent of the chilled meat from the United States and Canada. It was actually frozen meat coming from the Australian Colonies or from Argentina. The possibilities of the trade were enormous. It appeared that the discovery of refrigerators would probably revolutionize the food-supply of the world. He believed

Mr. Nelson there would be refrigerating stores in every town in England. There was in London alone a storage capacity for more than 1,000,000 sheep—a very large number when it was remembered that the total number of sheep in England was not more than about 27,000,000. The process applied not only to meat, but to butter and many other supplies. Within the last few days his Company had sold excellent peaches from South Africa at 4*d.* or 5*d.* each, leaving a good profit to the South African grower, since the cost of bringing peaches to England from the Cape was not great. Now that fresh meat could be conveyed 12,000 miles, the result had been that the supply had exceeded the demand. Meat was not like most other commodities, and a reduction in price did not necessarily lead to a largely increased consumption. Australian mutton was now to be obtained at 2*d.* per lb. Householders would remember how the price of meat increased between 1852 and 1872. In 1870, importations began from the United States, and they now formed 25 per cent. of the whole consumption in England. In 1880 the importations commenced from the Australasian Colonies and from the River Plate, with the result that meat was now cheaper than it was in 1852.

Hon. W. P. Reeves. The Hon. W. P. Reeves had the honour to represent a Colony which was sending yearly to Great Britain between 100 million and 150 million lbs. of frozen mutton. New Zealand did not export beef to any extent to Great Britain. For beef, such a defrosting process as the interesting one described by Mr. Nelson was a necessity; in the case of mutton it was in the nature of a luxury, since any intelligent person having a decently-built house ought to be able to successfully thaw his own mutton without trouble. On behalf of New Zealand he thanked the Author, who had not only studied and mastered the subject, and gained information of great value to himself and to the Dock Companies and owners of stores, but he had had the industry and generosity to make it public for the benefit of others. It was quite in the spirit of the Institution that scientific information should be made public for the benefit of science. Cold storage was now a question affecting not only London and two or three of the principal parts of the country, but every place of any magnitude in the United Kingdom, as well as in most other civilized countries.

Sir Alfred S. Haslam. Sir Alfred Seale Haslam observed that reference had been made in the Paper to an experiment tried at Deptford by his firm. It was more than experiment, for last season the chill-rooms available had been used for chilling eight hundred sides of beef per day of sixteen hours; and, now that the new rooms were finished, two thousand sides could be chilled in the same time. The plant consisted of an ammonia compression machine, combined with the Haslam cold-blast battery. In Fig. 1, Plate 2, the Author had shown a cold-air machine applied to a cold store at Victoria Docks, which Sir A. Haslam had fitted up many years ago. It was, he believed, one of the most successful stores of the kind in the kingdom, and was worked with the dry-air machine on the compressed-air system. It was fixed in a central position very favourable to working, but with a building like that erected at Smithfield by the Author, however good the results might be at the store No. 1 at Victoria Docks described in the Paper, still better results would have been obtained. From the cubical capacity of the store at Victoria Docks, and the surface of the wall and the loss by conduction, there would be found an immense interchange of heat. In the other case, at Smithfield, the interchange was vastly different. In the case of the Victoria Dock store (which he believed had answered fairly well), that was an unfavourable comparison with the Smithfield store. He desired to state a few of the results of the dry-air machines on board ship, and to call attention to a machine he had erected on board one of the first steamers that ever brought a cargo of meat to England. At that time there were three steamers fitted with Haslam machines, carrying 200 tons of meat per cargo. The walls of the chambers were of very large area. The steam-pressure was about 70 lbs. per square inch. It was a comparatively small machine, and it required about 30 cwt. of coal per day in bringing 200 tons of meat from Australia to England. A few days ago he had looked at some records of a recently fitted boat, one of a number of the same kind. They had brought from Australia about 90,000 carcases of sheep and lambs and 200 tons of cheese, with a coal consumption of 4 tons per day. The efficiency of cold-air machines had increased to a very great extent, and ships were now built specially for the trade; the machines could therefore be placed in the most favourable position for obtaining the best results. The cubical capacity of those chambers was very large compared with the surface of insulated walls; they had therefore an immense advantage. More than 2,000 tons of meat and dairy produce could now be brought over with 4 tons of coal. Considering the weight of a cold-air installation and the space it occupied, and remembering that weight and measurement on board ship were the two great things a shipowner had to consider, he maintained that the cold-air machines had an advantage over any economical chemical machine in existence. Moreover, air could be obtained all over the world,

Sir Alfred S. Haslam.

Sir Alfred S. Haslam. and water could be taken from the ocean, so that both articles were cheap. Very little difference would be found in the results on board ship, and the risk of accident to an air-machine was nominal.

Mr. Harris. Mr. H. Graham Harris noticed that the Author had given a description of three or four installations he had erected, where the principle of refrigeration was employed for the storage and preservation of food products. Although that was probably one of the main uses of refrigeration in England at present, it was by no means the use which was most common throughout the world. The employment of these machines in America and on the Continent was much more general, and this want of development in England was probably due to the temperate climate, as compared with the extremes of heat and cold of those countries. The uses to which refrigerating machines were being applied were extremely numerous, and he thought that if in years past the possibility of easy reduction of temperature had been known, those uses would by now have been enormously increased, and might have been as numerous as the uses of increases of temperature obtained from fuel and fire. Refrigerating machines were employed for skating-rinks, in chemical works, in the production of gelatine and of photographic films, in ice-making and chocolate-making, in dairies, for food storage and for brewers' purposes—probably brewers were the largest users of refrigerating machines throughout the world. Considering the question generally, there were two objects to be attained; one to produce the low temperature, and this was now an easy matter with almost all the machines available; the other to keep the "cold" when it was obtained, by providing a fairly perfect heat insulator. It was a truism that with a vessel absolutely and perfectly insulated, so that heat could not pass in, when once the temperature was reduced there would be no need to expend power to maintain the low temperature, and no need to reduce it again. The medium in which low temperatures had, as a rule, to be produced, was atmospheric air, which was a fluid, and, like all other fluids when at a low temperature, was denser than when at a higher temperature. He had taken an open-topped vessel, a cube of about 6 feet, then, insulating the sides and bottom as perfectly as possible, he had kept it standing in a mechanic's shop where the temperature ranged between 60° and 70°; the temperature of the air contained in the vessel had been reduced mechanically to 15° or 20°, and so little tendency was there for the hot air in the shop and the cold air in the vessel to mix, that the temperature of the air in the vessel, after being left for hours, had not sensibly

Mr. Harris. increased, and on putting the hand into the vessel, the difference in temperature between the atmosphere of the shop and the atmosphere of the vessel could be readily distinguished, the sensation being that of putting the hand into a tank of cold water. This experiment taught that a storage-chamber, in which to maintain low temperatures, should be without openings in the side, but with openings only in the top. He, with Sir Frederick Bramwell, had erected the great storage warehouse at Nelson's Wharf, which could hold nearly a quarter of a million of sheep, and consisted of a brick box carried down to the gravel some 23 feet below the surface to get a good foundation; in order to obtain sufficient storage capacity, having regard to the area of land at disposal, it was carried up some 23 feet or 24 feet above the surface; and there were no openings in it except in the top floor. The only purpose of the brick box was to contain the insulating box, which consisted of wood. This was constructed at the sides of three thicknesses of match-boarding with brown paper between, then 15 inches of sawdust, and then again match-boarding with brown paper between, the bottom being similarly insulated; this construction was adopted so that heat-infiltration might be prevented. The chamber, having a capacity of about 900,000 cubic feet, was now kept at a temperature of about 15° or 17° below freezing-point, with an expenditure of less than 1 ton of slack coal per day. This was easily accomplished by the refrigerating machine employed, but he did not think the small amount of coal required was entirely due to the efficiency of the machine; it was rather due to the shape of the store and to the efficiency of the insulation. The store had been designed and built in the manner described after a considerable number of experiments had been tried. With such a construction there must be an increase in the cost of handling the meat, as it was obvious that everything had to be lifted 23 feet from the ground and dropped into the store, it might be to a depth of 40 feet to 45 feet, depending on the floor where it had to be dealt with; and when it passed out, it had again to be raised to that height and again be lowered to reach the ground level before being taken away in carts. But this increased cost of handling was more than counterbalanced by the reduced cost of maintaining the low temperature, and most of all by the certainty with which this low temperature could be maintained. After years of experience at Nelson's Wharf, the new store now in course of erection on the bank of the Manchester Ship Canal was being built in an exactly similar manner. He should like to utter one or two words of caution as to the mode in which

Mr. Harris. "insulation," as it was called in the refrigerator business, had hitherto been tested. All the tests of which he had been able to find records had been tried in this way: a given weight of ice was enclosed in a box constructed of wood, or, in some cases, of tin, and round the box was placed a certain thickness of the insulating material to be tested—charcoal, slagwool, silicate cotton, coke, breeze, hard-wood sawdust, soft-wood sawdust, in fact every material that could be suggested had been tried. The ice when put in the box was carefully weighed; the box was then closed, and after a certain time it was opened; the weight of the ice left was taken, and the difference was estimated to represent the value of the material for insulation. Various materials were tried with the same weights of ice, and that which showed the greatest weight of ice unthawed after a given time was assumed to be the best. Now ice that was "hard frozen" would thaw very much less rapidly than ice "soft frozen"; and although the weight might be the same, and although the temperature registered by the thermometer when put in contact with the ice might be the same, yet the number of "cold units" contained in any given weight of ice might vary considerably, and also the rapidity with which different pieces would thaw would vary considerably, depending upon the way in which it was frozen, and upon the position in the original block from which the piece had been taken. The reason was obvious; frozen ice was more or less porous, and the more porous the piece the greater the surface, per unit of weight, exposed to the thawing action. Further, although atmospheric air was one of the best insulators, it was also one of the elements which would most rapidly communicate heat from one body to another, and thus most rapidly destroy the effects of insulation. He had come to the conclusion that the best insulator was a material which, while a non-conductor of heat in itself, divided the air into the smallest possible particles, and was so compact that each particle of the material was in touch with the adjoining particle, thus forming a number of minute air-cells, there being no circulation of air throughout the mass and from one cell to the other. The rapidity with which porous ice—"soft-frozen ice," as it was known in the trade—although its weight might be the same, would thaw, as compared with "hard-frozen ice," was very marked. As the result of many experiments, Sir Frederick Bramwell and he had come to the conclusion that ice was unsatisfactory when used for testing insulation, and that the results obtained might be fallacious. The neglect of these considerations probably accounted for the different results with the same materials recorded by different experimenters. In his experiments he had taken maximum and minimum thermometers, carefully calibrated before and after use, and suspended by pieces of string from each end from nails driven into an air-tight wooden box, placed inside another circular box, with the material to be tested between the two. The result of a great many experiments, taking into account the two elements of cost and efficiency, showed that hard-wood sawdust, "flour" sawdust, such as was obtained from cutting veneers, and was made in quantity by railway-carriage builders, &c., was the proper material to use. In fact, it had been used at Nelson's Wharf, where, as he had said, whether it was due to the brown paper, which was also used, or to the wood, it was possible to keep a store (containing the large storage capacity stated, and passing in and out every day probably from ten thousand to twenty thousand sheep) for years and through the hottest summer weather at a temperature of from 15° to 16°, with an average expenditure of less than one ton of Durham slack coal per day. Mr. Harris.

As to the coal efficiency of the various refrigerating machines, he thought it was not an all-important consideration. Refrigeration was almost always an adjunct, and only an adjunct to a trade. In the case of ice-making, which was probably one of the most concrete instances, many makers of machines would say that they could make a ton of ice for a little over 4*s.* That might be so, but it could not be sold to a customer for less than 11*s.*, after bearing the expense of storage, extending probably over many months, with the possibility of no sale to-day and of a large demand to-morrow. A difference of even 25 per cent. in the coal-efficiency of any two machines would make so small a difference upon the total cost of 11*s.*, and there were so many other ways in which it was possible to save the difference of cost between the coal for one machine and the coal for the other, that it was certain the engineer should not take into consideration merely the coal-efficiency, but the easy working of the machine—should obtain a machine which would give but little trouble, and which would not cost much in repair. Those were the points which had been considered at Nelson's Wharf. In addition to the de la Vergne machines by which the work was really performed, a comparatively expensive machine from the point of view of coal-efficiency—the dry cold-air machine—had been employed. The butchers had affirmed that it was absolutely necessary, in a store of that capacity, that there should be a continual circulation of cold air. It was true that the machine had been erected as a stand-by machine, and therefore to that extent it was an "insurance," but it had been adopted, although

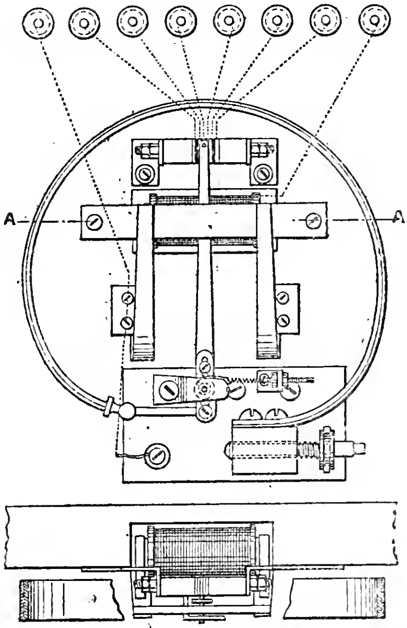
Mr. Harris. more expensive, because of the alleged necessity of a continual circulation of cold air where cold meat was to be stored, some of which might come in at times from the ships in a "soft" or semi-thawed condition. The cold-air machine was only worked once a month, the de la Vergne machine being ordinarily used. These latter were ammonia compression machines with two vertical pumps, and, probably, from the point of view of coal-efficiency, were the most satisfactory. He was not sure, however, that the old absorption machine, of which the brewers employed so many, was not as good as any for mere cold production. It was not perhaps scientifically as satisfactory, but it was good enough, and it scarcely ever gave any trouble. Such a machine had been erected at Meux's Brewery twenty years ago, and when his firm had been called upon to test it two years ago, after an expenditure of about £100 in cleaning and overhauling, its efficiency was practically the same as when it was first erected, and as regards coal-consumption it was practically as good as the best compression machine. His opinion was that coal-efficiency was not by any means the principal point to which the engineer should direct his attention; but where used for food storage, his great object should be to maintain the cold by means of good insulation. The use of the machines in America and on the Continent by brewers was far in excess of any use to which the machines were applied in England for all purposes, and it was to the American and to the foreigner, especially the German, that the English engineer had to look for knowledge on the subject.

Mr. Marcet. Mr. Alexander Marcet desired to refer to one of the newest machines, of a type introduced by Messrs. J. and E. Hall, of Dartford, about seven years ago, one of the peculiarities of which was that it used what was then an entirely new material for refrigeration purposes—carbonic-acid gas. Particulars were given in the Paper of various materials used for insulating purposes, and the Author stated that he had found silicate cotton more efficient when loosely packed than when tightly packed. Their experiments entirely agreed with that statement. All that was wanted was material which would form as many air-cellules as possible. There was, however, an objection to loosely packed insulating material, particularly on board ship or in any buildings subject to vibration, namely, that it might in time settle, and the place from which it settled would form a duct through which heat could pass; the material should, therefore, be so tightly packed that it would not settle, and, in case it did settle, arrangements should be made round the upper walls of the cold chambers to remove the top board and fill the space left vacant with further insulating material after, say, two years' work. He agreed with what Mr. Harris had said as to sawdust. His firm had made many experiments with different insulating materials, charcoal being previously considered the best. The apparatus used did not depend upon the rate of melting of ice, but consisted of a tin box containing a known weight of warm water at a given temperature surrounded with a certain thickness of insulation. The experiments lasted over twenty-four hours, the temperature outside the insulation being maintained constant, so that the loss of heat from the warm water contained in the tin vessel inside the insulating material could be measured accurately as the water cooled, by carefully recording the fall of the thermometer in the water, and a curve was afterwards drawn showing the fall. With this apparatus experiments with a dozen different materials were made, and a dozen different curves were obtained under exactly the same conditions, so that they could be compared. That material which maintained the water warm in the tin box the longest time was the best insulator. Sawdust was found very good if it was dry, but if it became damp, it lost a good deal of its insulating property. He entirely agreed with the Author that the vertical type of compressor was preferable; it was indispensable when a liquid seal had to be obtained around the gland, as was the case with some of the ammonia compressors. When no liquid seal was desired, it was a matter of importance to have vertical valves, so that the weight of the valve was evenly distributed, and the wear round the valve-seat was uniform. For that purpose they used steel compressors with vertical valves. An important point in all cold-storage installations was the method of applying the cold. With the air-compression machine, the cold air was pumped into the chamber, and nothing further was required beyond regulating the slides—dividing the cold air equally all over the chambers, if there were a number of them. But the newer or chemical types of machines were either utilized to cool brine, or cold was produced by direct expansion—ammonia being allowed to circulate in pipes within the chamber. The direct-expansion method was a good one in that it saved the brine altogether, so that one of the losses of the refrigerating machine was done away with, but it was somewhat risky. There had been occasions in almost every direct-expansion ammonia plant where some joint had been badly made and the ammonia had escaped into the chambers, the results being sometimes serious. A system had therefore been adopted by his firm in which brine was circulated through pipes in the chambers. That system had the advantage, Mr. Marcet.

Mr. Marcet. where there were seventeen chambers, as there were in the Smithfield store, of maintaining any temperature that might be required in any one of the chambers. Each chamber had its own circulation of brine-pipes, and each brine-pipe commenced at the main supply-pipe and terminated at the engine-room, where it was fitted with a thermometer and a regulating-valve. Another system consisted in circulating air by means of a powerful fan over the surfaces wetted by the brine. In that way the desired result might be obtained and air at only a moderately low temperature, as compared with the air-compression machine, could be circulated through the chambers, but it had a disadvantage that the moisture contained in the meat or the goods to be stored passed into the brine, which in the course of time became weakened and had to be reconcentrated. That presented no great difficulty, but it needed care in working the machine and maintaining the brine at a constant density. There was also loss in reconcentrating the brine and making it up to its proper strength. That system involved trunks and slides. When it was required to shut off or add a chamber, some regulation was necessary to distribute the air evenly by setting the slides, which sometimes meant going into the cold chambers. With the brine system the whole regulation could be done from the engine-room, which was considered by many persons to be a point of importance. The carbonic-acid machines, though using a safer material, differed from the ammonia machines in that the pressures required to liquefy the carbonic acid were high—they were hydraulic pressures and under temperate conditions, with condensing water at 70°, the pressure was sixty or sixty-five atmospheres, or about 900 lbs. per square inch. Those pressures would have been deterrent some years ago, but now that marine boilers were worked up to 300 lbs. per square inch with a diameter of 14 feet, he did not think that 900 lbs. pressure per square inch in a pipe of 1 inch diameter and $\frac{1}{4}$ inch thick could be a source of fear to engineers. Their methods of testing were special—every piece which was subject to the pressure of carbonic acid is first tested for strength to 3,000 lbs. per square inch by hydraulic pressure, or three or four times the working pressure, and then again tested when submerged in a tank of water, under compressed air at about 1,500 lbs. per square inch pressure, when any porosity would be indicated by bubbles, and after personal examination under both tests the foreman of that department then stamped the part with his initials; after taking that course leakages of the carbonic acid through the metal were almost unknown. Carbonic acid must be added to the machine from time to time, as with all machines using any material in a closed cycle. But the additions were small, and, moreover, the cost of the material was very small. Another point in connection with the safety of the machines was that, owing to the practically harmless qualities of carbonic-acid gas, it was easy to fit machines with a "weakest part," so that in the event of an attendant overcharging a machine or starting it with his delivery valve screwed down, say, after the examination of the compressor, instead of an accident occurring, the "weakest part"—a small copper disk about as thick as a stout piece of paper—gave way, making a noise like a pistol shot, the result being that the attendant took care on the next occasion to open the valve; no accident, however, could arise, and the carbonic acid might be replaced at a cost of a few shillings. With regard to machines using ammonia, the escape of ammonia was known to be dangerous, and he observed that the Board of Trade had recently taken the matter up with regard to ammonia machines in the main engine-rooms of steamers, where escapes of ammonia had been known to turn everybody out. The question of coal-consumption was a very important one in the trade, but he agreed with Mr. Harris that an unnecessary degree of importance was attributed to it. There were a great many other things besides coal-consumption to be considered; still it was a convenient basis of comparison. It had been said that with the air-compression machine on board ship 2,000 tons of frozen meat had been carried with a consumption of 3 tons of coal per day. He had results from recent logs of steamers fitted with Hall carbonic-acid machines. One steamer running from Buenos Ayres to London (her third trip), fitted two years ago with a carbonic-acid machine, carried 1,460 tons of meat; the refrigerating machine was of 110 I.HP., which at 2 lbs. per I.HP. per hour showed less than 1 ton of coal per day, the machine working on an average 10·4 hours per day. The value of the carbonic-acid gas used on that trip was £6—a not very deterrent element. Another steamer (on her fourth trip) sailed from Sydney to London in sixty days, carrying 1,461 tons of meat. The machines worked 7·8 hours daily, and 2 lbs. per I.HP. consumed 15·6 cwt. of coal per day. The value of the carbonic acid consumed was £8 10*s.* A third ship (on her first trip), fitted last year, carried 1,800 tons of frozen meat from New Zealand to London. That ship was fitted with a duplex machine, one half of which worked 10·7 hours per day, so that the consumption of coal in bringing that cargo and maintaining the holds at about 10° F. was less than ½ ton per day, which he ventured to say was an improvement on previous performances. The value of the carbonic-acid gas in that case was £11 10*s.* Owing to the careful method of testing the various parts Mr. Marcet.

Mr. Marcet.

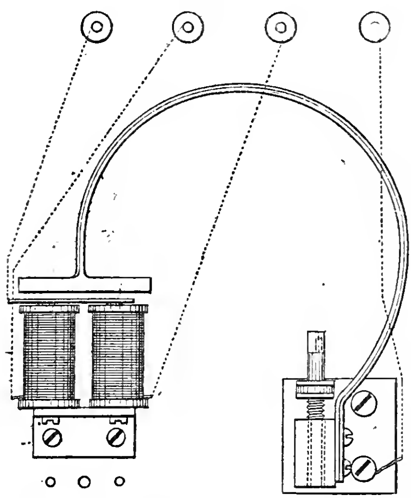
Figs. 22.



SECTIONAL PLAN ON A.A

SIX-WIRE LONG-DISTANCE THERMOMETER.

Fig. 23.



THREE-WIRE LONG-DISTANCE THERMOMETER.

and the presence of the safety-valve referred to, no accidents had occurred on account of the pressure of carbonic-acid gas in any of the refrigerating machines built by his firm.

Mr. Vernon.

Mr. C. E. VERNON explained that the electrical thermometers fitted to the West Smithfield Cold Meat Stores, *Figs. 22*, were on a multiple-wire system. For a range of 11° F. it was necessary to have a six-wire main with six points of contact with the instrument in the chamber, and a six-drop indicator in the engine-room. For a range of 20° it would be necessary to have eleven wires, so that for a long range the multiplication of wires might become an objection. Since the system had been fitted to West Smithfield, further experiments had been made on the three-wire system. The same compound coil of hard brass and steel was used; but instead of the connecting link and movable hand, a small iron bar was attached to the loose end of the coil at a given distance from an electro-magnet, *Fig. 23*. Owing to the unequal expansion and contraction of the two metals, the distance between the bar and the magnet varied according to the temperature, and the quantity of the current taken to draw the bar down to the magnet was measured by the ampere-meter. This was constructed so that when the bar touched the magnet it completed a second circuit and stopped the hand of the ampere-meter at a given point. The ampere-meter was calibrated and marked off into degrees Fahrenheit, and by that means a long range in temperature could be obtained with only three wires, accurate to within a degree, and which could be read at any distance. He might add, although not coming within the subject of refrigerating plant, that the same system had been applied to pressure-gauges, more especially where they were used as weighing machines for hydraulic and other cranes. On a wharf, for instance, where ten coaling cranes were used with the old system, a special man or meter in each box was necessary to take the weighing of the coals, whereas one man in an office could weigh for the whole of the ten cranes with the same speed and accuracy if fitted with electric weighing machines. Mr. Vernon.

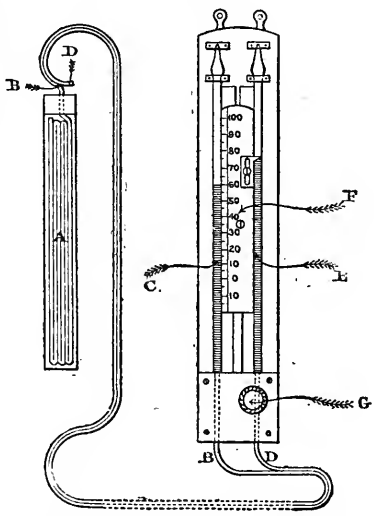
Mr. W. WORBY BEAUMONT thought the relative costs of the materials experimented upon should be added to the results the Author had given of tests of various heat-insulators. Different thicknesses of material were mentioned in the Paper varying between 4½ inches and 11 inches; and the materials used appeared to differ in value probably as much as 150 per cent. The differences in the value for equal thickness from the heat conductivity point of view were very small, as far as two at least of them were concerned. For instance, whereas the silicate cotton—which was the best in all cases—when represented in percentage of mean conductivity was 23·1, magnesia and asbestos fibre came out at 25·4. The difference between those two was so small that the question of the cost of the two materials would probably determine the use of the one or the other. So again with regard to the two other materials which worked out for equal thickness as 48·1 per cent. and 46·1 per cent.—two materials which he should think probably differed in value at least 300 per cent. Flake charcoal at, say, £4 5*s.* per ton, or about 5·5*d.* per cubic foot, would cost 2·75*d.* per square foot of wall insulated 1 foot thick, more than with silicate cotton at £5 10*s.* per ton, or, say, 6·25*d.* per cubic foot, because the conductivities were relatively as 23·1 and 35·15. The space occupied by the less efficient material must also be counted in the cost. The cost, therefore, of those materials, and the cost of the means of packing and holding them, would be seen to be of great importance in connection with the other figures which the Author had obtained. But there were other matters connected with the insulating walls which appeared to be of great import- Mr. Beaumont.

Mr. Beaumont. ance. In all cases brown paper was used, as was also match-boarding, &c., of certain thicknesses. In some of those materials the great desideratum was the prevention of the circulation of the air imprisoned in minute sponge-like or cellular volumes. That being the case, it appeared that investigations which might be of practical value could be extended to other materials than those mentioned, which included silicate cotton, sawdust, peat, charcoal, and magnesia and asbestos fibre. It was questionable whether some of those materials were not much more expensive per square foot and per unit thickness of walls than other materials which would effectively prevent the circulation of the air. If that were the case, it would appear that makers of brown paper and spongy papers might very usefully turn their attention to the production of cellular papers that would be wanted in large quantities for the purposes mentioned in the Paper. Further, it appeared that some of these questions might be usefully and economically borne in mind in connection with ice-making tanks, which were more or less efficiently covered, but still not in a manner to be expected in an apparatus in which the preservation of a temperature vastly differing from the surrounding temperature was of the greatest importance. It was true that in connection with those tanks the difficulties would be much greater than with the dry walls of the storage warehouses, because of the quantity of water and moisture always present, which might destroy the material. But that there was neglect of insulation of those tanks was shown by the great importance that was attached to the proper insulation of the walls in the warehouses.

Mr. Halpin. Mr. Druitt Halpin agreed as to the necessity for regarding the question of cost in all matters of insulation. There were commercial differences of 100 per cent. or 200 per cent., which in a case of that kind were not to be lost sight of. He could not agree that the Author's experiments on the insulation were conducted in the best way to obtain satisfactory results. It was well known that there were different qualities of ice, hard-frozen, soft-frozen, containing greater or less quantities of air, and of different porosity; but there was also the temperature of the ice to be considered. Whether experimenters started with a block of ice, say 1 lb., at a temperature of 25°, or whether the ice was at zero, there would be a totally different number of thermal units to deal with, and without taking special precautions, very irregular and anomalous results might be obtained. Even if the temperature was measured at the outside, by placing thermometers on it, he did not know whether it was known how the temperature varied inside. He agreed that the whole principle of insulation depended on the molecular entanglement of the air. Air was the worst conductor known, but it must not be alone imprisoned, as it could be by two boxes one outside another, forming an envelope, but it must be molecularly imprisoned, so that any motion was practically impossible. Of all the substances that might be used, cork had given the most perfect results. In heat-transmission experiments he had conducted on the Continent some fifteen or eighteen years ago, using a method by the condensation of steam, he had, with a thickness of 1½ inch of cork, obtained reductions in transmission of 93 per cent. In other words, where the condensation without clothing was 100 per cent., with a coating of only 1½ inch of cork, it fell to 7 per cent. Mr. Halpin.

Mr. Bertram Blount was struck with the great number of wires which the first instrument described by Mr. Vernon required for even a moderate range of temperature; but the feeling of dismay was removed when Mr. Vernon spoke of the excellent three-wire instrument since devised. The method of measuring the pull requisite to move the Breguet spring down to a determined point was a very happy one; but even with that clever modification, it appeared to him that further simplicity was still to be desired. There was another instrument in existence, and largely in use in a cold storage work, the long distance thermometer devised by Mr. A. P. Trotter, *Fig. 24*. If the stem of an ordinary thermometer were prolonged, the scale could be read at any distance from the stem, provided the temperature throughout the whole distance over which the stem extended was very much the same as that of the bulb. When there was a considerable difference between the temperatures of the stem and the bulb the expansion of the liquid in the stem was different from that in the bulb. That was fully recognised in the usual correction for the column outside the vessel the temperature of which was being measured. By greatly Mr. Blount.

Fig. 24.



Trotter Long-distance Thermometer.

Mr. Blount. extending the stem—making the thermometer with the scale at a long distance from the bulb—however capillary the tube connecting the bulb to the scale might be, the differences of temperature through which the stem passed would be sufficient to vitally affect the reading of the scale. Thus a thermometer consisting of a bulb placed in a cold store and a scale outside many feet away would not register correctly the temperature of the store, because the stem would pass through regions where the temperature was other than that of the bulb. In the Trotter instrument by the side of the elongated capillary stem, B, was placed a blind stem, D, which carried at its further end a scale-tube, E, precisely similar to that of the main thermometer, C. Whatever variation in reading was produced by the different temperatures through which the elongated capillary stem ran, the blind stem suffered the same alterations of temperature, and thus a shifting scale, F, adjusted by a thumb-screw, G, was established which precisely compensated the fluctuations of the main instrument. The plan of having a thermometer with a compensating index had been extended to other purposes than cold storage. Wherever it was necessary to read a temperature at a great distance, the thermometer could be applied, provided the temperature were not outside the range of ordinary thermometers. So that within the last year two modifications of the instrument had been devised; one was that in which temperatures ranging up to 260° F. could be read, suitable for drying-chambers, malting-floors, and the like; the other was one where the bulb was at a considerable height above the scale; that would be useful for the control of a ventilating and heating plant when the plant lay below the room to be heated or ventilated.

Sir Frederick Bramwell. Sir Frederick Bramwell, Past-President, said he might mention that, in regard to the question of there being ice and ice, a few years ago the Ordnance Committee, wishing to test the stability of armour-piercing projectiles against internal strains, were considering the question of keeping them in a cold chamber for a certain length of time. But before proceeding to build the chambers they, in order to ascertain the effect, prevailed on the late Mr. Perkins to freeze a projectile into a block of ice made by his Arktos apparatus and bring it down to zero. The block with a 100-lb. projectile in it travelled all the way from Gray's Inn Road to Woolwich, where it was exhibited at an evening entertainment, and during the whole of the time there was not the slightest dripping of moisture of any kind; the fact being that the block was thoroughly frozen through, and thus maintained a cold surface at such a temperature that there was no thawing whatever, in spite of its warm surroundings. Such a piece of ice, if used in an apparatus to show the value of non-conductors, would have given very abnormal results. Sir Frederick Bramwell.

Mr. Donaldson.

Mr. DONALDSON, in reply, desired to mention the great care with which Sir William Armstrong & Co. had carried out the construction of the lifts, which had given no trouble, and had worked continuously without accident of any kind. In his remarks as to the transport of frozen meat 200 miles or 300 miles to the port of shipment, he thought Mr. Nelson overlooked the fact that the atmosphere in Australia was very much drier than in England. He did not, however, wish to raise any point as to the feasibility of the transport of meat in Great Britain. It appeared a question of providing the necessary protection in order that the operation might be as satisfactorily carried out here as there. He imagined that before the carcases had started on their journey they were seen to be in a proper condition, that the trucks conveying them were also seen to be in a proper condition. And probably, seeing that they had to deal with a somewhat higher temperature, the animals were thoroughly chilled and frozen through before being started. All that could as easily be done in England, if necessary, as in Australia. The use of dry-air machines appeared to depend very much on the surrounding circumstances: the cheapness of the water, which was essential to its economical working, the dimensions of the store, whether they were of more than one storey, whether it was possible to keep the engine at a sufficient height in order that the dry air might be economically lifted to the top of the building, or the chamber, as the case might be, so as to fall by gravitation. There was no doubt, however, that the dry-air machines had been of great service to his Committee; therefore he looked favourably upon them. The West Smithfield Stores and the Victoria Dock Stores appeared to be very different in the matter of superficial wall area, or exposed or cooling area. He had roughly computed for every 100 cubic feet of chamber capacity, the area of the outer surface of insulation, walls, floors and roof, taking only exposed floors into account. The West India Dock had 29 square feet for every 100 feet of storage; Victoria Dock 15·5 square feet; West Smithfield, a six-storey building, 12·8 square feet. Therefore the Victoria Dock and the Smithfield Stores did not largely vary, not nearly as much as might be expected from the drawings. The size and shape was, no doubt, a matter of great importance. If the insulation experiments were carried out air-tight he could not see that it mattered

Mr. Donaldson. whether the box containing the ice was sealed or not. With regard to the experiments he had carried out, he was alive to the difference between soft and hard ice; and, with a view to bringing the experiments all in one line as nearly as possible, the pieces of ice had been cut from the same block in each experiment, or, at any rate, taken off the same freezing. Uniformity was aimed at without, as one speaker had suggested, taking the internal temperature of each block. Provided it could always be kept absolutely dry, he thought there was little doubt that peat would give far better results than anything which had been mentioned, silicated cotton, charcoal or cork. He did not think cork could be obtained at a price commercially possible in quantities that would be required for stores like the West Smithfield store. But peat was, as a rule, certainly for building, out of the question, on account of its large capacity for absorbing water. He believed that over ten times its weight of water was absorbed when it floated upon the surface of a basin. He was not able to state the prices of the various materials he had tested, but he had endeavoured to test the thicknesses of the materials in accordance with the relative prices of the different articles. If, therefore, the material was 4½ inches, that was probably owing to the price quoted at the time, and was the extreme thickness he could use as against, say, 11 inches of charcoal. He concluded his remarks with an expression of thanks for the kind way in which his Paper had been received by the Institution.

Correspondence.

Mr. Bost. Mr. W. D. A. Bost, of Paisley, observed, in reference to the Author's thermal conductivity experiments, that there were three kinds of flake charcoal. The original material was manufactured from shavings by the Cartvale Chemical Company, Limited, Paisley, by a special process; a much heavier charcoal was also made from shavings, and the third was made from spent logwood and other such refuse. It would thus have been advisable if the Author had specified which of the flake charcoals he had used. As the tests had been made with different thicknesses of material, the Author must have used either a larger inside box, or a smaller outside box, so that the surfaces exposed either to the cold or to the heat and convection currents were not identical. He had made several experiments to test the conductivity of different insulators, and had been met by the same difficulty when he attempted to compare the results obtained with varying thicknesses of the insulating materials, as it was impossible to get the two surfaces identical. He had therefore used boxes of exactly the same size inside and out. The value of the different insulators after long use was not referred to; and it would add to the interest of the results if the Author would state his experience with silicate cotton and sawdust. The latter when exposed to damp in confined spaces became rotten, heated and smelt; and it was practically impossible to obtain sawdust properly dried in the quantities necessary in cold storage. The amount of moisture which the Author found in the sawdust with which he experimented would be of interest. On the other hand, silicate cotton broke down when exposed to vibration, and, consequently, left open spaces which entirely spoilt the insulation. He had carefully observed that the quality of the ice was the same in all cases throughout his tests. As the Author stated that the tin boxes were identical, and assuming that they were 1 cubic foot each, the outside box of the silicate cotton having $4\frac{1}{2}$ inches thickness of insulating material, would be 1 foot 9 inches square, and the outside would give a total surface of 18 square feet; whereas the outside box of the charcoal (with 11 inches = 2 feet 10 inches square) would be 48 square feet of surface exposed to the air. He believed it was the wall surface, not the cubical contents, that affected the amount of heat or cold lost in refrigerating stores. This would show the charcoal to be much superior to the silicate cotton per square foot of surface; but in view of such a variety of errors the working in practice could never be calculated from results obtained in this way. Such small tests were only possible as comparative tests, and even then only carried out under identical conditions. Mr. Bost.

Mr. W. H. Le Mesurier agreed as to the disadvantages of the cold-air system, and of those attending the method of cooling the chambers by conveying brine or ammonia in conveyor pipes. At the Birkenhead Foreign Animals wharf, the first plant erected had been on the cold-air system, but, as it was much too small, it had been replaced by another, consisting of two cold-air engines capable of dealing with 450 carcases of freshly-killed bullocks in seventeen hours. An additional plant being found necessary to meet the requirements of the trade, the Linde system had been next adopted, and it proved so satisfactory that two more machines were laid down. The advantages of the latter were so marked that about a year ago a Linde machine had been substituted for the cold-air machine; the change, which involved considerable alterations to the buildings and additions to the chill-rooms, was effected Mr. Le Mesurier.

Mr. Le Mesurier. between November and the end of March, so that it was ready for the summer season, during which the machinery worked most satisfactorily, dealing with many more carcases, and at considerably less cost than under the former system. The cold-air plant could only cool 450 carcases in a fairly satisfactory manner in seventeen hours, the working expenses largely exceeding those of the Linde process. The Linde machine which replaced it dealt with 750 carcases, and the effect upon the meat (mainly due to the large circulation of air in the chambers) was such, that it was a common practice for the traders to remove some of the meat at the expiration of eight hours, and it was rarely left in as long as fifteen hours except at the week end. This was an enormous convenience to the trade, and at the same time did away with the congestion of traffic that arose when the rooms were emptied at the same time, an unavoidable arrangement under the circumstances. As regarded cost of working, that of the Linde system was less than one quarter for coal, two-thirds for attendance, about one half for supplies, and a little more than one-third for repairs. During the season of 1895 the number of carcases dealt with by the cold-air system was 41,025, and the amount of coal consumed was 1,522 tons. In 1896, the chill-rooms and insulation being in all respects similar though larger, the number of carcases dealt with by the Linde machine was 59,287 on a consumption of coal of 533 tons. The arrangement of the installation was as follows:—Two tanks containing cooled brine were placed in an insulated chamber over the chill-room; the brine was then raised by revolving perforated cylinders, whence it descended back into the tank in the form of rain. A $5\frac{1}{2}$-foot reversible Blackman fan was placed at the end of each tank, the air being driven through the rain to one end of the chill-rooms, and drawn out at the other, causing a voluminous circulation of air through the rooms; and as the hot air and fumes were thus drawn out of the chambers they were condensed by the brine and passed away through an overflow pipe. This process naturally diluted the brine, which must of course be kept up to its proper strength, but the cost of providing chloride of calcium, or salt and soda for this purpose, was much less than that of getting rid of snow in the cold-air system by manual labour. Another advantage of this system was that the brine in the tanks acted as a store of cold. The usual practice was to bring down its temperature before the doors of the chill-rooms were closed and the chilling of the meat had begun. When small lots were being dealt with, or between Saturday and Monday, after the temperature of the meat had been sufficiently reduced, the main engine was often stopped for hours at a time, the temperature of the rooms being maintained merely by working the Blackman fans. During last season 138,359 carcases of freshly-killed bullocks had been dealt with at Birkenhead, besides 8,095 which had been kept in to suit the convenience of the traders, making a total of 146,454, besides 1,100 sheep. Mr. Le Mesurier.

Mr. L. STERNE noticed that the Author had adopted charcoal for the insulation after carrying out a series of experiments with different materials, but amongst the various insulators tested "still air" was not included, although the merits of those tested depended principally on the presence of a multitude of air-spaces between their particles. An insulation formed entirely of "still air" spaces between wooden linings was most satisfactory, besides realizing a great saving in dead weight, and getting rid of the trouble caused by the charcoal or other material settling in compact masses wherever vibration existed. It was necessary to take special precautions that the air-spaces were as nearly as possible air-tight, but this was a condition readily obtained in practice. Brown paper appeared to have been somewhat extensively used by the Author between the matchboardings, but as damp rendered this useless, a waterproof paper such as Willesden, or some of the special insulating papers, was preferable. The insulation of the doors and portholes throughout seemed insufficient, as this should be as nearly as possible equal to the insulation of the walls. This could have been secured by using the ordinary taper plugs, with hinges and rubber jointing, which were in many ways more convenient than the loose covers employed. Brine circulation seemed to have been adopted in the present instance through fear of a possible escape of ammonia if direct expansion had been used, but the Author admitted that such a contingency was remote; and when it was realized that the pressure in these pipes averaged 25 lbs. or 30 lbs. per square inch, and that ammonia pipes and joints could be made as tight as pipes for steam, gas, or any other material, it was evident that the contingency could be readily provided against. It was a matter of good workmanship, and his firm had erected many hundreds of miles of direct-expansion piping, without a single instance of trouble by leakage having occurred. In one plant in London alone, that of the Colonial Consignment and Distributing Company, Limited, at Nelson's Wharf, there were some 10 or 12 miles of this piping, and in a plant at present under construction for the North Eastern Railway Company, there was almost as great a length. The economy in using direct-expansion Mr. Sterne.

Mr. Sterne. over brine-circulation was very great, as was evident from the fact that the efficiency of a compression machine varied considerably with the difference of temperature of ammonia before and after expansion, or, in other words, with the difference between the condenser and suction-pressures; increasing as the difference became less, and *vice versâ*. Thus a machine working with a given condenser-pressure and a suction-pressure of, say, 30 lbs. per square inch, was working much more economically than the same machine with same condenser-pressure and a suction-pressure of 15 lbs. per square inch. Whereas, therefore, with direct expansion the pressure in the pipes might be maintained at such a point as would allow the expanded ammonia to be within a few degrees of the temperature required to be kept in the cold chamber; with brine it must be kept a great deal lower, as the brine must be at a temperature below the desired temperature of the chamber, and the ammonia again kept at a temperature below the brine. This might be overcome to some extent by increasing the surface-area of the brine-pipes, and consequently allowing for a smaller difference in temperature than was usual with direct expansion, but the cost and space occupied by the plant was thus increased. In addition to this direct source of loss there was also the additional work required to circulate the brine, which in a large plant was no inconsiderable amount, especially where direct-acting steam-pumps were used. The only advantage that could be adduced in favour of the brine system was the possibility of providing to some extent a store of cold by cooling the brine to a very low temperature, thus enabling the machine to be stopped for a time and still keep the temperatures of the chambers down by circulating this cold brine, but such a plan was wasteful and not applicable to large plants where the machine was constantly at work. It would have been interesting to know the cubical capacity of each of the sets of stores operated by the cold-air, de la Vergne, and carbonic-anhydride machines, together with an idea of the class of work done in each. Without this information the horse-powers absorbed by each system, as given by the Author, were unintelligible. It was also to be regretted that no particulars of trials were given, more especially as the results, viz., that the costs of working the three systems were alike, were so much at variance with general experience. The great economy of the ammonia compression-machine over the cold-air machine had been so often demonstrated, and his firm had so often replaced cold-air machines by ammonia machines, and in every case with the most gratifying results as regards economy of working, that he could only suggest that the Author's difficulties in obtaining satisfactory comparative conditions had been so great as to render his conclusions in this instance incomplete till such further information as that indicated was afforded. Mr. Sterne.

Mr. DONALDSON, in reply to the Correspondence, agreed with Mr. Bost's suggestion, that in experiments with insulating materials, the exposed surfaces of the boxes should in all cases be identical. Other than the original test experiments, which appeared conclusive, he had not used sawdust as an insulator. He thought, however, the damage which would accrue to the insulation from the very smallest continuance of damp formed an objection to its use. At the Birkenhead lairages, referred to by Mr. W. H. Le Mesurier, the system was specially used for chilling purposes, and the condition and requirements were not quite the same as for the storage of meat frozen hard. He was much struck with the apparent efficiency for its particular purpose of the system there adopted. He thought the efficiency of "still air" spaces depended upon their number, and the dimensions of the divisions between the spaces; in other words, that the material which lent itself to the construction of the greatest number of air spaces per cubic inch would be a better insulator than a "still air" space of a cubic inch without any fibre or other material to break it up into numerous cells. Brown paper had been used in the Joint Committee's stores in such places as were not specially subject to the action of damp. Where such a state of affairs existed, at least one layer of waterproof paper had been used to keep the damp away from the rest, and it was with a view to economy that this material was not adopted throughout the whole insulation, nor was it essential that this expenditure should be incurred. The suggestion that the ordinary taper plugs with hinges and rubber joinings should be used in place of the port-holes adopted in the Joint Committee's stores, was open to grave objection on the score of wear and tear, because the passage of frozen carcases over one face would, in a comparatively short space of time, wear a groove more or less deep, and consequently the suggested taper plugs ceased to be efficient, and a current of air or leak would at once be caused. He therefore adhered to his opinion that the doors and port-holes should lap over the orifice and not fit into it. From the theoretical point of view, no doubt the elimination of all possible intermediate methods was advantageous in obtaining the greatest efficiency; but other considerations must receive their due share of attention, and he admitted that he had some fear of putting in miles of Mr. Donaldson.

Mr. Donaldson. direct-expansion ammonia pipes into the chambers where the result of trouble by leakage would cause damage, the extent of which it would be hard to estimate.

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16 February, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President, in the Chair.

The discussion upon the Paper, "Cold Storage at the London and India Docks," occupied the evening.

23 February, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President,
in the Chair.

(*Paper No. 3029.*)

The Main Drainage of London."

By JOHN EDWARD WORTH and WILLIAM SANTO CRIMP,
MM. Inst. C.E.

THE main drainage of London was last brought before the Institution in a Paper by the late Sir J. W. Bazalgette, Past-President, in March, 1865,[1] and its past history may be briefly referred to here. Prior to 1847 the sewers of London had been managed by eight distinct public bodies; but in that year these were superseded by the Commission of Sewers, the members of which were nominated by the Government. Within nine years of its formation the Commission was reconstituted no fewer than six times, lastly in 1855; and during the period referred to, the question of main drainage was discussed in all its phases, but without practical result. In the drainage system in operation in 1854, the main sewers followed generally the valley lines, and discharged their contents into the Thames at various points within the metropolitan area, at about mean-tide level. As the tide rose it closed the outlets and dammed back the sewage flowing from the higher ground, which accumulated in the low-lying portions of the sewers and remained stagnant for several hours daily. The fact that a gigantic system was subsequently carried out at a cost of several millions sterling, affords conclusive proof of the necessity which existed for dealing with the sewage upon comprehensive lines, and it is unnecessary to describe the state of the Thames within the metropolitan area further than to say that it was notoriously bad.

In 1856 a Metropolitan Board of Works was constituted, and formed the first authority elected under the system of Local Government; and by and for the purposes of the Act which brought that body into existence, London was divided into thirty-

[1] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 280.

nine districts. Sir J. W. Bazalgette was appointed Engineer to the Board, and was instructed to prepare plans for the interception from the Thames of the sewage of the metropolis. The objects sought to be attained by the proposed works were the interception of the sewage, as far as practicable, by gravitation, together with so much of the rainfall as could be reasonably dealt with, and its conveyance to points some distance below the metropolitan area. In designing the works, Sir J. W. Bazalgette, who was assisted by Messrs. Bidder and Thomas Hawksley, Past-Presidents, observed the principles of a constant flow in the sewers, the abolition of tide-locking with its well-known disadvantages, and the provision of improved outfalls, to enable the main-drainage system to deal with the sewage of districts previously imperfectly drained. The system of sewers as designed and executed comprised, Plate 3, on the north side of the Thames, three large intercepting sewers, two of which, known as the high-level and the middle-level, are gravitation sewers from their commencement, in the western and the north-western parts of the metropolitan area, to the outfall works at Barking; and a low-level sewer, which deals with the drainage area which is at too low a level to allow gravitation into the two intercepting sewers referred to.

These sewers may be briefly described as—

(A) The high-level sewer, commencing with the junction of the Fleet sewer at the foot of Hampstead Hill and proceeding to Old Ford.

(B) The middle-level sewer, constructed generally in the lowest portion of the gravitation-area commencing at Harrow Road and joining the high-level sewer at Old Ford.

(C) The low-level sewer, which follows generally the north bank of the river.

There is an important exception to the general rule in the route of the low-level sewer, by reason of the configuration of the Thames; for, instead of following its tortuous course, the sewer passes in an easterly direction from Blackfriars Bridge to the Abbey Mills Pumping-Station, the large area lying between it and the river below the point referred to, being drained by a subsidiary sewer, known as the Isle of Dogs branch.

At the point of junction of the high-level and middle-level sewers at Old Ford, there is a large storm-overflow chamber for the purpose of relieving the outfall sewers beyond from excessive volumes of storm-water into the River Lea; because the two sewers continuing onwards from Old Ford to the outfall works at

Barking are of much smaller carrying-capacity than the two sewers referred to. The two outfall sewers from Old Ford onwards are constructed side by side at the same level, and are each 9 feet by 9 feet, constructed throughout in an embankment considerably above the level of the ground, and pass through the site of the Abbey Mills pumping-station. At the latter place, the low-level intercepting sewer terminates; and the sewage is pumped into a third sewer of similar dimensions, the three sewers being then carried side by side to the Barking outfall works. In order to obviate the necessity of constructing this low-level sewer at a great depth, and of raising all the sewage to a great height at Abbey Mills in one lift, a second pumping-station, known as the Western, was built at Grosvenor Road, Pimlico, for dealing with the districts westward of that place. On arrival at the outfall at Barking, the sewage could be discharged either into the river direct, or into a tidal reservoir, of a capacity of 35 million gallons and covering an area of 9½ acres, in order to admit of the sewage being discharged during ebb tide.

Western Pumping-Station.—The western pumping-station occupies about 4 acres of land, and contains four single-acting beam-engines, each of 90 HP., all placed in a rectangular building, with a pump-well occupying the entire basement divided into two compartments, one under each pair of engines. These compartments communicate with each other, but means are provided for separating them for cleansing or other purposes, and there is a separate inlet into each from the main sewer so that each pair of engines can work independently. There are also movable screens in order to intercept any solid substances which might interfere with the action of the pumps. These screens are in duplicate and are lifted out for cleansing-purposes when necessary. The engines are condensing rotative beam-engines, constructed by Messrs. James Watt and Company; there are two pumps to each engine, one on either side of the beam centre; the steam-cylinders are 3 feet 1 inch in diameter, with a stroke of 8 feet; the pumps have a diameter of 5 feet 3½ inches, with a stroke of 4 feet, and are of the single-acting plunger type. Steam is supplied by eight boilers, 6 feet 9 inches in diameter and 22 feet long, working at a pressure of 40 lbs. per square inch. There are coal-vaults and other accessories necessary for the proper working of the station. There is also a cold-water reservoir for condensing purposes situated in the grounds, capable of containing half-a-million gallons of water.

In order to provide for the contingency of a breakdown of the principal engines, an auxiliary engine was erected in a separate building at the rear of the principal buildings. It is a horizontal engine of 120 HP., supplied with steam from two boilers of the same dimensions as those in the main boiler-house. It works two pumps, each 4 feet in diameter, placed in a separate well, and is provided with separate inlet- and outlet-channels distinct from those of the main pumping-station. Buildings are provided for the accommodation of the staff, which consists of eighteen men. The works were commenced in July, 1873, and the station was opened on the 5th of August, 1875. The cost was £183,739, of which sum £56,879 was for engines and pumping-machinery. At this station the lift is 18 feet, and about 54 million gallons can be pumped per day of twenty-four hours. The sewage at this pumping-station is discharged into the head of the main low-level intercepting sewer, flowing in an easterly direction, as already described, to Abbey Mills.

Abbey Mills Pumping-Station.—The Abbey Mills station is situated upon a site of 7 acres of ground, through which the northern outfall sewer passes at a height of about 17 feet above the surface of the ground. On the south-west side of the embankment stand the boiler- and engine-houses, chimney-shafts, coal stores and other accessories, whilst on the north-west side are the reservoirs for water for condensing purposes and eight workmen's cottages. The engine- and boiler-houses form one building, the engine-house being cruciform in plan. There are eight beam-engines, each of 142 HP., arranged in pairs, each arm of the structure containing one pair, parallel to one another. All the steam-cylinders are at the inner end of each arm, so that the cylinders are arranged symmetrically round the centre of the building under the dome. The engines provided were condensing rotary beam-engines with cylinders 4 feet 6 inches in diameter and 9 feet stroke; the pumps being of the double-acting piston type, each engine working two of a diameter of 3 feet 10½ inches, with a stroke of 4 feet 6 inches. The capacity of this station as designed was equal to 135 million gallons per day, and the lift was 36 feet. Sixteen boilers were provided, 8 feet in diameter and 30 feet in length, at a working pressure of 30 lbs. per square inch, in two batteries of eight, one battery being situated in the western and one in the eastern boiler-house. Arrangements were made for straining the sewage before being pumped, as at the western pumping-station. The pumps deliver into cast-iron mains, 6 feet in diameter, running along the middle of three arms of the building, where, at the point of junction in the centre of the engine-house, an air-vessel 10 feet in diameter was placed. The sewage was then passed along the middle of the fourth arm, into which the sewage from the pumps situated in that arm was also discharged, the whole being forced through a cast-iron rising main, 10 feet 6 inches in diameter, which discharged into the northern high-level outfall, at this point enlarged by the construction of a third sewer of the same dimensions as the two others. The cold-water reservoirs at this station cover 1 acre and contain about 1 million gallons. The works were formally opened on the 30th July, 1868, the cost of the buildings being £218,300, and that of the engines and other machinery about £61,000.

Soon after the opening of the station, the air-vessel, with that of a similar kind at the western pumping-station, was destroyed, probably by the air-space becoming filled by corks and other floating substances, and open-top stand-pipes were substituted. When the accident occurred two additional discharge-mains were constructed, so that in the event of an accident occurring to the rising-main some of the sewage could be pumped through these independent mains.

The northern outfall-sewer from Abbey Mills to Barking consists of three parallel lines of culverts, each 9 feet by 9 feet of horse-shoe section, with a fall of 2 feet per mile, and is carried over the various rivers and railways by means of aqueducts of special construction. The invert level of the outfall-sewers at Barking is 11 feet above Ordnance Datum, whilst the highest tide recorded in the Thames during recent years, at that part of the river, is about 17 feet above Ordnance Datum. The largest reservoir at the outfall before referred to was intended for the purpose of storing the sewage against the incoming tide, so as to enable the greater portion of it to be discharged on the ebb. The main outlet to the river, which is at about low-water level, consists of nine culverts, each 6 feet in diameter, and the works were provided with penstocks and sluices for the purpose. These works came into operation in August, 1864.

The works on the south side of the Thames were designed generally in accordance with the principles observed for those on the north side; but there is an important difference, inasmuch as all the sewage on the south side has to be pumped; therefore the main intercepting sewers on the south side may be regarded as low-level sewers. There are for the drainage of the districts west from Greenwich three main lines, namely, the Effra branch, commencing at Norwood, the southern high-level sewer, commencing at Balham, and the southern low-level sewer, commencing at Putney. The two sewers first mentioned are brought into the New Cross Road near New Cross station, and they are carried along that road to

Deptford. The southern low-level sewer is nearer the river and passes through Battersea, Lambeth, Walworth and Deptford, to the pumping station at Deptford Creek. At this point its contents are pumped into the southern outfall sewer, into which the two first-mentioned main lines drain by gravitation.

Deptford Pumping-Station.—The Deptford station, which is built at the side of Deptford Creek, covers an area of three acres, and was completed in May, 1864. It was erected at a cost of £109,455, and contains four beam-engines, each of 125 HP., the total cost of which was £28,993. These were condensing rotative beam-engines capable of pumping about 123 million gallons daily. The steam-cylinders are 4 feet in diameter, with a stroke of 9 feet, and the pumps, two of which are worked by each engine, are of the single-acting plunger type, the diameter of the rams being 7 feet and the stroke 4 feet 6 inches. Steam was originally supplied by ten Cornish boilers, each 30 feet long and 6 feet in diameter, the working pressures being 40 lbs. to the square inch. The lift of the pumps is about 18 feet. Thirty-three men are employed at this station.

Crossness Pumping-Station.—From the Deptford pumping-station all the sewage flows to Crossness through the southern low-level outfall sewer, which has a diameter of 11 feet 6 inches and a fall of 2 feet per mile. At Crossness all the sewage of the area south of the Thames was pumped either into the river direct or into a tidal reservoir, which, like that at Barking, was constructed for the purpose of enabling the sewage to be discharged on the ebb tide. The power was at first furnished by four beam-engines, each of 125 HP., of the type already described, but the pump-rams were in groups of four at each side of the beam centre, which was probably thought a better arrangement than that of having one plunger, on account of the great size. The steam-cylinders were 4 feet in diameter, with a stroke of 9 feet. Steam was supplied by twelve Cornish boilers, each 30 feet by 6 feet, the working pressure being 40 lbs. per square inch. This machinery was designed to pump about 153 million gallons per day. The lift varied between 10 feet and 30 feet according to the level of the tidal water in the river at the time of pumping. The tidal reservoir covered an area of 6½ acres and had a capacity of 25 million gallons, and, like that at Barking, was covered by brick arches soiled over.

Soon after the works were opened two auxiliary pumping-engines of 300 HP. were provided. These works were opened by H.R.H. The Prince of Wales on the 4th April, 1865. The cost of the buildings, &c., was £395,674 13*s.* 10*d.* and the engines and other machinery cost £54,176 18*s.* 6*d.*

The length of sewers under the control of the London County Council is as follows:

North Side of Thames.

	Miles.	Miles.
Main Sewers	113	
Intercepting Sewers	48	
Storm Relief Sewers	$17\frac{1}{2}$ =	$178\frac{1}{2}$

South Side of Thames.

Main Sewers	60	
Intercepting Sewers	41	
Storm Relief Sewers	$4\frac{1}{2}$ =	$105\frac{1}{2}$
Total . . .		284

The total cost of the Main Drainage Works as briefly described was, at the date of opening the Crossness Works, about £4,600,000. Having regard to the magnitude of the undertaking, to the absence of precise information upon many points, the physical difficulties to be overcome, and the opposition encountered, the designers of the scheme have left behind them an enduring monument to their perseverance and ability.

The effect of the works was to intercept the sewage formerly flowing into the river at various points within the metropolitan area, and to transfer it to points about 14 miles below London Bridge. Subsequent events showed that the nuisance as regards the Metropolis was remedied, but that the enormous volume of pollution transferred to a lower point reproduced there the insanitary conditions previously prevailing in the heart of the Metropolis. That the nuisance became serious is proved by the fact that in the year 1882 a Royal Commission was appointed to inquire into and report upon the state of the Thames. The inquiry was of a prolonged and exhaustive character, and the Report of the Commissioners contained fourteen distinct recommendations, and stated that steps should be taken to purify the sewage of the Metropolis before its admission to the river.

As a preliminary step, experiments were undertaken by the chemist to the Metropolitan Board of Works, Mr. W. J. Dibdin, in order to ascertain how best to treat the sewage to satisfy the recommendations of the Commissioners.[1] The results were submitted to Sir Frederick Abel, K.C.B., Dr. William Odling, Dr. Williamson, and Dr. Dupré, who reported in favour of the treatment proposed. The Board then determined to construct works for the chemical clarification of the sewage, and to establish precipitation works at Barking for dealing with the sewage of the north side. In

[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. pp. 155–298.

January, 1887, a contract was made for the execution of these works, which may be briefly described as follows:—

Barking.—There are thirteen precipitation channels, Fig. 1, Plate 4, ranging in length from 860 feet to 1,210 feet, 30 feet in width, of a working depth of about 8 feet, and capable of holding 20,315,925 gallons. These extend over an area of 11 acres, and are covered by brick arches. There are two openings to each channel from the main outfall sewers, regulated by hydraulic penstocks 7 feet by 6 feet. The effluent from the above channels passes through the old reservoir and out of the nine openings in it into the river. Any one of the precipitating channels can be shut off for cleansing purposes. There are also twelve sludge-settling channels, each 140 feet long and 20 feet wide, capable of holding sludge to a depth of 13 feet. These channels are for the purpose of further concentrating the solids in the rather liquid sludge. There are stores under them for receiving and storing the finally settled sludge to the extent of 20,000 tons, exclusive of that stored in the sewage-settling channels; and by this means provision is made against foggy weather, when the sludge vessels may be delayed in discharging their cargoes. There are culverts or communications with the various precipitation channels and the sludge-settling channels, also for conveying the sludge to the pumps, liquor stores, &c. There is also an engine-house with two boiler-houses, one on each side, together with a repairing shop. The engine-house contains four 8-inch centrifugal pumps, with 27-inch fans, each driven by a vertical inverted single-cylinder engine, capable of discharging 5 tons per minute. There are also two 12-inch centrifugal pumps with 36-inch fans of the same type as the others, but with more powerful engines. These are for lifting the diluted sludge as run from the precipitation channels into the sludge-settling channels, a maximum lift of 21 feet. Two Murray chain-pumps are provided for lifting thick sludge from the lower store into the suction-well of the pumps next to be described. There are four horizontal compound pumping-engines, with 13-inch high-pressure cylinders, and 22½-inch low-pressure cylinders, of 18-inch stroke. The pumps are 13-inch double-acting ram-pumps, each rod being coupled to the tail-rod of the steam-cylinders. Each pump can discharge 4 tons of sludge per minute into the iron main leading to the jetty for loading the steamers. There are three liquor pumps of a similar type to those above-mentioned, but with a 12-inch high-pressure cylinder, 21-inch low-pressure cylinder, and 18-inch stroke, the pump-rams being 14 inches in diameter. These are for pumping the liquor drawn from the settled sludge through a 14-inch main to the liming station. Two hydraulic engines and accumulators supply power for lifting the twenty-six penstocks in the precipitation channels. Steam is furnished by ten boilers 22 feet long and 6 feet in diameter, working at a pressure of 75 lbs. per square inch. There are sluices for opening and closing the communications between the various chambers, and pipes and appliances for ventilating and flushing the several chambers; and also a lever-house which contains the means for lowering the telescopic weirs in the precipitating-channels. There is also a river-water settling-pond 218 feet by 155 feet for supplying water to the liming and iron-water stations.

The liming station, for the preparation of lime-water for treating the sewage, includes lime-stores, slaking-floor, wash-mills, pipes and troughs for conveying sewage-water from the sewer, and the liquor from the settled sludge to mix with the slaked lime; also six large lime-water mixing tanks: an engine- and boiler-house, coal-shed and chimney shaft, and two large iron tanks or reservoirs for lime-water above the lime-store. There are two 17-inch centrifugal pumps, with a capacity of 22 tons per minute; the maximum lift is 40 feet. Each pump is driven by its own tandem engine, having inverted cylinders, the high-pressure being 12 inches, and the low-pressure 22½ inches in diameter, the stroke 14 inches, and the fan 4 feet 6 inches in diameter, making 250 revolutions per minute. Each is supplied with a surface-condenser. The boilers are steel, three in number, 25 feet long, 6 feet in diameter, working at a pressure of 75 lbs. per square inch. These buildings are situated about half a mile from the precipitation channels.

The iron-water station is situated below the liming station, and about 300 yards from the precipitation channels. It comprises sheds for storage of protosulphate of iron, with engines, boilers and pumps for lifting water into mixers; also distributing-pipes for conveying the iron solution into the sewage. In this station there are two 6-HP. Robey horizontal engines and locomotive boilers, driving shafting, wash-mills, iron-mixers and rotary 6-inch water-pumps, &c.

Near these works are a superintendent's house and twelve cottages for those workmen whose presence on the works is necessary. There is a light railway with two locomotives and wagons for conveying coal, lime, and iron from one part of the works to another. The establishment, including liming station, &c., extends over an area of 83 acres, 2 roods, 27 poles. It was completed in July and August, 1889, at a cost of £430,834 12*s.* 9*d.*, to which must be added the cost of the engines and other machinery, amounting to £42,567. The number of workmen engaged averages 198.

In the treatment of the sewage, the requisite quantity of lime-water (nearly 4 grains to one gallon of sewage, equivalent to $\frac{1}{4}$ ton of lime per million gallons, or 38 tons per day) is first discharged into the sewage as it flows past this station in the three culverts. The allotted amount of solution of protosulphate of iron is added (about 1 grain per gallon, making 9 tons daily), then the sewage with its dose of chemicals flows into the precipitation channels, which were first constructed on the intermittent system (that is to say, when a channel was full it was allowed to be quiescent for a short time to allow precipitation of the sludge). The clarified effluent was carefully drawn off through the telescopic weirs into the old reservoir, and thence to the river through the nine channel outlets previously described. When it was necessary to remove the sludge from any channel, the large penstocks to each channel were closed, and the supernatant effluent was drawn off by the telescopic weirs, regulated from the lever-house, until the sludge was reached. The sludge was then run off through a culvert into the sludge store-chamber, and was lifted by centrifugal pumps for further consolidation in the sludge-settling channels. The settled sludge, which contains between 87 per cent. and 91 per cent. of moisture, is run off as required into a store under the engine-house, and is pumped through a main along the jetty to the sludge-boats, or may be run into a still lower store under the settling channels should there be more than the boats can discharge at sea through delay by fogs, &c.

Sludge-Vessels.—The first sludge-vessel was built by the Naval Construction and Armaments Company, of Barrow, at a cost of £16,353. It arrived in the Thames at the end of June, 1887, and was named the "Bazalgette." This vessel was found to work satisfactorily, and a second with certain improvements was ordered from the same builders. The following is a complete list of the vessels now found necessary for the disposal of the sludge:—

Name of Vessel.	Trial Trip.	Horse-Power on Trial.	Length.	Breadth.	Depth.	Moulded Depth.	Cost.
			ft. in.	ft. in.	ft. in.	ft. in.	£
Bazalgette	Aug. 18, 1887	900	230 2	38 2	13 8	14 6	16,353
Barking .	Apr. 1, 1889	1,150	232 3	38 2	15 0	15 6	24,875
Binnie .	Mar. 21, 1892	1,251	232 1	38 2	13 8	14 6	26,500
Barrow .	May 18, 1892	1,025	232 1	38 2	13 8	14 6	26,500
Belvedere	May 31, 1892	1,094	232 1	38 2	13 8	14 6	26,500
Burns .	Apr. 10, 1895	1,136	234 0	38 2	13 8	14 6	23,750

The sludge is delivered to the vessels, Figs. 3, Plate 4, through telescopic sludge-loading pipes, the inner and lower ends revolving upon a hollow trunnion, which allows the upper end to radiate to different levels to suit the state of the tide. The first two vessels are loaded through ordinary hatchways, and the last four vessels are constructed with a central hopper into which the sludge is received from the loading pipes. At the lower part of this hopper, four rectangular valves are placed, each governing the inlet to one of the four compartments into which the sludge-tank is subdivided by a longitudinal and thwartship bulkhead; each subdivision carries approximately 250 tons of sludge. Each compartment is about 61 feet 6 inches long, by a maximum width of 19 feet and is about 8 feet high. The bottom of the tank when empty is about 9 inches above the light-load line and each vessel discharges her cargo by gravity. The minimum time taken to discharge 1,000 tons through the eight valves is six minutes. Between the bottom of the tank and the bottom of the ship, a distance of about 6 feet, is an air space to give the ship the requisite buoyancy; the sludge is discharged through this space by means of tubes. Forward of the sludge-tanks the crew space is formed, with berths for the seamen on one side of the ship and firemen on the other; and the space between this and the bow is occupied by ship's stores, chain locker, fresh-water tank, rope locker and paint room. Below the crew space and stores a water-ballast tank is formed, holding about 170 tons of water, which is pumped in or out by the ballast-pump in the engine-room as required. Abaft the sludge-tank is the stoke-hold, containing two multitubular boilers, having together a heating-surface of 2,800 square feet, working at a pressure of 150 lbs. per square inch, and the coal bunkers, which contain between 40 tons and 60 tons of coal. Further aft is the engine-room, containing two twin triple-expansion engines, each having steam-cylinders 15 inches, 23 inches, and 35 inches in diameter, with a stroke of 2 feet. The engines indicated together about 1,000 HP. on the trial trip. The engine-room contains also centrifugal circulating-pumps, feed-pump, 2-inch feed-water make-up, lathes, &c. Abaft the engine-room is the tunnel used for the screws and lockers for engine stores; above this are the officers' quarters and mess room and steward's pantry. Between the officers' quarters and the stern are battened lockers and a bath-room; below is a small water-ballast tank, which if filled immerses the screws deeper in the water when the ship is light. On deck forward is an anchor deck, lamp room, steam-windlass, mast and derrick loading hopper bridge; below is a room for the steam quarter-master's steering engine, a saloon containing two state-rooms, galley and coal shoot; and above the boiler-casing are two fresh-water tanks which contain 3 tons of fresh-water for supplying the boilers. There is a fire-service with six screwed unions for attaching hose, supplied from the ballast pump, for use in case of fire and for washing down the decks and sludge-tanks. The arrangement of the "Burns" differs from that of the three earlier vessels, chiefly in the captain's room being on deck and by being fitted with electric light, the dynamo being in the engine-room. Each ship is manned by a crew of twenty-three officers and men.

The ships convey the sludge to that part of the estuary some miles beyond Southend or Shoeburyness known as the "Barrow Deep," where it is distributed over a length of 8 miles to 10 miles in the open sea. Although the sludge can, upon emergency, be discharged in six minutes, in practice one hour is occupied, during which time the vessel is steaming ahead at her usual speed of 10 knots, thus distributing the sludge over a large area.

Soon after the completion of the precipitation works at Barking, it was found that the sewage would have to be screened on account of the large amount of floating substances passing through the tanks and flowing off with the effluent water. In July, 1890, the contractors commenced a filth-hoist over the three lines of sewers at the liming station, in which are machinery and appliances for raising and lowering large iron cages or screens. These are duplicated, one being down whilst the other is raised and cleared. There is a refuse-destructor, with two cells, to burn the rubbish from the screens. These works were started on the 21st July, 1891, and cost £8,488. The destructor has been much used since that time with the assistance of coke breeze, but the quantity obtained exceeds that consumed by the destructor, and a barge load per week has been removed down the river for use on agricultural land.

Crossness.—Whilst the works were being carried out at Barking, plans for those required at Crossness were prepared, with such improvements as resulted from experience gained at the former place. A contract was entered into on the 4th May, 1888, which comprised the alterations to the existing reservoir by converting it into four precipitation channels, constructing other two adjoining; sludge-settling channels; liming and iron-water stations, settling-ponds, engine- and boiler-houses, coal-vaults, chimney-shaft, superintendent's house, three houses for the staff, twenty-nine cottages for workmen, a school-house for children, a pier, jetty and tramways.

The length of the channels of the old reservoir is 559 feet 10½ inches, and each has a width of about 128 feet and a capacity of 4,421,719 gallons. The two new precipitation channels are 558 feet 4 inches long by about 99 feet wide, and each has a capacity of 1,953,125 gallons, making a total of 21,593,126 gallons of precipitation-reservoir capacity, built in the form of vaulted subterraneous galleries. There are eight sludge-settling channels, each 130 feet long by 22 feet wide, with a working depth of 13 feet, and with an upper and lower sludge store. The precipitation channels have an average working depth of 10 feet. The sludge-settling channels hold on an average 15 feet in depth. There are seven lime-water mixing tanks, about 60 feet long and 23 feet wide. There are also two large river-water settling-ponds. The jetty is about 300 feet long and 17 feet in width, with the end in the shape of the letter T; the western arm being 105 feet and the eastern 195 feet long and 23 feet in width. There is also a lime-store and a slaking shed, and an iron-water mixing shed. The engine- and boiler-houses were constructed for the treatment and precipitation of sewage, and for pumping the sludge through 16-inch mains to the steamers. At Crossness the lime and iron-water are added to the sewage immediately after it reaches the main pumping-engines. The sewage is then pumped into the above-described precipitation channels. After the sludge has precipitated, one of the tanks is shut off from the remainder, the upper portion of the liquid is carefully drawn off and the sludge is pushed into the sludge-sump from the tank floor, whence it is raised into the settling-channels by two inverted three-cylinder compound engines, each cylinder driving a plunger pump of 21 inches diameter; the high-pressure cylinders are 14 inches in diameter, and the two low-pressure cylinders 18½ inches diameter with 2 feet stroke. The maximum lift is 36 feet.

When the sludge has settled, the liquor is decanted by telescopic weirs to be returned for re-liming, for which purpose it is raised by two 8-inch centrifugal pumps, the steam-cylinders being 7 inches diameter and the stroke 8 inches. The water for liming is taken from the river and pumped into liming tanks by four horizontal compound double-ram engines, having 14-inch and 26-inch cylinders, driving a double-acting ram 18 inches in diameter by 2 feet stroke. These pumps have a maximum lift of 36 feet. The lime is first treated in three wash-mills 12 feet in diameter, the water for them being taken by two 6-inch centrifugal pumps from that lifted by the main pumping engines. The 6-inch centrifugal pumps and the wash-mills, together with the iron crushing-mills, are driven by compound Davy-Paxman engines, having two high-pressure cylinders 8 inches in diameter, and low-pressure cylinders 12¾ inches in diameter, with an 18-inch stroke.

The sludge collected from the sludge-settling channels is raised and discharged into the ships by two three-cylinder inverted compound engines. The high-pressure cylinders in this case are 18½ inches and the low-pressure cylinders 22 inches in diameter, with 22-inch pump-rams, the stroke being 2 feet, and the maximum lift 54 feet.

These engines have each a pumping capacity of 10 tons per minute. Two horizontal hydraulic pumping-engines, and two accumulators, are employed to supply power for lifting the large penstocks. The engines supply $2\frac{1}{2}$ cubic feet of water per minute at a pressure of 800 lbs. per square inch. Each engine has two horizontal cylinders, high-pressure, 9 inches in diameter, and the low-pressure 12 inches. The two accumulators have 10-inch rams with a stroke of 7 feet. These engines also supply power for raising the filth-hoist, lime-lift, ash-hoist, and control the telescopic sludge loading-pipe. The effluent passes in its transit to the pumps through three surface-condensers, each holding its own independent steam-driven duplex double-acting air-pump. Each condenser has 162 tubes 8 feet long and 2 inches diameter. They are connected by a pipe with the exhausts of all the engines in the precipitation engine-house, and considering the lengths of the connecting pipe give a fairly good vacuum. Steam is supplied to all these engines by two 30 feet by 8 feet Lancashire boilers, working at a pressure of 100 lbs. per square inch. These precipitation works were completed and brought into use on the 2nd June, 1892, the cost having been £262,377 5*s.*, to which must be added the cost of the engines and machinery, £55,256 7*s.* 8*d.* An average of two hundred and three men are employed on these works. The area of land on which the works at Crossness are constructed, Fig. 2, Plate 4, comprises $37\frac{1}{2}$ acres. The sewage is treated at Crossness in the same manner as at Barking.

Effra Pumping-Station.—In consequence of repeated complaints of flooding, the Board of Works decided, in 1878, in order to form a relief to the southern low-level sewer when surcharged with storm-water, to erect a pumping-station at the Effra outlet, Vauxhall, and another at Falcon Creek, Battersea. The Effra pumping-station was completed by about the middle, and the Falcon pumping-station towards the end of 1879. At the former, the storm-water is raised and discharged into the Effra Creek at any state of the tide, the maximum lift being 17 feet. The pumping machinery consists of a 5-foot 8-inch fan turbine-pump, having a vertical spindle driven by bevel and other wheels geared to the crank-shaft of an old broad-gauge locomotive engine obtained from the Great Western Railway Company. The delivery is 4,000 cubic feet per minute, and the steam-pressure is 100 lbs. per square inch. The diameter of the cylinders is 16 inches, and the stroke is 22 inches. The speed is 118 revolutions per minute. The diameter of the fan is 68 inches, the depth 15 inches, and the speed 134 revolutions per minute.

Falcon Pumping-Station.—At this station similar arrangements are in force. The lift is only 11 feet, and the total delivery is 6,500 cubic feet per minute. The steam pressure is 100 lbs. per square inch, and the number of revolutions per minute is 123. The diameter of the cylinders is 16 inches, and the stroke 24 inches; the diameter of the fan is 72 inches, the depth 16 inches, and the number of revolutions is 123 per minute.

Isle of Dogs Pumping-Station.—In order to provide a permanent remedy for the occasional flooding at the Isle of Dogs, it was decided in the autumn of 1885 to acquire land near the river and to erect pumping machinery. The engines are high-pressure horizontal condensing in duplicate, with 27-inch cylinders, and 3 feet stroke, making 28 revolutions per minute. Each engine actuates two single-acting lift-pumps 40 inches in diameter, with 4 feet stroke. There are two Cornish boilers 22 feet by 6 feet, working at a pressure of 60 lbs. per square inch. Each pump is capable of lifting 1,600 cubic feet per minute, or together 3,200 cubic feet per minute from a depth of 20 feet. These are used for storm-water, and discharge into the River Thames. These works came into operation in 1888, and cost about £25,000. The following Table shows the work performed at this station, which comes into operation when there is a combination of heavy rainfall with a high tide or other special circumstances:—

Year.	Hours of Working.	Rainfall.
		Inches.
1889	1,091	28·3
1890	226	23·8
1891	292	25·5
1892	101	22·1
1893	233	19·4
1894	241	27·1
1895	64	19·9
1896	38	20·9

being an average during the seven years of 321 hours, or thirteen days per annum. It will be observed that since the Northern low-level sewer has been duplicated (1894) the storm-water pumped into the river is much less than before.

King's Scholars' Pond Pumping-Station.—Previously to 1890 many complaints were received from the local authorities and residents in the district of Westminster about frequent flooding of houses in the locality. This was due to the overcharging of the sewers, and in June, 1890, it was proposed that pumping machinery, consisting of centrifugal pumps actuated by gas-engines, should be erected on the King's Scholars' Pond sewer at the point where it formerly discharged into the Thames. The building was erected, and two 100 I.H.P. Otto gas-engines, working at 160 revolutions per minute, were supplied. Each engine drives a 24-inch centrifugal pump, running at 200 revolutions per minute, having 4-foot fans, with a lift of 15 feet, and discharging 44 tons per minute. The cost of this station was £5,662. From the 24th July, when first started, to the 31st December, 1894, the two engines and pumps worked for 66 hours 35 minutes. For the year 1895 they worked for a total period of 73½ hours, and during 1896, 73 hours 35 minutes, that is to say, when the tide would not permit the storm-water to pass through the ordinary outlet into the river. This installation is well adapted for its purpose, and is preferable to steam machinery.

Generally, the main drainage system as described was that in operation or contemplated when the Metropolitan Board of Works ceased to exist, and its duties were undertaken by the London County Council. This body came into office on the 21st March, 1889, when the late Sir Joseph Bazalgette retired from the office he had held so long and honourably. It may be of interest to note that the rateable value of the metropolis upon the establishment of the late Board of Works in 1855 was £11,283,665; in 1889, when the Board became defunct, the rateable value was £31,033,786, and the population had correspondingly increased. The first officer appointed by the County Council was the late Mr. J. Gordon, M. Inst. C.E., who entered upon his duties in July, 1889, but who died on the 9th November following, deeply regretted by all who knew him. His successor was Mr. A. R. Binnie, Member of Council of the Institution, who commenced his duties in February, 1890, Mr. Santo Crimp, M. Inst. C.E., commencing his duties as district engineer for the northern section of the metropolis at the same time; Mr Crimp on his retirement from the service of the Council in 1893 was succeeded by Mr. J. E. Worth, M. Inst. C.E.; and they have, together with Mr. Hart Bennett, had the honour of carrying on the work described in connection with the main drainage of London under the direction of Mr. Binnie.

Soon after Mr. Binnie's appointment he was requested by the Council to furnish further information upon the main drainage and sewage disposal of London. Sir Benjamin Baker, K.C.M.G., Past-President of the Institution, was associated with him, and their joint report suggested—

(1) The construction of additional relief sewers in the Metropolis for the further mitigation of the frequent flooding;

(2) The enlargement of the main outfall sewers, in order to

prevent the too frequent occurrence of overflows of storm-water and sewage into the river; and

(3) If it should be found necessary after experience, the conveyance of the sewage or the effluent to points lower down the river where it would be diluted with larger volumes of river and sea-water.

The works proposed for the north side of the Thames were estimated to cost £920,000, whilst those for the south side were to cost £1,300,000. Certain of these works were recommended to be executed forthwith, as of pressing necessity.

The most important of the works carried out by the Council is, perhaps, that of preventing flooding in the East End of London, notably in Limehouse, Poplar, and the Isle of Dogs. As originally constructed, what was known as the Isle of Dogs branch, which joined the northern low-level sewer near Bromley Station, was 5 feet in diameter, with a gradient of 1 in 5,000. The inverts of the main sewer and of the branch were at the same level; and upon the occurrence of heavy rainfall, when the low-level sewer became surcharged, the sewage backed up into the districts referred to through the branch. It was determined, therefore, to deal separately with that part of the district, for which purpose a new pumping-station was erected at Abbey Mills. The low-level sewer was duplicated between that station and the Isle of Dogs branch, but at a lower level, so as to give a free discharge to the sewer, which was then disconnected from the northern low-level. The new sewer is 9 feet in diameter, and about $\frac{3}{4}$ mile in length, and it has proved effectual in preventing the flooding which was formerly so frequent. Since it came into operation not a single complaint has been received. This work has also resulted in a large addition to the pumping-power available at Abbey Mills, as the new pumping machinery at that station is capable of lifting 36 million gallons per day to an average height of 40 feet; so that not only are the districts referred to relieved, but more power is available for dealing with the sewage delivered at the Abbey Mills Station by the northern low-level sewer. The pumping-machinery at the new station consists of a pair of triple-expansion Worthington engines. The high-pressure cylinders are $14\frac{1}{2}$ inches, the intermediate $28\frac{1}{2}$ inches, and the low-pressure 33 inches in diameter, with a stroke of 4 feet. The rams of the pumps are 3 feet in diameter, with a stroke of 4 feet. These works cost in all about £77,000. Communication was also made with the northern low-level sewer, in order that the sewage could, in an emergency, be pumped at either station.

The next work of importance carried out in accordance with the recommendations in the report referred to, is the increase of the pumping capacity at Crossness, which works are now in hand, and are estimated to cost £76,000. Having regard to the rapid growth of population, the time cannot be far distant when the larger works suggested in the report must be undertaken.

It is necessary to refer to the improvements made in the works handed over to the County Council as suggested by experience.

In regard to the pumping machinery, much progress has been made since the date when the works were originally constructed, and steam is now employed at much higher pressure. The coal bill at the various stations was found to be very large, at least 50 per cent. more than it should be with first-rate machinery and high-pressure steam. The pumps, moreover, at Abbey Mills, which were of the double-acting piston type, were worn out; as a result, the sewage could never be pumped down in the northern low-level sewer, which was surcharged as far up as Westminster. The improvement of the machinery at this station was therefore undertaken at the earliest possible moment; all the old boilers were removed, and ten new Lancashire boilers, each 30 feet by 8 feet, seven working at a pressure of 100 lbs. and three at a pressure of 150 lbs. per square inch, were substituted; the boilers being provided with mechanical stokers and fuel economisers. After the new boilers were fixed, the compounding of the machinery was proceeded with. New pumps were also provided, and the machinery at this station may be said to fully accord with the latest practice. The work was carried on without causing any interruption in the work of pumping the dry-weather flow, together with as much rainfall as the machinery in work was capable of. This work was carried out from 1892 to 1895 and has cost £21,000. The cost of pumping the sewage before the alterations was between 16*s.* and 17*s.* per million gallons, whilst subsequently it became only 11*s.* per million gallons (see Appendixes I, II, and III). But more important than this, from the sanitary point of view, it may be stated that the northern low-level sewer is now kept pumped down; and that there is in consequence an enormous reservoir capacity available in this sewer and its branches for the reception of moderate rainfalls, which, before the alterations, caused frequent overflows into the river. Sixty-eight men are employed at this station and the work is performed continuously.

At Crossness, the four rams on each pump already referred to, were removed, new pump-barrels, with single plungers 9 feet in diameter, were substituted, and the compounding of the engines is now being proceeded with on the same general lines as those at Abbey Mills. The estimated cost of this work is £76,000. The substitution of the large plunger has proved quite satisfactory.

At Deptford, too, the work of compounding is well in hand, of which the new boilers, seatings, economisers, &c., have cost £11,614. Also, in order to deal with the storm-water discharged into the low-level sewer at Battersea, the late Board built the two relief pumping-stations, one at the Falcon Brook, and the other over the Effra Creek as described. As these stations have single pumps only, it was proposed to duplicate them; but the space, particularly at the latter station, being so limited, it has been decided to build a new station at Heathwall, in Nine Elms Lane, this being approximately mid-way between the other two stations. This station is fast approaching completion, and will contain three horizontal Otto gas-engines, each of 200 I.HP., driving three belt-driven centrifugal 28-inch pumps. The capacity of each pump will be 66 tons per minute, with a lift of about 20 feet. The cost of the land, buildings, &c., is about £16,500, and that of the machinery £5,238. The mechanical work has been executed under the superintendence of Mr. E. T. Atkinson.

The precipitating channels at Barking were designed for use on the intermittent system, and were provided with large telescopic weirs for the purpose of decanting the effluent water; but in practice it was found impossible to produce a satisfactory effluent by this means, as was indicated by the small amount of sludge produced, namely 7,300 tons per week, being less than one-third of the quantity known to be contained in London sewage. Moreover, crude sewage was frequently discharged into the river during periods of heavy rainfall. The matter received the careful and anxious consideration of the Chief Engineer, and, as a result, it was determined to build weir-walls across the further ends of the precipitation channels, to abandon the telescopic weirs, with the exception of those necessary for decanting the effluent for cleansing purposes, and to treat the sewage upon the continuous system. These alterations were carried out in 1891 at a cost of £1,890, and the immediate result of the alteration in the mode of working was to raise the production of sludge to 23,000 tons per week, whilst in 1895 the sludge sent to sea averaged 26,760 tons per week, the increase in population and more perfect methods of working accounting for the latter increase. It may be said that as a consequence of these improvements, since March, 1892, no sewage has passed direct into the river at the outfall works; for no matter what storms have occurred in London, all that has come to Barking has first been treated, and passed through the precipitation channels. Whilst the works were in progress, the experience gained at Barking was brought to bear upon those at Crossness, the designs were altered, and the works as completed are upon the same general lines as those at Barking. The average weekly production of sludge at this station during 1895 was about 15,000 tons per week.

Among other improvements, either in progress or about to be carried out, for the further improvement of the main drainage works, may be mentioned the provision of large steel sludge-tanks at Barking situated at a sufficient elevation to permit of the sludge gravitating into the steamers; so that night and Sunday pumping of the sludge is not necessary, and the loading of the steamers is much facilitated. These tanks hold about three shiploads, or upwards of 3,000 tons, and cost £11,220. Telescopic weirs were introduced, at a cost of £1,710, into the sludge-settling channels at Barking, to facilitate drawing off the liquor from the settled sludge, thus enabling the latter to be sent to sea in a more concentrated form. A not unimportant improvement has been that of dealing with the liquor drawn off from the settled sludge, separately from the main body of sewage, into which it was formerly discharged. This liquor, amounting to 1,200,000 gallons per day at Barking and 600,000 gallons at Crossness, which is approximately 1 per cent. of the daily sewage flow, is treated with 20 grains of lime and 10 grains of proto-sulphate of iron per gallon, which quickly precipitates the suspended matters and deodorizes this black and filthy liquid. The jetty was also lengthened and widened in order to provide more berthing room for the steamers and to permit of the lime, coal and other stores being delivered alongside by steamer at all states of the tide.

The drainage of North Woolwich is also about to be undertaken at a cost of £67,000; the sewage from this part of the metropolis having hitherto passed direct into the Thames.

Experience has suggested certain other improvements at Barking, mainly in the shape of a liming station to be constructed upon the foreshore of the river alongside the jetty; which will obviate the necessity of conveying the lime to the present liming station, upwards of ½ mile distant, and will also enable a more perfect solution of lime to be produced. The lime water will be conveyed from this new station to the main outfall sewers at a distance of about 500 feet above the new liming station, to which place it will be conveyed in a channel. Clarified sewage effluent will be used in the manufacture of this lime water, in place of the sewage which has been used hitherto. This liming station with the necessary adjuncts will cost about £60,000.

Other works of an important character are contemplated, including a new sewer from Hackney Wick to Abbey Mills for the purpose of relieving the River Lea from the too-frequent overflows of storm-water; also the erection at Chelsea of a storm-water pumping-station with gas-engines and pumps like those provided at the Heath Wall and King's Scholars' Pond outlets. The cost of these works will be about £50,000.

A small but not unimportant addition to the Main Drainage Works at Barking may be mentioned, namely, the artificial filter, which is generally known as the coke-breeze filter, and was the outcome of certain experiments made on smaller filters in 1892. The experimental work in connection with these filters has been published and the results are generally known. The Authors may, therefore, confine their remarks to a bare statement of fact that the filter composed of coke-breeze gave the best results. As the works are situated near the Beckton Gas Works, where large quantities of breeze and cinders are produced, and as it was found that these materials could be obtained alongside the Council's works at a cost of about 1*s.* 6*d.* per ton, it was determined to make a filter of them with a superficial area of about 1 acre. This filter was constructed for the Main Drainage Committee by Mr. Crimp in 1893 at a cost of about £2,000. It consists of 3 feet of what is known as pan breeze, or cinder, with a layer of gravel at the top, 3 inches in thickness, intended to act as a weighting material. Advantage was taken of the experience gained in working the smaller filters, and arrangements were made for the filter to be charged with effluent from the precipitation channels; the effluent can then be kept in contact with the filter for any required length of time, the purified effluent then flows off by a channel into the Thames and the filter is again charged. As is well known, the purification of the effluent is effected by means of organisms which establish themselves in the filter, and the amount of purification effected depends upon the length of time the effluent is allowed to remain in contact with these organisms. In practice it is found that a purification of about 78 per cent. of the dissolved organic matters can be effected with a contact of about two hours. The filter is worked day and night for six days of the week in periods of eight hours. In each period the filter is charged, the time occupied being about one hour, the effluent remains in contact for two hours, whilst the remainder of the time is occupied in drawing off the filtrate. The volume dealt with per twenty-four hours, when the filter is in operation, is 1,000,000 gallons; and so far as present experience goes, the filter is apparently capable of continuing its function for a considerable period of time. This filter indicates that if it should ever become necessary to further purify the effluent generally, as now discharged into the Thames, the object sought to be attained might be accomplished by means of filters of the kind referred to.

Some details of the working of the Main Drainage Works and the annual cost, are shown by statistical information given in the Appendixes. The figures relate particularly to the working of the system during the past three years, and include not only a statement of the volumes dealt with, but also the cost of carrying on the works.

As to the dry-weather flow of sewage on the north side of the Thames, the Authors have had some difficulty in determining what are and what are not "dry days." In order to obtain a fair standard of comparison, it was considered that those days may be said to be dry on which there is no fall of rain either on the day itself or during the previous twenty-four hours. Adopting this standard, it is found that the number of dry days in 1893, 1894 and 1895 were respectively 161, 117 and 182. In the following Table will be found the figures for these periods set out for the whole of the years in question, and also for each of four quarters of the years.

SEWAGE DISCHARGED AT BARKING OUTFALL.—THREE-MONTHLY PERIODS, 1893-4-5.

Year.	Sewage Discharged.	
	Number of Dry Days.	Average Daily Discharge.
1893.	Days.	Gallons.
First three months . .	34	108,039,000
Second " " . .	65	106,777,000
Third " " . .	32	113,720,000
Last " " . .	30	102,373,000
The whole year . . .	161	107,377,000
1894.		
First three months . .	24	115,167,000
Second " " . .	33	112,478,000
Third " " . .	33	120,306,000
Last " " . .	27	99,759,000
The whole year . . .	117	112,045,000
1895.		
First three months . .	44	125,160,000
Second " " . .	53	128,437,000
Third " " . .	45	115,447,000
Last " " . .	40	98,582,000
The whole year . . .	182	116,990,000

In investigating, however, the dry-weather flow of sewage, it is necessary to bear in mind that it varies considerably during the several days of the week, as will be seen from the following Table :—

TABLE SHOWING THE AVERAGE DRY FLOW OF SEWAGE ON DIFFERENT DAYS OF THE WEEK DURING THE YEARS 1893, 1894, 1895.

	1893.		1894.		1895.	
Days of the Week.	No. of Dry Days.	Average Daily Discharge.	No. of Dry Days.	Average Daily Discharge.	No. of Dry Days.	Average Daily Discharge.
		Gallons.		Gallons.		Gallons.
Sunday .	26	96,364,000	18	99,664,000	27	102,565,000
Monday .	24	103,414,000	18	107,135,000	31	116,918,000
Tuesday .	23	110,097,000	19	117,765,000	28	120,078,000
Wednesday	18	114,307,000	13	116,305,000	24	125,955,000
Thursday .	19	110,387,000	15	117,195,000	24	120,851,000
Friday . .	27	111,927,000	18	113,655,000	23	121,331,000
Saturday .	24	108,557,000	16	114,945,000	25	116,186,000
Total . .	161		117		182	

Some careful observations have been made in order to determine the rain-flow from an area fully built over. The details relating to one such area are subjoined. The district referred to is shown upon the general plan, Plate 3, and is drained by a branch sewer discharging into the Counters Creek sewer. The branch sewer always has a free discharge, and is therefore well adapted to the purpose. It is 5 feet high, 3 feet wide, with semi-circular top and invert, and its discharging capacity is 3,860 cubic feet per minute. The area drained is 160 acres, and it is fully built upon; the number of persons living in the district is 18,325, which is about 114 persons per acre. The dry-weather sewage flow, at 36 gallons per head per day, is about 73 cubic feet per minute as an average. This sewer has been observed to run just full, but not surcharged, on five occasions since 1889, three of which were in 1895, in the months of August, September and October. The falls of rain producing this result ranged from 0·61 inch to 1·39 inch, and were falls of great intensity. When running full, the sewer under consideration can carry off about $\frac{2}{5}$ inch of rain per hour from the area drained by it; and on the occasions referred to was carrying about that volume, which is equal to a rate of about 24 cubic feet per minute per acre. As the extreme wet-weather flow in such a case is about fifty-three times the dry-weather flow, it may be said that a sewer that will carry off all the rainfall from a fully-built-upon area will also carry off the sewage; because it is in practice almost impossible to construct works of the class under consideration so exactly proportioned to their work that an excess of less than 2 per cent. would render them ineffective. This matter should be carefully studied by those advocates of the separate system who fail to understand why it has not been adopted in London. With such facts, the Authors do not think that the question of a separate system for the Metropolis is likely to be advocated, particularly as its cost would not be less than 20 millions sterling.

Experiments bearing on the question of the discharging capacity of sewers have been made upon the three main outfall sewers to Barking, which were designed in accordance with the formula—

$$v = 53 \cdot 64 \sqrt{H2\,F},$$

and were calculated to discharge 33,800 cubic feet per minute, or a maximum with a chord subtended by an angle of $49\frac{1}{2}$ degrees (about $\frac{19}{20}$ full bore), 34,000 cubic feet per minute. As a fact, continuous automatic records taken within all reasonable limits of accuracy upon the three 10-foot weirs at the outfall works, show that during periods of great storms the discharge reaches 45,062 cubic feet per minute, the last occasion having been on the 18th March, 1896. This is at least $29\frac{1}{2}$ per cent. more than the sewers were originally calculated to carry. These sewers cannot become surcharged, and therefore do not work under pressure. The ordinary dry-weather flow is 13,000 cubic feet per minute, and the maximum discharge during heavy falls of rain is as stated to be about 45,000 cubic feet per minute.

It is difficult to appreciate the vastness of the work carried on in connection with the disposal of the sewage of the Metropolis. A staff, consisting of 460 men on the north side of the Thames, 310 men on the south side, and 150 men on the sludge-vessels, is engaged in this work of pumping and chemically treating and dealing with the sludge of the 75,000 million gallons of sewage produced in each year, which is transformed into a clear innocuous effluent flowing into the Thames. The sludge, consisting of 2,169,000 tons per annum, is conveyed 50 miles down the river and deposited in the German Ocean, leaving no trace either in the sea or on shore. The work proceeds incessantly night and day, in order that the daily flow of 205 million gallons of sewage may be disposed of without offence; and all who are familiar with the lower reaches of the Thames will agree that the pollution of the river is thus practically prevented.

The Paper is accompanied by a map and four drawings, from which Plates 3 and 4 have been prepared.

APPENDIXES.

APPENDIX I.

Barking.

1893.

			£	s.	d.	
Precipitation,	41,993,000,000 gallons,	cost	40,648	7	7	19s. 4·32d. per million gallons.
Deodorization,	6,762,000,000 ,,	,,	6,282	19	2	18s. 7d. per million gallons deodorized.
Sludge (land cost),	1,314,000 tons	,,	6,977	9	1	1·27d. per ton.
,, (sea cost),	1,314,000 ,,	,,	20,575	13	4	3·76d. ,,
	Total . . .		£74,484	9	2	

1894.

			£	s.	d.	
Precipitation,	45,780,400,000 gallons,	cost	38,444	12	8	16s. 9·54d. per million gallons.
Filtration	94,223,416 ,,	,,	233	9	2	£2 9s. 6·65d. per million gallons.
Sludge (land cost),	1,328,000 tons	,,	11,349	19	2	2·05d. per ton.
,, (sea cost),	1,328,000 ,,	,,	19,327	2	7·64	3·49d. ,,
	Total . . .		£69,355	3	7·64	

1895.

			£	s.	d.	
Precipitation,	45,568,820,000 gallons,	cost	38,113	3	9	16s. 8·73d. per million gallons.
Filtration,	230,944,000 ,,	,,	405	9	9	£1 15s. 1·39d. per million gallons.
Sludge (land cost),	1,408,000 tons	,,	12,239	16	7	2·086d. per ton.
,, (sea cost),	1,408,000 ,,	,,	20,160	18	3	3·436d. ,,
	Total . . .		£70,919	8	4	

Crossness.

1893.

			£	s.	d.	
Precipitation,	25,590,224,845 gallons,	cost	19,192	9	7¾	15s. per million gallons.
Deodorization,	1,044,986,885 ,,	,,	1,065	11	0¾	£1 0s. 4½d. per million gallons deodorized.
Sludge (land cost),	707,000 tons	,,	4,953	18	3¼	1·682d. per ton.
,, (sea cost),	707,000 ,,	,,	11,187	19	4¾	3·76d. ,,
	Total . . .		£36,399	18	4½	

1894.

			£	s.	d.	
Precipitation,	28,277,900,000 gallons,	cost	15,537	17	2	10s. 11·9d. per million gallons.
Sludge (land cost),	724,000 tons	,,	5,553	15	5	1·84d. per ton.
,, (sea cost),	724,000 ,,	,,	10,884	18	3·31	3·6d. ,,
Total . . .			£31,976	10	10·31	

1895.

			£	s.	d.	
Precipitation,	29,289,868,276 gallons,	cost	16,868	16	1½	11s. 6·22d. per million gallons.
Sludge (land cost),	761,000 tons	,,	4,962	0	8	1·56d. per ton.
,, (sea cost),	761,000 ,,	,,	11,294	18	0	3·56d. ,,
Total . . .			£33,125	14	9½	

The operations in connection with the treatment, as will be seen above, divide themselves under the following heads:—

Precipitation.—The operations at the filth-hoists, treatment with chemicals, and drawing off the effluent water.

Sludge (land cost).—The work done by flushers in clearing the precipitation channels, settling in the sludge store, pumping off the liquor and pumping into the ships.

Sludge (sea cost).—The conveyance of sludge to sea by steamers.

There is included at both outfalls the cost of deodorization for the year 1893. Since that year it has not been found necessary to treat the effluent. In the years 1894 and 1895 is included the cost of filtration experiments.

The cost of the sludge-vessels has been as follows:—

Name of Vessel.	1893.						1894.						1895.					
	Cost each Trip.						Cost each Trip.						Cost each Trip.					
	Including Repairs.			Exclusive of any Repairs.			Including Repairs.			Exclusive of any Repairs.			Including Repairs.			Exclusive of any Repairs.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Barking .	17	5	11·04	13	7	9·99	15	19	8·97	14	3	4·9	16	6	11·52	15	10	8·24
Barrow .	14	13	4·97	12	16	10·63	13	17	4·39	12	19	7·7	14	17	10·32	13	18	7·25
Bazalgette	16	10	8·88	13	0	10·13	14	17	9·19	13	13	4·5	15	11	10·46	13	16	1·13
Belvedere.	14	1	4·80	12	10	6·29	14	3	4·12	13	2	2·4	13	19	0·88	12	15	6·83
Binnie .	16	7	0·48	13	7	0·33	14	15	7·15	13	7	4·5	12	10	10·72	12	9	3·60
Burns . .		..			..			..			..		14	2	9·92	13	19	8·42
Average over all the trips	15	14	3·84	13	0	4·61	14	14	5·57	13	8	11·8	14	10	0·59	13	13	0·74

Each trip required on an average, for 1894, 4·96 tons, and for 1895, 5·22 tons of coal.

APPENDIX II.

Treatment for the past Three Years.

Outfall.	Total Flow Treated.	Sludge Produced.	Quantity of Sewage to Produce 1 Ton of Sludge.	Average Percentage of Moisture in Sludge as sent to Sea.	Solid Matter in Sludge.	Solid Matter sent to Sea, in Grains per Gallon of Sewage.	Filth Taken from Screens.	Lime.		Protosulphate of Iron.		Solid Matter in Effluent. Grains per Gallon.
								Quantity Used.	Grains per Gallon.	Quantity Used.	Grains per Gallon	
	Million Gallons.	Tons.	Gallons.		Tons.		Tons.	Tons.		Tons.		
1893.												
Barking . .	41,993	1,314,000	32,000	90·98	118,522·8	44·26	4,285	13,934	5·2	2,816	1·05	6·915
Crossness . .	25,590¼	707,000	35,500	91·68	58,822·4	36·00	1,009	5,392	3·3	1,600	0·98	5·834
Total .	67,583¼	2,021,000			177,345·2		5,294	19,326		4,416		
1894.												
Barking . .	45,780·4	1,328,000	34,473	90·70	123,504	42·30	4,055	13,924	4·77	2,685	0·92	7·1
Crossness . .	28,277·9	724,000	39,058	91·25	63,350	35·16	1,288	6,343	3·52	1,785	1·00	6·2
Total .	74,058·3	2,052,000			186,854		5,343	20,267		4,470		
1895.												
Barking . .	45,568·8	1,408,000	32,364	91·38	121,370	41·76	4,323·8	13,983·5	4·81	2,939·6	1·01	7·7
Crossness . .	29,289·8	761,000	38,488	91·50	64,685	34·77	688·2	7,873·2	4·21	2,094·9	1·12	4·9
Total .	74,858·6	2,169,000			186,055		5,012·0	21,856·7		5,034·5		

It should be noted that during the hot weather of the year 1893 the effluent was deodorised at Barking for sixty-one days, and at Crossness for twenty-eight days, when 7,807 million gallons were so treated.

The deodorization was effected by means of manganate of soda and sulphuric acid.

APPENDIX III.

Main Drainage Expenditure during the past Six Years.

	£	s.	d.	£	s.	d.
1890–1.						
Sewerage and drainage, working and maintenance	29,788	8	11			
Pumping stations	55,835	18	1			
Sewage deodorization and removal	81,533	6	1			
Tidal experiments in sea reach	320	4	2			
				167,477	17	3
1891–2.						
Sewerage and drainage, working and maintenance	30,841	16	1			
Pumping stations, maintenance	62,885	7	6			
Sewage deodorization and treatment at outfalls	75,970	6	1			
Sludge-vessels, cost of working	12,478	15	8			
				182,176	5	4
1892–3.						
Sewerage and drainage, working and maintenance	37,121	12	3			
Pumping-stations (not at outfalls), maintenance	39,606	4	0			
Barking and Crossness outfalls ,,	90,339	14	3			
Sludge-vessels, cost of working	27,697	14	8			
				194,765	5	2
1893–4.						
Sewerage and drainage, working and maintenance (£18,000 of this is arrears for rates, &c., on sewers, and extra chemicals)	54,418	9	4			
Pumping-stations, maintenance	34,724	11	6			
Barking outfall ,,	55,096	3	2			
Crossness ,, ,,	57,331	14	11			
Sludge-vessels, cost of working	37,030	19	6			
				238,601	18	5
1894–5.						
Sewerage and drainage, working and maintenance	34,314	7	3			
Pumping-stations, maintenance	37,530	15	7			
Barking outfall ,,	45,164	18	10			
Crossness ,, ,,	44,219	17	9			
Sludge-vessels, cost of working	32,304	14	9			
Incidental expenses	78	6	2			
				193,613	0	4
1895–6.						
Sewerage and drainage, working and maintenance	32,708	11	5			
Pumping-stations, maintenance	34,077	17	1			
Barking outfall ,,	45,811	4	10			
Crossness ,, ,,	45,371	5	1			
Sludge-vessels, cost of working	32,011	5	9			
Incidental expenses	208	9	8			
				190,188	13	10

The average yearly expenditure on main drainage, including repayments of capital and interest, during the past six years, was equivalent to a rate in the £ on rateable property in the metropolis of 3·20*d.*; 1890–91, 3·21*d.*; 1891–92, 3·15*d.*; 1892–93, 3·13*d.*; 1893–94, 3·26*d.*; 1894–95, 3·17*d.*; 1895–96, 3·31*d.* (estimated).

APPENDIX IV.

Comparative Statement of Cost and Work done at the Pumping-stations during the Years 1893, 1894 and 1895.

Average cost of lifting 1,000,000 gallons of sewage 1 foot.

—	Abbey Mills. 1893	Abbey Mills. 1894	Abbey Mills. 1895	Western. 1893	Western. 1894	Western. 1895	Crossness. 1893	Crossness. 1894	Crossness. 1895	Deptford. 1893	Deptford. 1894	Deptford. 1895
	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.
Staff (engineers, stokers, cleaners and trimmers)	0·638	0·602	0·67	1·122	1·068	1·10	0·988	1·093	2·32	1·024	1·499	1·74
Staff, other than attending to engines	0·542	0·717	0·72	1·448	1·294	1·20	1·629[1]	1·487[1]	0·22[1]	0·992	0·464	0·15
Coals for engines only	1·469	1·897	1·41	1·758	2·318	1·81	2·420	2·973	2·48	1·901	2·060	2·02
Coals for other purposes	0·017	0·060	0·01	0·229	0·033	0·03	0·277	0·059	0·16	0·010	0·008	
Repairs, cleansing and maintenance	0·160	0·176	0·17	0·231	0·340	0·20	..	..	..	0·324	0·232	0·27
Gas, water, rates and taxes	0·696	0·625	0·65	1·541	1·430	1·48	0·391	1·288	1·48	0·587	0·559	0·57
Stores	0·200	0·283	0·29	0·267	0·267	0·24	0·448	0·377	0·28	0·234	0·203	0·16
Totals	3·722	4·360	3·92	6·596	6·750	6·06	6·153	7·277	6·94	5·072	5·025	4·91

[1] Includes labour for repairs, cleansing and maintenance. Rates and taxes account for the wide difference.

Total Cost of Stations and Quantities of Sewage Pumped.

Year.	Abbey Mills. Lift 38 feet.[1] Lift 41 feet.[2] Sewage Pumped (in Million Gallons).	Abbey Mills. Cost.	Abbey Mills. Cost per Million Gallons.	Western. Lift 18 feet. Sewage Pumped (in Million Gallons).	Western. Cost.	Western. Cost per Million Gallons.	Crossness. Lift 25 to 30 feet. Sewage Pumped (in Million Gallons).	Crossness. Cost.	Crossness. Cost per Million Gallons.	Deptford. Lift 18 feet. Sewage Pumped (in Million Gallons).	Deptford. Cost.	Deptford. Cost per Million Gallons.
		£.	s. d.		£.	s. d.		£.	s. d.		£.	s. d.
1893	24,429¼	13,699	11 1·68	9,005⅓	5,156	11 5·41	26,574¼	15,481	11 6·63	17,861¾	6,841	7 7·93
1894	26,482½	17,376	12 8·0 [1] 14 5·5 [2]	9,627⅓	5,683	11 9·68	28,345⅕	18,884	13 3·89	18,946	7,074	7 5·62
1895	26,303⅔	16,484	11 4·78 [1] 20 1·89 [2]	9,734⅘	5,226	10 8·86	29,289⅕	17,896	12 2·64	19,817	7,241	7 3·71

[1] Beam engines. [2] Worthington engines (working intermittently).

APPENDIX V.

The following return shows the results of the recent trials of the engines and boilers at the Abbey Mills pumping-station :—

It will be noticed that there is a perceptible variation in the evaporative performance of the boilers as tested on the dates of the respective trials, namely, 7·11 lbs. of water per lb. of coal on 12th October, 7·32 lbs. on 14th October, and 7·9 lbs. on 21st October. If the result of the trial on the 21st October be taken as a standard, then the cost of coal to raise 1,000,000 gallons 1 foot high would be 0·76*d.* on 12th October, 0·70*d.* on the 14th October, and 0·73*d.* on 21st October; and the comparative coal consumption on the same dates would be 2·81 lbs., 2·59 lbs., and 2·62 lbs. per indicated HP. per hour.

Boiler Trials.

Boiler Observations.	Worthington Engines.		Beam Engines.
Date	12th Oct., 1896	14th Oct., 1896	21st Oct., 1896.
Duration of trial	10 hours	10 hours	10 hours.
Description of boilers	Lancashire	Lancashire	Lancashire.
Number of boilers	One	One	Two.
Dimensions of shell	8 feet × 30 feet	8 feet × 30 feet	8 feet × 30 feet.
Diameter of furnaces	3 feet 2 inches	3 feet 2 inches	3 feet 2 inches.
How fired	Mechanically	By hand	Mechanically.
Heating-surface	1,130 square feet	1,130 square feet	1,130 square feet each boiler.
Grate-area	34·8 square feet	38·0 square feet	31·7 square feet each boiler.
Steam-pressure in boiler-house (average)	111·8 lbs. per square inch	114·8 lbs. per square inch	89·4 lbs. per square inch.
Description of coal	"Maude" rough small	"Maude" rough small	"Maude" rough small.
Total coal consumed	11,256 lbs.	9,520 lbs.	18,760 lbs
Coal consumed per square foot of grate	32·3 lbs.	25·1 lbs.	29·6 lbs.
Ash	552 lbs.	410 lbs.	840 lbs.
Clinker	392 lbs.	616 lbs.	772 lbs.
Description of economiser	Green	Green	Green.
Temperature of gases at inlet to economiser (average)	422° F.	406° F.	333° F.
Temperature of gases at outlet from economiser (average)	315° F.	294° F.	207° F.
Air-pressure in side flues (average)	0·75 in. of water	0·62 in. of water	0·56 in. of water.
Total water evaporated	73,051 lbs.	63,820 lbs.	137,723 lbs.
Temperature of feed-water (average)	160° F.	164° F.	175° F.
Water evaporated per lb. of coal	6·49 lbs.	6·70 lbs.	7·34 lbs.
Equivalent evaporation from 212° F. to steam at atmospheric pressure	7·11 lbs.	7·32 lbs.	7·90 lbs.
Cost of coal per ton	9*s.* 3*d.*	9*s.* 3*d.*	9*s.* 3*d.*
Cost of coal per 1,000 lbs. of water evaporated	7·64*d.*	7·39*d.*	6·75*d.*

APPENDIX V—*continued.*

ENGINE TRIALS.

Engine Observations.	Worthington Engines.		Beam Engines.
Date	12th Oct., 1896	14th Oct., 1896	21st Oct., 1896.
Duration of trial	10 hours	10 hours	10 hours.
Description of engines	High duty, triple expansion	High duty, triple expansion	Compound beam.
Number of engines	Two (duplex)	Two (duplex)	Four.
Diameters of cylinders	$14\frac{1}{2}$ in., 22 in., 33 in.	$14\frac{1}{2}$ in., 22 in., 33 in.	25 in., 40 in.
Stroke of engines	4 feet $2\frac{3}{32}$ inches (mean)	4 feet $1\frac{15}{16}$ inches (mean)	6 feet $5\frac{3}{8}$ inches, 9 feet.
Number of double strokes per minute (average)	17·30	17·27	10·32
Steam-pressure in engine-room (average)	110·3 lbs. per square inch	110·2 lbs. per square inch	86·4 lbs. per square inch
Indicated HP. (average)	175·2	169·6	170·5
Barometer	29·85 inches	30·20 inches	29·45 inches.
Type of condenser	Jet	Jet	Jet.
Vacuum in condenser (average)	13·7 lbs. per square inch	13·8 lbs. per square inch	13·9 lbs. per square inch.
Temperature of injection water (average)	52·2° F.	49·8° F.	50° F.
Temperature of ejection water (average)	74·4° F.	70·3° F.	79·8° F.
Water from cylinder-jackets and drains	12,049·5 lbs.	12,324 lbs.	2,925 lbs., drains only, no jackets.
Description of pumps	Double-acting plunger	Double-acting plunger	Double-acting piston.
Number of pumps to each engine	Two	Two	Two.
Diameter of pumps	3 feet	3 feet	3 feet $10\frac{1}{2}$ inches.
Stroke of pumps	4 feet $2\frac{3}{32}$ inches (mean)	4 feet $1\frac{15}{16}$ inches (mean)	4 feet 6 inches.
Lift in feet (average)	41·8 feet	40·9 feet	37·13 feet.
Pump HP. (average)	160·9	156·7	152·8
Ratio of P.HP. to I.HP.	0·918	0·924	0·896
Coal consumed per I.HP. per hour	3·12 lbs.	2·80 lbs.	2·62 lbs.
Water evaporated per I.HP. per hour	20·85 ,,	18·81 ,,	20·19 ,,
Steam used per I.HP. per hour	19·42 ,,	17·92 ,,	18·79 ,,
Sewage pumped, in million gallons	15·24	15·16	32·58
Cost of coal to raise 1,000,000 gallons 1 foot	0·85*d.*	0·76*d.*	0·73*d.*

(Paper No. 2957.)

"The Purification of the Thames."

By William Joseph Dibdin, F.C.S., F.I.C.

The scheme adopted by the late Metropolitan Board of Works for the treatment of the London sewage at the Barking Creek and Crossness outfalls was explained before the Institution in January, 1887,[1] by the Author. It is now proposed to show, first, the work carried out in accordance with it in effecting the purification of the sewage of the metropolis; secondly, the effect of that work in freeing the river from the task formerly imposed upon it in disposing of the raw sewage of five millions of people; and thirdly, the best method of effecting still further improvement if desired.

In the Paper referred to, it was shown that in determining the most effectual and at the same time economical method of treating sewage, the effluent from which could be turned into a tidal river of good volume in relation to that of the sewage, the following points were to be considered:—The detrimental effect of an excess of chemicals; the limited reduction of organic matters in solution by chemical treatment; the use of iron salts as an auxiliary to lime when necessary; the action of bacteria in completing the process of purification; the objections to the filtration of crude sewage; the final purification of the effluent by proper filtration through land; the subsidiary treatment of the effluent when necessary; aeration as an aid to bacterial life; the disposal of the sludge.

The method adopted was first submitted by the Author to the Royal Commission on Metropolitan Sewage Discharge in 1884, as will be seen from the following extract from the minutes of evidence, p. 113 *et seq.*:—"We found that whatever process of chemical precipitation might be used which could be applied in practice would have but a very slight effect in removing the dissolved organic matter. Then we came to the conclusion that the only result which might be expected would be the removal of the suspended matter, and that we might neglect for this purpose

[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 155.

the whole of the dissolved matter. . . . Proceeding with our experiments, we found that the use of those four grains of lime and the one grain of protosulphate of iron was sufficient practically to remove the whole of the suspended matter and the grosser part of the offensive odour. In fact, we were satisfied that it would do all that was required to be done with the London sewage at Barking and Crossness, and that the effluent, if discharged into the Thames there, would certainly hardly be noticeable, and by the time it was thoroughly diluted with river-water that it would certainly be to all intents and purposes invisible; that the present black stream that is seen at the point opposite the present sewage works would be entirely done away with, and that all effect of the sewage in the river in point of appearance would be annihilated. The matters in solution in the sewage would still be there, but the matters in solution are those which are more readily oxidised by the action of the river, and so would disappear at a much greater rate than they do at present."

From the following extracts of the "conclusions and recommendations" of the Commission, it will be seen that the Commission substantially agreed with the above suggestions:—

"3. We are of opinion that some process of deposition or precipitation should be used to separate the solid from the liquid portions of the sewage.

"4. Such process may be conveniently and speedily applied at the two present main outfalls.

"5. The solid matter deposited as sludge can be applied to the raising of low-lying lands, or burnt, or dug into land or carried away to sea.

"6. The entire processes of precipitation and dealing with the sludge can be and must be effected without substantial nuisance to the neighbourhoods where they are carried on.

"7. The liquid portion of the sewage remaining after the precipitation of the solids, may, *as a preliminary and temporary measure*, be suffered to escape into the river.

"10. But we believe that the liquid so separated would not be sufficiently free from noxious matters to allow of its being discharged at the present outfalls as a *permanent* measure. It would require further purification, and this, according to the present state of knowledge, can only be done effectually by its application to land."

The "safety clause," as No. 10 may be called, is now fully met by the results of the experimental filtration operations hereafter described, which can be applied in a far more convenient and economical manner than that contemplated by the Commissioners, whenever the increase in the quantity of the sewage may render such further action desirable. In accordance with the above suggestions and the Report of the Royal Commission, the late Metropolitan Board of Works instructed their engineer to proceed with the construction of the necessary works. The sewage was to be treated chemically by small quantities of lime and iron at the existing outfalls; the effluent was to run directly into the river at these points; and the sludge was to be carried to sea in specially constructed vessels. In the absence of knowledge of the action of bacteria in relation to the filtration of the sewage effluent, no action in this respect had been decided upon. The works constructed for the purpose of carrying out the operations indicated are described in the Paper [1] on "The Main Drainage of London" by Messrs. J. E. Worth and W. S. Crimp, MM. Inst. C.E.

The sewage north of the Thames is delivered at the Northern Outfall by three main sewers. After passing the screens it receives its proper quantity of lime, which varies with the strength and rate of flow of the sewage. At the liming station the lime, after being weighed as it is taken from the store, is placed in large mixing trays 15 feet in diameter, fitted with four revolving arms, to each of which a heavy rake is suspended. Sufficient water is then let into the tray to slake the lime. This being accomplished, more water is added and the mixing-arms are rotated by steam-power, the lime and water being thus stirred into a cream as dilute as possible. Water is continually admitted and the cream of lime flows out into a channel leading to the lime-water tanks, where it meets a large access of water, and is thereby diluted and carried into the tanks, six in number, each having a capacity of about 100,000 gallons. The mixture of the lime and water is further facilitated by the fall from the trough into the tank, and thus the whole bulk is kept in agitation until the tank is full. As required, the lime-water so obtained is forced by centrifugal pumps to an overhead tank placed on the top of the boiler-house and lime-store, whence it is drawn off as required. At first, the lime-water was made with crude sewage and the top liquor drawn from the sludge-settling channels, but the extent to which the lime is destroyed by these was so great that they have been replaced at Crossness by river water, with such marked advantage that the same plan will be adopted in connection with the new liming station at the Northern Outfall works.

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[1] *Ante*, p. 49.

After receiving the lime, which under the new system will be entirely in solution, as originally intended, the sewage passes the iron-water station where the solution of iron-sulphate is added. No special mixing arrangement is applied, as the rolling motion of the sewage as it passes along the sewer is found to answer the purpose. The iron salt is dissolved in a tank of water heated by a steam-coil, and the concentrated solution thus obtained is sufficiently diluted and passed direct into the sewer containing the already limed sewage. The precipitation thus effected by the combined action of the lime and iron is completed in thirteen precipitation-channels.

The method of discharging the sludge from the precipitation-channels to the sludge-settling channels is by sweeping the deposit obtained from the action of precipitation through culverts leading under the main sewer to the receiving chamber at the engine-house, whence it is pumped into the settling channels. On its way to these the sludge is again passed through gratings to collect rags, etc., which may have escaped the first filth-gratings. The quantity of solid matter extracted by the combined action of the double sets of gratings is between 80 tons and 100 tons per week, of which large quantities have been utilized as manure. A destructor-furnace is built close to the filth hoist, or first set of gratings, and when necessary is used for calcination of the refuse.

The following are the results of an analysis of a sample of this refuse:—

Analysis of Filth from Gratings at the Northern Outfall.

		Per Cent.
Moisture		77·2
Wood		1·0
Coarse string and fibre		0·7
Coarse rags		0·4
Fine rags, pulp, &c.		16·6
Very fine fibrous matters, sand, earthy matter, &c., containing volatile organic matter, of which one-fiftieth is nitrogen	51·5	
Phosphoric acid	2·6	4·1
Sand, earthy matter, &c.	42·2	
Moisture	3·7	
	100·0	100·0

The amount of nitrogen in the fine fibrous and earthy matter is only 0·041 per cent., and of phosphoric acid 0·11 per cent. of the whole. While, therefore, its manurial value is but slight, it would appear to be well suited from its fibrous nature for making coarse paper; and experiments on a working scale are in progress with the view of ascertaining its adaptability for that purpose.

After the sludge has settled and the top-water has been drawn off by means of siphons, the sludge is let into the storage-tanks under the settling-channels, whence it is forced by direct-acting pumps to the ships. Formerly the water drawn from the settled sludge was pumped to the liming-station, but alterations have been made which enables this liquor to be separately treated with lime and iron, and after such treatment to settle in the sewage-precipitation channels.

The sewage of London south of the Thames is carried by a large sewer to Crossness, where the precipitation works are much more compact, in consequence of local conditions. As the whole of the sewage is screened, it was not necessary to erect an additional filth-hoist as at the Northern Outfall works, except on a small scale for the sludge. The lime water was formerly put into the sewer before the pumps, but it is now added to the sewage after them. The liming-station is admirably suited to the requirements of the works, practically the whole of the lime being in solution before its addition to the sewage. The lime mixers at Crossness are similar to those at the Northern Outfall, and are 12 feet in diameter. The charge of lime varies between 1 ton and 1½ ton, to meet the flow of sewage. The lime, having been formed into a cream, is discharged from the mixers into a culvert where it meets with river-water pumped for that purpose, and then through a series of tanks, six in number, each of a capacity of about 40,000 gallons. In two of these tanks a pair of Gabbott stirrers, 12 feet in diameter, are fixed. The lime water passes first through one of the end tanks and thence over weirs into four others successively, into the lime-water culvert. The quantity of river water pumped for this purpose is between 2,500,000 gallons and 4,000,000 gallons daily. The quantity of commercial lime taken for making the lime water is about 110 grains per gallon, of which, on an average, about 70 per cent. is in solution. It will be noticed that it is necessary to employ an excess of lime to allow for the hard-core, and the neutralization of a portion of the lime by the carbonic acid in the river-water employed for its slaking and solution. The iron-water is made at Crossness by the simple agitation of the crystals of iron salt with water in an ordinary mixing-mill from which the rollers are removed, stirring arms being substituted in their place, the effect being equally efficacious with that of the steam-coil at the Northern Outfall works. The precipitation-channels at Crossness are not fitted with the telescope weirs for the purpose of emptying the channels, but with the ordinary floating arms, the bulk of the effluent, however, falling over the weirs as at Barking Creek. In other respects these channels are almost identical. In consequence of the more effective arrangements for making lime water at Crossness, the results have been much more satisfactory than those at Barking Creek. The method of collecting the sludge, settling it, and loading the ships is identical with that at the Northern Outfall works.

The fleet of vessels employed for the purpose, carried to sea during the year 1894, 2,052 cargoes of sludge, of which quantity 1,380 cargoes, containing 90·7 per cent. of moisture, were conveyed from the Northern Outfall, and 724 cargoes, containing 91·25 per cent. of moisture from the Southern Outfall. The discharge takes place in the Barrow Deep, commencing at a point 10 miles east of the Nore, and proceeding thence from 5 miles to 10 miles down that channel, which is unused for traffic, being about half way between the Swin Channel, or route for vessels proceeding north, and the Princes Channel, which is the ordinary route for vessels going south. As the sludge is discharged from the bottom of the vessel, some 10 feet under water, and is thus agitated with the sea-water by the action of the twin-screws, the diffusion of the sludge in the water in the wake of the vessel is very complete, so much so that when there is but a slight ripple the visible effect of the sludge is lost after a few minutes. The sand and earthy matters soon separate by subsidence, and the animal and vegetable debris is rapidly consumed by the organic life in the sea-water. This is evidenced by the fact that, although about 10,000,000 tons of sludge have now been deposited in this part of the estuary, the most careful microscopical examination and chemical analysis fail to detect more than the merest trace of the mineral portion of the sludge, either in dredgings from the bottom of the channels or on the surface of the sandbanks, which are now as clean as in 1888, before more than a few trial cargoes had been discharged. The cost of this operation has been found to work out to about $4\frac{1}{4}d.$ per ton of sludge.

Character of Sewage and Effluent.—The effect of the general desire to lessen the pollution of the Thames by refuse from manufactories has been largely to increase the quantity of foul matters received at the outfalls, and this has necessitated careful watching. In almost every case, however, it has been satisfactory to find that such increases in the pollutive matters have been fully met by the treatment adopted. The average character of the sewage before and after treatment is set out in Table I, Appendix I, showing the monthly averages of the daily analyses of samples taken every two hours, day and night, at each outfall, during the year 1894. These include storm water, which increases the average amount of suspended matters left in the effluent, as in many instances the quantity found in the dry weather sewage is considerably lower. It will be seen that at Crossness, in consequence of the better solution of the lime water, there is a material reduction of the matters held in solution, the oxygen absorbed from permanganate in four hours being reduced from 3·7 to 3·1 grains per gallon, or 17 per cent., a result which agrees closely with the laboratory experiments referred to in the Paper by the Author in 1887.

At the Northern Outfall, the results are not yet so good, but this will doubtless be remedied as soon as the new liming station is erected. By analyses it is shown that the average quantity of suspended matters in the sewage at the Southern Outfall was 31·5 grains per gallon, and at the Northern Outfall 29·8 grains per gallon; results which agree very closely with the quantities determined in 1883, and given in evidence before Lord Bramwell's Commission, with the exception that the former is now somewhat stronger than at that date. The average results then found over a period of three months were, southern 26·26 grains per gallon; northern 29·1 grains per gallon. Having regard to all the circumstances it would probably be difficult to obtain a closer agreement, especially when it is considered that the actual quantity of sludge obtained as measured in the sludge stores, after correction for quantity of chemicals used, moisture and matters left in the effluent, agrees with the above results within a fraction of a grain.

Cost.—In a report to the late Metropolitan Board of Works on the 24th November, 1884, by Sir Joseph Bazalgette and the Author, an estimate for the precipitation of 162,500,000 gallons of sewage at the present outfalls was submitted as follows:—

	£
Chemicals	22,000
Barging to sea	37,200
Labour and pumping	26,300
	85,500
10 per cent. contingencies	8,500
Bay effluent treated with about 4 tons of manganate per day for three months in the year	6,000
Total annual estimate	£100,000

First outlay (estimated), £1,140,000, including £131,000 for barges.

The manganate has not been found essential, as was originally suggested, and is provided for only as a safeguard. The working expenses are thus reduced to £94,000, which, interest on capital at 3 per cent., or £34,200, give a total of £128,200 per annum.

The following are the figures actually obtained in practice during the year 1894 :—

	£
Working expenses (including chemicals, &c.) for precipitation	71,119
Barging to sea	30,212
	101,331
Interest on capital	25,400
	£126,731

First outlay (capital), £932,000.

This close approximation to the estimate of 1884, especially considering the difference in the daily volume of sewage then taken into account, viz., 162,500,000 gallons, as against the volume in 1894, viz., 203,000,000 gallons, may be regarded as satisfactory. If the estimated working expenses, viz., £85,500, are increased proportionately to the volume of sewage, the original estimate will be raised to £106,800, as against the actual cost of £101,331. These figures, coupled with the results obtained, speak for themselves as to the wisdom of the action of the late Board with reference to the question of the treatment of the sewage of London.

It will be of interest to note that as a rate of $\frac{1}{4}d.$ in the pound produces £35,320 per annum, the cost of working is less than a rate of $\frac{3}{4}d.$ in the pound, or, including repayment of loan and interest on capital, only a fraction over 1*d.* in the pound. In comparison with this result of a capital expenditure of £932,000, and a working expense of only £101,331 per annum, it may be of interest to shortly glance at some of the alternative proposals which have been made for dealing with the sewage of London. One proposal was to remove the outfalls to Hole Haven, below Gravesend, at a first cost of £4,000,000 sterling, there to erect the necessary works and precipitate as at present. This, it will be seen, would have involved a first outlay of about £5,000,000 sterling. Another, very strongly and influentially supported, was to expend £12,000,000 sterling and carry the sewage to the Maplin Sands. Again, another authoritative opinion, expressly invited by the present London County Council, was to the effect that in the event of the present scheme proving unsuccessful, the next alternative would involve an outlay of £8,000,000 sterling.

Many other proposals for the chemical treatment of the sewage alone, or in combination with extensive farming operations, have been made from time to time, the lowest estimate for which involved an annual cost of double that of the present scheme.

It will thus be seen that on financial grounds alone the adoption of the system which the Author had the honour of submitting to Lord Bramwell's Commission in 1884, has been of vast benefit to the ratepayers of the Metropolis; in addition to which the information on the general question of sewage treatment which that system has been the means of disseminating throughout the country, has enabled alterations to be made on large numbers of sewage works, resulting in greater efficiency and considerable economy, to the advancement of pure sanitation, and the relief of the public purse.

Effect on the River.—In order to judge of the effect of the process upon the river, daily analyses of the river-water at both high and low tide have been made since 1885. Tables I, II, and III, Appendix II, show the average monthly, annual and summer results, from which it will be seen that the most marked features are: the reduction in the quantity of matters held in suspension; a marked decrease in the quantity of free or "saline" ammonia, as well as in the "albuminoid" ammonia at high water; a large increase in the degree of aeration, namely from a summer average of 17·4 per cent. in 1887 to one of 55·5 per cent. in 1892 at high water, and from 14·0 per cent. in 1887 to 47·4 per cent. in 1894 at low water. This factor, in conjunction with the reduced quantity of "free" ammonia, forms a most reliable indication of the difference in the character of the water, and shows conclusively that the change in the state of the river is not one of appearance only. When these tables of average analyses are examined, in view of the history of the work done in connection with the deodorization and treatment of the sewage since 1885, they are found to be most instructive. For instance, after the temporary deodorization with chloride of lime in 1884, which was then the only substance available in sufficient quantity, manganate of soda was resorted to, in 1885 and 1886; but in consequence of the wisdom of that course being questioned, chloride of lime was again tried, under other advice in 1887, with the result that the condition of the river in that year was notoriously bad. On examining Table III, "average summer analyses," it will be seen that, comparing 1886 with 1887, *i.e.*, manganate year as against chloride of lime year, and taking the average of both high and low water, the oxygen absorbed from permanganate by the matters in the water increased from 0·23 to

0·40 grain per gallon; the "free" ammonia increased from 0·098 to 0·272; the "albuminoid" ammonia increased from 0·025 to 0·051; while the aeration decreased from 22·3 per cent. to 15·7 per cent. When the use of manganate in limited quantities was again resorted to matters improved, but not until after the opening of the precipitation works did the river return to as good a condition as it was in 1886 when manganate was freely used from May to October.

The condition of the river between Teddington and Southend is well shown by the results of an examination of the water collected at fifteen points between and inclusive of those places, conducted by the Author from the dry season, commencing in July, 1893, to the following wet season ending in March, 1894, the samples being collected daily at high and low water at each place. The monthly averages of the dissolved oxygen, or measure of the degree of aeration, stated in terms of the percentage of the maximum possible, is shown in Table III, Appendix III. The total averages being given in Table I, for convenience in comparing with Table II, which gives the average amount of oxygen absorbed from permanganate. The organic matters held in suspension in the water are given in Table IV, and a summarized statement of the dissolved oxygen and that required to oxidize the organic matters held in solution, in terms of the total quantities per section of the river, as well as in terms of tons per 100,000,000 cubic feet in each of nine sections of the river between those points, are shown in Table V. In this Table is also shown, in columns 7 and 8, the average rate at which oxygen is reabsorbed from the atmosphere, having regard to the actual degree of saturation. The sectional volumes are taken from a Report prepared by Professor Unwin in 1884 for the Thames Pollution Commission. These analyses showed that from Teddington to Chiswick the average aeration of the water was 80 per cent. of the maximum possible. From the latter point it decreased gradually to Woolwich, where it was at its lowest, viz., 23 per cent., and from thence increased again until a point below Gravesend was reached, where it was found to average 75 per cent. From this it is seen that, having regard to the sectional volume of the river and the rate at which oxygen is reabsorbed from the atmosphere, the quantity of oxygen so taken up varied between 9 tons above Chiswick and 1,898 tons between Gravesend and Southend. This comparison is, however, no measure of the character of the water, as the sectional volume increases so enormously, viz., from 250,000,000 cubic feet to 34,695,000,000 cubic feet. When considered in terms of equal volumes of 100,000,000 cubic feet of water, this factor clearly shows the relative character of the work of purification which is being effected. Thus, between Teddington and Chiswick the river absorbed 3½ tons of oxygen per 100,000,000 cubic feet per day; at North Woolwich nearly 44 tons per 100,000,000 cubic feet per day; and at Southend nearly 5½ tons per 100,000,000 cubic feet per day. From the Table it is seen that the average area of maximum impurity may be taken as extending from Deptford to Erith, between which points 1,206 tons of oxygen are daily utilized. The analyses of the water, however, showed that only 516 tons of oxygen were required for the matters in solution, thus leaving 690 tons for the oxidation of the solid organic bodies held in suspension. A consideration of the quantities of organic matters so suspended shows that about 5,792 tons of oxygen are required for their complete destruction, which, added to the quantity required, for the merest surface of the mud on the foreshores and bed of the river, at once accounts for the utilization of these hundreds of tons of oxygen per day. From these facts it is clearly apparent that the matters in solution form but a small portion of the real impurities in the river; the solid organic bodies in suspension being by far the most important factor in bringing about the pollution of the water. The average quantity of suspended matters in the effluent during the year 1894 were 6·65 grains per gallon, of which, as an estimate, one half, or 3·325 grains, may be assumed to be organic. If the whole of this existed as carbon the amount of oxygen required for its complete oxidation would be 8·866 grains per gallon, which, on the daily average of 202·8 million gallons, is equal to 114·67 tons of oxygen, or less than one-tenth of the daily total quantity of oxygen absorbed by the water from the atmosphere between Deptford and Erith alone. As the dissolved matters in solution in the London effluent requires each day only 41 tons of oxygen (see oxygen absorbed from permanganate by effluents Table I, Appendix I, the average being 3·17 grains per gallon on 203,000,000 gallons daily) it is evident that the many other sources of pollution, such as sewage outfalls, docks, factories, floating population, flotsam and jetsam, &c., are largely responsible for the total impurities present in the river. As will be shown later, under the head of filtration, even this 41 tons can be very largely reduced in addition to the complete removal of the matters in suspension, if necessary, at a comparatively trifling cost, but even then it is a question, in view of the above facts, and of the improvement shortly to be effected at the Northern Outfall by the new liming-station, how far such an extension would make any serious alteration in the admittedly present satisfactory condition of the river, except by increasing the degree of aëration and thus rendering the water of the river more capable of supporting fish life.

The improvement in the state of the river since the opening of the outfalls in 1890–2 has been so great that many observers have evinced surprise that such results could have been achieved by such apparently simple means. The secret, if secret there be, lies solely in the fact that while the addition to the sewage of certain purifying agents was evident to ordinary observation, the invisible but far more potent action of the bacteria already in the sewage and in the river-water ready to destroy the organic matters remaining after chemical treatment, was not so evident; and thus, although their action was clearly indicated in the Paper on "Sewage Sludge and its Disposal," already referred to, their work has been overlooked by the majority who largely judge by external appearances.

The following comparison of the annual and summer rainfall during the last ten years, being five years before and after the opening of the precipitation works at Barking and Crossness, shows that equally dry years have been experienced since the process came into operation, and which thus has been fully tested, especially during the dry seasons of 1893 and 1895:—

RAINFALL.

Year.	Total.	Summer (June, July and August).
	Inches.	Inches.
1885	24·0	3·49
1886	24·2	4·05
1887	19·8	3·79
1888	27·5	13·83
1889	28·3	5·95
1890	23·8	9·58
1891	25·1	8·07
1892	22·3	6·84
1893	20·1	5·40
1894	26·9	8·33
1895	18·83	5·72

Proposed Deodorization of the Effluent if necessary.—It will be noted that, in the evidence given by the Author before the Royal Commission in 1884, it was suggested that in the event of the purity of the effluent being found insufficient in itself to free the river from nuisance, a further precaution was available in the form of deodorization of the effluent by means of manganate of soda and sulphuric acid. The Author was anxious, in placing this suggestion before the Commissioners, to make it clear that in his opinion this would not be necessary when the river was again in good condition, and this point was again insisted upon both in the Paper above referred to and in the discussion thereon;[1] the Author, in reply, stating that "The mere removal of the sludge would doubtless effect such an enormous improvement that there seemed little likelihood of any danger in the future of the river indicating in any way the presence of sewage matters. As a further precaution, however, it was proposed to add a small quantity of chemically active oxygen to the effluent, and so do away with any possible chance of nuisance."

The belief that the process of precipitation alone would be sufficient to answer all the requirements of the case has been so justified by the rapid manner in which the river recovered itself as soon as the works were opened, that the use of manganate has been discontinued without any perceptible difference except a slightly lowered average quantity of the dissolved oxygen in the water. This result is indeed satisfactory, as leaving a reserve of power in hand should it be required at any future time. The remarkable results attending the experimental filtration operations next to be described has, however, placed such an enormous power in the hands of the sanitarian for the purposes of sewage purification, that it does not appear likely that any necessity will arise for the more extended use of chemicals than the lime and iron necessary for the preliminary precipitation of the suspended matters.

Filtration of the Effluent.—In the Author's 1887 Paper the following paragraph appears.[2] "The lesson to be learnt from the numerous experiments published by various authorities, both in this country and on the Continent, is that bacteria and other low forms of organic life are most potent in the destruction of all objectionable refuse. Modern experience shows that, when this subject is better understood and thoroughly worked out, in all probability the true way of purifying sewage, where suitable land is unavailable, will be first to separate the sludge, and then to turn into the neutral effluent a charge of the proper organism, whatever that may be, specially cultivated for the purpose, retain it for a sufficient period, during which time it should be fully

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. pp. 164 and 264.

[2] *Ibid*, vol. lxxxviii. p. 161.

aerated, and finally discharge it into the stream in a really purified condition." This forecast of the position has now been shown to have been correct with the exception that, instead of its being found necessary to cultivate a special organism, those which are effective for the purpose are found to be freely present in the sewage, and merely require the necessary conditions to enable them to accomplish their work. That this is so will be seen from the following condensed account of the work accomplished in this direction by the experimental filtering operations carried out during the past five years at the Northern Outfall precipitation works, under the direction of the Main Drainage Committee of the London County Council, who, as the successors of the late Metropolitan Board of Works, have had charge of the main drainage operations of the Metropolis since 1889. The remark at the conclusion of the above quoted paragraph: "It is true that knowledge on the subject is not yet sufficiently advanced to put such a system into operation," no longer applies, and if desirable, the method then foreshadowed is now available.

After the publication of these observations in 1887, the State Board of Health of Massachusetts commenced their now well-known series of experiments.[1] The trials, however, were carried out on an experimental scale only; and it was desirable to obtain reliable data on working lines.

The first experiments were conducted on four filters, each having an area of $\frac{1}{200}$ of an acre. These were filled with pea ballast, coke-breeze, burnt clay, and a proprietary arrangement of sand and a special filtering medium. As the sand was in a tank separated from the special medium, the opportunity was taken to ascertain the character of the work accomplished by that material when acting alone. The result of a 2,160-hours experiment, during which the filters worked 484 hours, and rested empty 1,676 hours, showed that the coke-breeze gave the best analytical results, although the coke was not quite so good as that of the filtrate from the combined sand and proprietary material. In each case the results were satisfactory from the general standpoint, as in no instance did after-putrefaction take place when the samples were kept for lengthened periods in either open or closed bottles. The following are the average results of numerous analyses made during the experiments which were conducted in the months of June, July and August, 1892.

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[1] Report of the State Board of Health, Massachusetts, on Water Supply and Sewerage, Parts I and II. Boston, 1890.

Description of Filter.	Oxygen absorbed in 4 hours.		Albuminoid Ammonia.		Average Purification effected, as determined by Oxygen absorbed.
	Crude Effluent.	Filtrate.	Crude Effluent.	Filtrate.	
	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Grains per Gallon.	Per Cent.
Burnt ballast	1·881	1·072	0·243	0·125	43·3
Pea-ballast	1·881	0·880	0·257	0·142	52·3
Coke-breeze	1·881	0·711	0·262	0·103	62·2
Sand	1·725	1·001	0·250	0·132	42·0
Sand and Proprietary material	1·881	0·721	0·267	0·106	61·6

It being thus established that coke-breeze was as satisfactory a material as any for the purpose, a large filter, having an area of 1 acre was constructed with that substance. The depth of the bed was 3 feet, the breeze being covered with coarse shingle to a depth of 3 inches to keep it in position.

The first experiments with this filter were conducted with the view of ascertaining the rate which it was possible to pass effluent through it, rather than obtaining the best results. The coke-breeze, however, speedily became clogged, and after six weeks all the filtrates were putrid. The daily quantity fell from 1,000,000 gallons to 250,000 gallons per day, and at the end of twelve weeks the filter was useless, being choked and in a putrid condition throughout. This result showed that rest and aeration are vital. During this period the following analytical results were obtained, and show clearly by the decrease in the productions of nitrates the effect of this method of working.

Date. 1893.	Oxygen absorbed in 4 hours.		Albuminoid Ammonia.		Nitrogen as Nitrates.		Purification effected on Oxygen absorbed.
	Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	
	Grains per Gall.	Grains per Gall.	Grains per Gall.	Grains per Gall.	Grains per Gall.	Grains per Gall.	Per Cent.
Sept. 28 to Oct. 6	3·631	2·128	..	..	0·000	0·083	41·0
Oct. 9 to 13	2·884	0·509	..	..	0·029	0·215	82·0
Oct. 16 to 20	3·295	0·502	..	..	0·029	0·117	85·0
Oct. 23 to 30	3·915	1·447	..	..	0·103	0·021	53·0
Oct. 30 to Nov. 6	4·420	1·546	..	..	0·000	0·000	65·0
Nov. 6 to 13	4·404	1·285	0·394	0·110	0·283	0·203	71·0
Nov. 13 to 20	4·122	1·125	0·368	0·097	0·299	0·317	73·0
Nov. 20 to 27	4·366	1·203	0·403	0·091	0·304	0·241	72·0
Nov. 27 to Dec. 4	4·832	1·135	0·457	0·119	0·180	0·175	77·0
Dec. 4 to 8	4·745	1·070	0·435	0·109	0·077	0·080	77·0
Dec. 11 to 18	3·821	0·979	0·401	0·092	0·021	0·130	76·0
Dec. 19 to 23	4·877	1·387	0·393	0·191	0·000	0·000	71·6

The first series of biological experiments was then undertaken. The surface was raked over, and the filter allowed to rest for three and a half months, when the putrid odour had disappeared and the coke-breeze was sweet at all depths. From that time the filter was kept constantly at work for nearly a year, with the exception of a period of seven weeks in November and December to allow alterations to be made to admit of more rapid emptying. The process adopted was to begin with small quantities, the filter being filled and emptied twice daily in order to allow the necessary biological conditions to develop. This was commenced on the 2nd April, 1894, and continued for a few weeks, the purification effected gradually increasing. The filtered effluent was produced at the rate of 500,000 gallons per day, and the purification increased to 70 per cent. and 80 per cent., the highest efficiency being attained on the 3rd May, or after a month's working. The purification reached 83 per cent., and fish came up the ditch which carried away the filtrate into the marsh ditches.

Alterations were then made to increase the rate of filling, the feeding-trough being doubled and the daily rate increased to 600,000 gallons with continued good results. Towards the end of 1894 the emptying facilities were supplemented by a pump to prevent tide-locking, and the resting time was shortened until the filter passed 1,166,666·4 gallons per day for six days, resting from 10 P.M. on Saturdays until 6 A.M. on Mondays, thus averaging 1,000,000 gallons per day, including all periods of rest. The method adopted was to fill the filter level with the surface, which occupied an average of 2 hours, allow it to remain standing full for 1 hour, and then empty it slowly during 5 hours, thus completing the cycle of 8 hours, or one shift. Nitrification proceeded satisfactorily, and the filter was apparently capable of continuing to work indefinitely. A point of great importance is the fact that the filter was able to do its work satisfactorily during the exceptionally severe weather in January and February 1895, when a thin coat of ice was formed on the surface, but the filtration proceeded without intermission, the only noticeable change being a decrease of nitrification.

After the filter had been successively dealing with 1,000,000 gallons daily for eight weeks, about 10 tons of sludge was accidentally run upon it. The result was an immediate falling off in the quality of the filtrate, and a putrescent odour was observed. After twenty days' rest, however, the recuperative power of the filter exerted itself, and the breeze was quite sweet to a depth of 2 feet. After a total of twenty-eight days' rest, work was again resumed with good results. From that time until the end of September in the same year, the filter was kept continuously at work on the same system, when the experiments were concluded, it having been satisfactorily established that with proper care the filter was capable of continuing its work as long as might be required at the rate it was then working, viz., an average quantity of 1,000,000 gallons per day for seven days a week.

The following are the averages of the daily analyses :—

Date.	Quantity of Effluent passed per Acre. Average of 7 Days.	Oxygen absorbed in 4 Hours.		Albuminoid Ammonia.		Nitrogen as Nitrates.		Purification effected as determined by Oxygen absorbed.
		Effluent.	Filtrate.	Effluent.	Filtrate.	Effluent.	Filtrate.	
	Gallons.	Grains per Gal.	Grains per Gal.	Grains per Gal.	Grains per Gal.	Grains per Gal.	Grains per Gal.	Per Cent.
Apr. 7 to June 9, 1894 . . .	500,000	4·096	0·856	0·416	0·095	0·128	0·238	79·3
Aug. 3 to Nov. 9, 1894 . . .	600,000	3·608	0·730	0·396	0·113	0·223	0·141	79·6
Nov. 16, 1894, to Mar. 2, 1895 .	1,000,000	4·113	0·935	0·382	0·114	0·396	0·670	77·5
Apr. 8 to 20, 1895	1,000,000	3·512	0·884	0·360	0·102	0·143	0·770	75·4
May 4 to Sept. 28, 1895 . . .	1,000,000	3·233	0·638	..	..	..	..	80·7

A comparison of these results with those obtained at Massachusetts and by Mr. S. R. Lowcock[1] will not be uninteresting. The Massachusetts results showed that only about 60,000 gallons of raw sewage could be continuously treated on one filter, so that the effect of the suspended solids in the sewage would increase the area of filter-bed required to 16·6 acres per 1,000,000 gallons. By means of artificial aeration, Mr. Lowcock reduced this to 3·8 acres per 1,000,000 gallons.

The following is a summarized statement of the work accomplished by the 1-acre coke-breeze filter at the Northern Outfall, between September, 1893, and November, 1896, during which period it had filtered 500 million gallons of effluent. Since the effluent, which is passed on to the filter, contains, on an average, 7 grains of suspended matter per gallon, a quantity equal to 2,232 tons of sludge, of 90 per cent. moisture, has been entirely removed, the filtrate containing practically no suspended matter. Of the matter thus removed about 110 tons were organic, the whole of which has been oxidized; whilst the sand amounted

[1] Minutes of Proceedings Inst. C.E., vol. cxv. p. 297.

to about 40 tons, which, calculated at 24 cwts. per cubic yard, would cover the filter to a depth of 0·267 inch if spread equally over its surface. Such sand has, however, been carried into the body of the coke, and at present there is no appearance of any danger of choking arising from this cause. The organic matters in solution in the crude effluent absorb, on an average, 3·5 grains per gallon of oxygen from permanganate in four hours, while the filtrate absorbs only 0·7 grain. The amount of oxidation effected, measured in this way, would require 90 tons of oxygen, or, in other words, is equal to the effect which could be obtained by the use of 1,000 tons of good commercial manganate of soda. The organic matter in solution that has been completely removed, as determined by the difference between the loss on ignition of the solids in the crude effluent and the filtrate respectively, amounts to 250 tons; making, with the 110 tons of organic matter, a total of 360 tons. About 32 tons of nitrogen, existing either as ammonia or in combination with the organic matter, have been converted into nitric acid, equal in quantity to nearly 200 tons of nitrate of soda. The organic matter that remains in the filtrate is in such a condition that no signs of after-putrefaction are exhibited, however long the filtrate may be kept, either undiluted or diluted, in open or closed bottles.

Similar experiments, conducted at the Author's suggestion, with sewage collected on the separate system at Sutton, Surrey, gave equally satisfactory results, and clearly prove that while the sewages of two places so widely different as London and Sutton can be readily treated, but little difficulty should be experienced in the application of this inexpensive and thoroughly efficient system to the purification of the sewage of towns intermediate between those two, either in size or conditions. If a higher degree of purity is required than is indicated by the foregoing, it can easily be obtained by a slower rate of filtration, thus allowing longer time for the micro-organisms to complete their work. The cost of the filter need not be great, especially when clay land is available. At Sutton, the total expense of digging out the clay for a depth of 3 feet over an area of a little more than $\frac{1}{10}$ acre, burning and replacing it, thus making a burnt-ballast filter, was less than £100. Probably the cost of coke-breeze instead of burnt ballast would have slightly increased this amount.

By the adoption of such a system, the question of sewage purification is placed on a different footing, and the necessity for costly sewage-farms is entirely obviated. The results are completely under control, and filters can be arranged and worked to suit all requirements. It must not be overlooked, however, that unless the process is carefully watched, the first sign of overwork is noted by careful analyses, and rest is given when required, great risk of failure will be incurred; but when once the filter is fairly started and worked systematically, little fear need be felt that it will go wrong. The filter, in fact, is a delicate organism, and requires as much care and attention to keep it in good working order as any piece of machinery. It does not require constant renewal or alteration, but, like a good engine, it requires watchful care to enable it to give the best results.

The work of freeing the Thames from pollution was begun by the Metropolitan Board of Works in 1887; and the present Paper records its successful completion by the London County Council. The purification of the Thames has been one of the most vexed questions for many years, but no difficulty of the kind need arise in future in this or similar cases, as present-day knowledge is sufficient to deal with the subject to any desired extent; and this has added one more to the many conquests made by the science of sanitation during the present century.

APPENDIXES.

APPENDIX I.

Table I.—Sewage Precipitation. Monthly Averages of Daily Analyses of Sewage Effluent.

Each daily sample was from a mixture of samples taken every two hours day and night.

1894. Month.	Analysis of Average Sewage.						Analysis of Average Effluent.					
	Total suspended Matters.	Total dissolved Solids.	Chlorine.	Oxygen absorbed from Permanganate in 4 Hours.	Ammonia. Free.	Ammonia. Albuminoid.	Total suspended Matters.	Total dissolved Solids.	Chlorine.	Oxygen absorbed from Permanganate in 4 Hours.	Ammonia. Free.	Ammonia. Albuminoid.
Northern Outfall.												
Jan.	31·5	60·0	9·4	3·396	2·806	0·388	8·6	62·6	9·4	3·284	2·713	0·351
Feb.	28·3	58·4	8·2	3·415	2·946	0·372	7·1	60·9	7·9	3·389	2·658	0·358
Mar.	28·3	54·8	8·4	3·283	3·242	0·337	7·7	59·8	8·3	3·441	3·358	0·368
Apr.	28·8	53·0	8·7	3·172	3·241	0·339	8·2	58·8	9·3	3·516	3·572	0·362
May	36·9	52·2	10·1	3·269	3·367	0·311	8·3	61·3	9·8	3·506	3·598	0·361
June	25·7	59·0	10·2	2·924	3·218	0·348	6·0	59·6	9·9	3·070	3·189	0·330
July	28·8	63·0	13·3	3·013	2·871	0·327	6·1	64·2	12·5	3·004	3·024	0·334
Aug.	31·3	62·2	14·1	2·814	2·621	0·294	7·1	63·7	13·2	2·968	2·838	0·324
Sept.	25·5	65·2	15·5	2·856	3·008	0·322	5·1	65·5	14·3	2·944	3·442	0·328
Oct.	34·6	69·6	17·8	3·221	3·334	0·442	7·4	70·3	16·1	3·202	3·524	0·428
Nov.	27·2	63·8	9·3	2·942	2·708	0·381	6·1	66·3	9·1	3·024	2·696	0·343
Dec.	31·1	61·5	8·8	3·186	2·947	0·371	7·6	65·2	8·9	3·360	3·031	0·386
Average	29·8	60·2	11·1	3·124	3·027	0·353	7·1	63·2	10·8	3·225	3·137	0·356
Southern Outfall.												
Jan.	38·1	84·8	20·4	3·418	2·553	0·365	8·9	85·7	22·3	2·910	2·261	0·294
Feb.	30·2	79·1	17·3	3·474	2·386	0·433	6·1	81·6	19·3	3·268	2·431	0·299
Mar.	29·5	81·5	17·9	4·050	3·552	0·622	7·8	83·1	20·8	3·492	2·479	0·348
Apr.	30·2	82·1	20·5	3·658	2·424	0·381	7·2	87·6	26·0	3·253	2·316	0·359
May	33·5	113·2	37·3	3·614	2·696	0·431	7·1	109·1	34·2	3·330	2·545	0·397
June	30·6	86·4	26·4	3·952	3·351	0·515	6·3	100·8	33·1	3·122	2·731	0·408
July	36·1	93·7	29·5	3·721	2·790	0·394	6·6	130·3	45·8	3·324	2·768	0·389
Aug.	36·1	81·5	34·5	3·554	2·684	0·388	6·1	120·4	41·9	3·036	2·539	0·335
Sept.	26·6	118·6	37·8	3·799	5·724	0·647	5·7	119·2	37·7	3·089	2·880	0·402
Oct.	35·3	113·8	30·3	3·951	2·566	0·329	5·0	128·6	36·7	2·925	2·425	0·306
Nov.	22·5	79·1	14·2	3·420	2·402	0·266	3·2	76·4	12·9	2·758	2·001	0·197
Dec.	29·1	76·3	12·2	3·892	2·431	0·266	5·0	68·1	10·5	2·876	2·140	0·240
Average	31·5	90·8	24·8	3·709	2·963	0·420	6·2	99·2	28·4	3·115	2·460	0·331

APPENDIX

TABLE I.—MONTHLY AVERAGES OF DAILY ANALYSES OF THE WATER OF THE

Month.	High Water.										
	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895
											Suspended Matter
Jan.	2·95	6·76	2·74	1·85	2·19	1·83	2·10	1·94	2·82	4·56	4·05
Feb.	3·75	7·70	3·28	1·78	5·31	1·77	1·64	2·36	2·91	3·72	2·99
Mar.	5·89	6·16	2·38	1·86	3·90	2·04	2·45	2·54	2·71	2·64	5·58
Apr.	9·12	6·35	4·41	3·58	3·19	1·65	2·88	1·87	2·25	2·28	3·05
May	8·69	6·15	1·90	2·81	1·58	1·54	1·67	1·65	3·08	2·15	2·22
June	9·39	7·23	1·57	2·15	1·52	1·59	1·73	1·89	2·35	1·92	2·17
July	10·71	9·41	2·47	1·50	2·31	1·56	1·66	2·09	2·47	1·85	2·38
Aug.	11·73	9·59	2·47	1·80	5·83	1·46	2·25	2·58	2·47	1·61	2·87
Sept.	10·40	9·49	2·45	2·06	2·82	1·49	2·14	3·03	2·96	1·30	2·94
Oct.	9·70	9·01	2·10	2·27	2·73	2·28	1·50	2·40	2·48	1·47	2·85
Nov.	4·87	8·42	1·94	2·24	2·87	2·36	1·35	1·51	2·29	1·72	1·97
Dec.	4·08	6·75	2·38	2·14	1·82	1·75	3·36	2·13	3·85	2·17	2·46
											Chlorine (grains
Jan.	550·9	179·9	501·5	436·6	196·7	277·7	576·0	160·0	296·0	356·0	185·9
Feb.	206·5	135·8	158·9	512·7	228·6	203·5	350·0	259·0	190·0	322·1	225·2
Mar.	235·0	269·0	287·5	309·1	222·6	367·6	424·0	320·0	233·0	323·5	350·8
Apr.	344·0	274·7	393·6	240·6	299·0	450·0	473·0	470·0	405·0	480·8	369·6
May	462·3	269·0	458·0	385·8	306·9	505·2	570·0	550·0	515·0	519·9	454·5
June	522·7	319·4	434·2	560·5	304·4	653·6	589·0	608·0	568·3	561·6	618·4
July	673·4	516·8	602·9	491·5	483·0	558·1	674·0	632·0	645·0	625·2	676·6
Aug.	774·8	617·5	721·2	343·1	587·2	568·8	700·0	672·0	687·2	645·2	643·7
Sept.	749·6	665·8	717·3	523·0	645·5	658·0	600·0	639·0	757·8	654·7	699·2
Oct.	658·5	652·5	769·2	638·8	629·6	740·0	370·0	524·0	716·5	637·2	711·3
Nov.	296·1	361·3	556·6	345·9	422·3	736·5	128·0	177·0	646·7	109·4	476·7
Dec.	162·8	233·3	412·5	154·3	423·8	607·0	101·0	215·0	510·5	135·1	290·0
											Oxygen absorbed from Permanganate
Jan.	0·260	0·269	0·274	0·305	0·240	0·263	0·444	0·296	0·408	0·344	0·366
Feb.	0·252	0·271	0·246	0·318	0·176	0·301	0·421	0·297	0·344	0·333	0·383
Mar.	0·284	0·275	0·271	0·265	0·237	0·326	0·472	0·271	0·372	0·345	0·369
Apr.	0·263	0·246	0·249	0·267	0·226	0·351	0·413	0·385	0·385	0·342	0·341
May	0·219	0·262	0·293	0·312	0·287	0·364	0·377	0·376	0·329	0·309	0·328
June	0·232	0·237	0·341	0·328	0·325	0·352	0·364	0·377	0·354	0·319	0·314
July	0·249	0·227	0·404	0·336	0·354	0·389	0·316	0·362	0·368	0·337	0·354
Aug.	0·211	0·209	0·385	0·364	0·292	0·328	0·416	0·428	0·296	0·324	0·341
Sept.	0·199	0·214	0·336	0·308	0·310	0·351	0·399	0·474	0·338	0·324	0·333
Oct.	0·218	0·219	0·291	0·273	0·272	0·296	0·424	0·338	0·349	0·386	0·352
Nov.	0·273	0·299	0·324	0·336	0·374	0·324	0·374	0·377	0·423	0·397	0·390
Dec.	0·268	0·174	0·335	0·294	0·251	0·571	0·347	0·395	0·335	0·361	0·356

II.

River Thames off Crossness during the Years 1885 to 1895 included.

Low Water.										
1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895
(grains per gallon).										
4·95	5·39	6·99	10·52	8·70	9·86	4·69	3·60	6·26	18·66	8·71
3·27	5·86	6·24	11·18	14·99	5·33	2·76	4·99	4·93	18·91	6·90
7·04	6·60	4·80	10·20	12·63	5·74	3·76	5·87	5·53	5·44	9·48
5·90	6·12	8·60	16·14	7·29	2·74	4·15	6·58	5·15	6·24	2·97
7·68	6·52	4·46	20·20	6·16	2·63	3·93	1·94	6·48	5·38	5·11
8·82	7·44	4·23	23·56	6·89	3·87	2·83	2·29	7·82	5·38	4·78
9·22	8·37	13·25	20·39	8·45	3·46	5·38	1·94	7·87	6·12	5·41
12·40	8·42	9·22	20·40	13·21	2·94	6·05	4·16	9·44	6·88	6·32
8·87	7·96	8·19	30·23	6·33	5·10	6·46	5·13	14·41	7·78	8·31
8·47	8·29	7·42	27·23	4·73	10·37	4·03	4·64	6·84	5·62	5·25
3·34	5·91	5·76	9·67	5·33	7·47	2·40	3·82	8·86	4·71	3·95
6·12	7·51	6·75	7·98	4·79	4·77	4·50	6·00	7·68	8·53	5·85
per gallon).										
228·3	38·2	9·7	179·4	23·8	89·0	282·0	13·0	49·0	30·2	22·1
22·8	22·8	20·5	218·2	43·0	63·3	85·0	31·0	20·0	62·4	19·0
62·4	46·5	72·3	83·6	38·2	107·5	148·0	39·0	39·0	71·1	41·1
150·0	58·2	140·3	58·9	68·3	185·7	194·0	101·0	120·0	162·1	67·5
216·2	86·8	171·1	161·9	98·2	213·6	269·0	180·0	211·7	227·1	128·8
257·5	110·8	167·7	264·4	82·8	387·2	266·0	251·0	497·5	239·0	263·0
396·7	247·3	345·2	181·2	244·1	240·4	377·0	291·0	372·9	313·0	342·0
514·4	314·4	427·3	138·8	296·3	312·0	391·0	342·0	422·7	342·5	312·2
451·4	361·8	442·6	264·0	392·9	409·2	299·0	325·0	527·3	323·8	384·5
332·1	325·1	471·2	333·8	417·3	485·8	135·0	234·0	424·2	289·8	379·0
82·8	114·4	252·3	102·9	196·7	423·2	11·1	43·0	346·9	11·7	147·8
35·8	21·3	146·4	32·6	192·1	400·0	7·4	36·0	214·5	13·8	63·6
at 80° F. in Four Hours (grains per gallon).										
0·287	0·265	0·267	0·264	0·199	0·276	0·398	0·263	0·333	0·295	0·246
0·288	0·233	0·198	0·286	0·242	0·290	0·358	0·231	0·302	0·317	0·254
0·263	0·233	0·210	0·246	0·227	0·307	0·448	0·188	0·318	0·320	0·257
0·275	0·241	0·241	0·246	0·210	0·335	0·431	0·307	0·307	0·359	0·271
0·233	0·252	0·256	0·316	0·241	0·338	0·464	0·351	0·357	0·402	0·370
0·256	0·242	0·295	0·369	0·297	0·424	0·397	0·386	0·451	0·409	0·459
0·298	0·236	0·448	0·323	0·345	0·417	0·491	0·412	0·489	0·467	0·489
0·281	0·231	0·501	0·385	0·322	0·390	0·482	0·470	0·411	0·429	0·451
0·273	0·236	0·362	0·296	0·340	0·430	0·427	0·481	0·379	0·406	0·457
0·252	0·265	0·317	0·292	0·384	0·375	0·372	0·349	0·433	0·458	0·454
0·274	0·260	0·292	0·294	0·332	0·404	0·353	0·334	0·451	0·384	0·371
0·266	0·153	0·305	0·278	0·292	0·609	0·311	0·339	0·393	0·274	0·304

TABLE I.—

Month.	High Water.										
	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895
											Free Ammonia (grains
Jan.	0·084	0·095	0·133	0·285	0·159	0·162	0·389	0·180	0·215	0·158	0·109
Feb.	0·145	0·104	0·122	0·298	0·116	0·143	0·261	0·167	0·144	0·086	0·239
Mar.	0·117	0·104	0·099	0·243	0·115	0·146	0·238	0·219	0·118	0·094	0·220
Apr.	0·113	0·059	0·076	0·139	0·117	0·158	0·244	0·235	0·133	0·132	0·121
May	0·041	0·101	0·103	0·128	0·187	0·215	0·246	0·192	0·064	0·065	0·084
June	0·064	0·049	0·168	0·211	0·192	0·204	0·274	0·160	0·100	0·067	0·051
July	0·100	0·083	0·303	0·203	0·217	0·210	0·257	0·144	0·076	0·059	0·067
Aug.	0·149	0·146	0·302	0·145	0·158	0·201	0·253	0·098	0·049	0·072	0·057
Sept.	0·131	0·168	0·219	0·152	0·232	0·235	0·214	0·100	0·101	0·082	0·067
Oct.	0·122	0·165	0·207	0·168	0·227	0·185	0·193	0·172	0·139	0·151	0·114
Nov.	0·129	0·166	0·275	0·162	0·241	0·213	0·157	0·215	0·176	0·115	0·194
Dec.	0·103	0·128	0·309	0·118	0·261	0·288	0·147	0·178	0·179	0·196	0·135
											Albuminoid Ammonia
Jan.	0·022	0·024	0·038	0·038	0·033	0·038	0·070	0·034	0·034	0·031	0·019
Feb.	0·030	0·022	0·031	0·051	0·027	0·033	0·059	0·035	0·038	0·024	0·032
Mar.	0·038	0·018	0·013	0·039	0·025	0·035	0·046	0·043	0·035	0·028	0·027
Apr.	0·035	0·011	0·009	0·035	0·031	0·039	0·046	0·039	0·030	0·022	0·027
May	0·039	0·019	0·025	0·035	0·039	0·036	0·045	0·038	0·030	0·027	0·028
June	0·033	0·016	0·032	0·037	0·036	0·035	0·039	0·042	0·039	0·027	0·021
July	0·038	0·021	0·042	0·036	0·041	0·034	0·045	0·038	0·028	0·026	0·025
Aug.	0·035	0·034	0·051	0·035	0·024	0·038	0·024	0·034	0·029	0·026	0·024
Sept.	0·032	0·035	0·036	0·030	0·034	0·035	0·032	0·027	0·026	0·027	0·021
Oct.	0·031	0·033	0·029	0·034	0·037	0·034	0·044	0·035	0·031	0·025	0·022
Nov.	0·033	0·055	0·035	0·041	0·043	0·036	0·038	0·049	0·042	0·025	0·027
Dec.	0·025	0·037	0·042	0·035	0·035	0·055	0·039	0·052	0·028	0·028	0·027
											Dissolved Oxygen—Percentage
Jan.	29·3	27·6	59·2	21·7	21·6	28·8	44·2	55·9	40·3	41·3	38·9
Feb.	..	26·3	33·6	27·9	37·1	38·0	45·4	54·4	41·3	43·4	33·2
Mar.	22·2	36·2	25·5	45·7	50·5	40·9	45·4	53·1	43·2	36·2	28·7
Apr.	28·8	34·6	35·6	35·7	34·6	39·5	39·8	36·4	31·1	40·6	24·0
May	28·9	21·8	25·9	31·0	41·0	33·4	39·0	51·8	30·8	49·1	41·1
June	32·2	27·7	23·5	21·4	33·6	33·2	39·9	57·0	27·7	57·0	40·7
July	17·1	22·1	13·7	25·1	32·9	42·3	41·0	56·0	32·2	55·2	36·7
Aug.	12·4	19·0	15·0	27·7	40·4	35·7	43·3	53·6	45·3	43·2	41·8
Sept.	13·8	17·8	22·7	30·9	34·6	38·4	38·1	45·1	51·8	36·6	42·8
Oct.	27·1	13·6	28·0	32·4	41·3	27·9	51·0	45·5	42·4	31·7	33·6
Nov.	20·9	17·9	25·2	28·5	33·8	34·6	45·8	45·2	48·3	39·2	47·6
Dec.	22·9	31·0	28·1	29·1	42·4	35·9	59·0	41·3	37·3	31·2	51·7

continued.

Low Water.										
1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895
per gallon).										
0·113	0·099	0·082	0·274	0·148	0·170	0·421	0·182	0·233	0·215	0·125
0·153	0·069	0·116	0·307	0·130	0·192	0·231	0·179	0·141	0·145	0·160
0·125	0·097	0·110	0·211	0·123	0·214	0·257	0·228	0·169	0·153	0·242
0·134	0·104	0·097	0·130	0·147	0·253	0·308	0·317	0·209	0·255	0·199
0·058	0·106	0·129	0·168	0·226	0·300	0·324	0·339	0·215	0·224	0·230
0·074	0·051	0·180	0·327	0·208	0·345	0·355	0·318	0·218	0·206	0·175
0·125	0·111	0·346	0·242	0·252	0·319	0·372	0·313	0·222	0·225	0·221
0·180	0·150	0·329	0·175	0·221	0·334	0·376	0·223	0·144	0·167	0·187
0·133	0·188	0·262	0·180	0·308	0·387	0·339	0·287	0·215	0·179	0·168
0·135	0·159	0·230	0·193	0·297	0·362	0·195	0·265	0·297	0·294	0·286
0·123	0·158	0·280	0·164	0·266	0·377	0·155	0·187	0·315	0·092	0·252
0·102	0·125	0·311	0·131	0·277	0·352	0·117	0·162	0·270	0·150	0·156
(grains per gallon).										
0·025	0·029	0·034	0·034	0·034	0·036	0·081	0·033	0·040	0·038	0·019
0·031	0·011	0·025	0·051	0·025	0·040	0·055	0·037	0·032	0·029	0·021
0·037	0·023	0·014	0·034	0·025	0·040	0·064	0·043	0·034	0·037	0·031
0·039	0·015	0·010	0·033	0·029	0·041	0·033	0·051	0·035	0·037	0·032
0·037	0·018	0·029	0·035	0·037	0·040	0·050	0·050	0·040	0·045	0·043
0·034	0·021	0·033	0·041	0·036	0·048	0·055	0·049	0·056	0·043	0·040
0·041	0·022	0·063	0·038	0·038	0·043	0·073	0·053	0·051	0·047	0·041
0·035	0·036	0·085	0·035	0·028	0·050	0·061	0·050	0·050	0·046	0·039
0·034	0·034	0·039	0·039	0·044	0·054	0·045	0·043	0·039	0·046	0·031
0·033	0·033	0·034	0·037	0·059	0·050	0·043	0·044	0·045	0·042	0·037
0·035	0·044	0·027	0·035	0·037	0·053	0·039	0·043	0·045	0·023	0·038
0·029	0·039	0·041	0·029	0·029	0·048	0·036	0·044	0·040	0·023	0·036
of Complete Aeration.										
..	47·2	73·3	15·9	53·0	36·0	46·4	66·2	54·3	49·5	61·0
27·9	38·7	47·0	25·6	53·4	40·8	49·0	57·3	57·0	51·3	62·5
31·6	41·4	31·0	47·7	59·9	38·5	48·4	58·1	48·9	44·2	40·0
24·1	42·7	26·0	42·9	36·7	33·8	31·4	42·7	32·4	37·9	33·3
20·4	24·7	19·6	26·1	33·0	32·1	34·5	36·4	33·4	41·8	42·2
26·4	31·8	24·9	13·5	27·7	34·5	35·4	42·3	30·8	51·8	42·2
15·8	19·1	7·9	22·6	27·9	28·5	33·0	41·2	32·2	48·5	41·7
7·1	14·6	9·3	27·8	31·1	26·7	35·7	38·8	51·9	42·0	51·6
8·7	13·2	20·0	30·5	24·5	20·9	44·3	43·6	44·8	32·2	49·7
20·1	12·3	25·0	24·8	35·0	21·8	56·1	38·2	35·7	19·2	30·4
23·6	20·1	22·3	30·9	32·6	27·1	72·5	46·9	34·6	50·9	48·5
47·3	49·1	20·8	38·5	28·3	27·3	75·6	52·8	26·1	42·7	48·5

TABLE I.—

Month.	High Water.										
	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895
											Temperature
Jan.	..	37·6	35·6	38·0	38·6	41·8	34·0	37·2	34·1	39·4	38·5
Feb.	43·0	36·9	40·3	37·3	39·0	40·1	40·0	40·2	42·1	42·5	33·1
Mar.	43·5	37·2	40·3	38·4	40·9	42·3	41·0	39·0	45·3	44·3	40·9
Apr.	49·0	48·4	45·0	45·0	46·4	47·9	45·0	47·2	50·5	51·6	48·7
May	54·4	55·5	50·6	53·6	57·2	55·7	52·9	53·8	58·3	52·7	56·5
June	63·0	60·3	60·7	60·8	63·4	58·4	60·0	61·9	63·4	58·3	63·2
July	66·2	66·2	68·9	62·0	65·0	62·4	64·6	63·0	65·5	64·9	65·8
Aug.	64·2	64·6	67·4	62·6	62·7	64·0	62·2	64·1	67·1	63·4	64·1
Sept.	60·5	63·9	60·4	60·3	61·0	61·7	61·6	61·1	62·0	61·5	64·5
Oct.	52·2	57·3	51·5	52·3	52·4	55·4	54·6	51·8	55·7	55·0	56·4
Nov.	45·5	48·5	44·6	47·8	47·1	47·4	46·0	47·4	46·4	49·2	47·1
Dec.	40·9	40·9	41·0	44·4	39·8	38·9	43·6	40·4	42·4	38·5	41·1

Particulars of Treatment

1885. Deodorization with permanganate from June 1 to Oct. 12.
1886. ,, ,, ,, ,, May 17 ,, Oct. 26.
1887. ,, ,, bleach ,, July 2 ,, Oct. 5.
1888. ,, ,, permanganate ,, June 18 ,, Oct. 12.
1889. ,, ,, ,, ,, May 16 ,, Oct. 6.
1890. Partial precipitation and deodorization with permanganate from May 21 to Sept. 29.

continued.

Low Water.										
1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895
(° F.)										
25·2	37·6	35·3	38·1	38·3	42·0	33·8	37·1	39·1	39·4	38·2
42·7	36·9	30·5	37·5	39·2	40·5	40·7	40·3	42·0	42·5	33·9
43·7	37·4	40·1	38·6	41·0	42·5	41·3	39·2	45·2	44·0	42·1
50·4	48·7	45·2	45·0	46·4	48·0	45·0	47·7	50·6	51·9	49·0
54·5	55·2	50·1	54·0	57·3	55·8	53·1	54·2	58·4	52·6	57·1
63·3	60·5	60·7	61·0	63·3	58·3	60·2	62·0	63·5	58·4	63·2
66·2	66·3	68·7	62·3	65·3	62·5	64·7	63·0	65·5	65·3	65·1
64·0	64·5	67·3	62·7	62·8	63·6	62·2	64·0	67·1	63·3	63·9
60·6	63·7	61·0	60·4	61·0	61·8	61·5	61·2	61·8	61·5	64·4
52·3	57·2	57·3	52·5	62·5	54·6	54·7	51·2	55·6	54·7	55·2
45·3	48·3	44·5	47·7	47·2	47·6	46·3	47·1	46·3	48·9	46·9
40·3	40·2	41·0	44·0	39·8	38·5	43·4	39·8	42·3	38·2	40·9

of the Sewage.

1891. Partial precipitation and deodorization with permanganate from June 1 to Sept. 15.

1892. Precipitation and deodorization from Aug. 23 to Sept. 30.

1893. ,, ,, ,, ,, June 17 ,, Sept. 16.

1894. ,, only.

1895. ,, ,,

TABLE II.—ANNUAL AVERAGE RESULTS OF DAILY ANALYSES OF THE WATER OF THE RIVER THAMES AT CROSSNESS DURING THE YEARS 1885 TO 1895 INCLUSIVE.

Year.	High Water.							Low Water.							Rainfall.	Sewage Treatment.
	Total Suspended Matters.	Chlorine.	Oxygen Absorbed from Permanganate in 4 hours.	Ammonia. Free.	Ammonia. Albuminoid.	Dissolved Oxygen. Percentage of Complete Aeration.	Temperature F.	Total Suspended Matters.	Chlorine.	Oxygen Absorbed from Permanganate in 4 hours.	Ammonia. Free.	Ammonia. Albuminoid.	Dissolved Oxygen. Percentage of Complete Aeration.	Temperature F.	Inch.	
1885	7·61	469·7	0·244	0·108	0·033	23·2	52·1	7·17	229·2	0·270	0·121	0·034	23·0	50·7	24·0	Permanganate.
1886	7·75	374·6	0·242	0·114	0·027	24·6	51·4	7·03	145·6	0·237	0·118	0·026	29·6	51·3	24·2	,,
1887	2·51	501·1	0·312	0·193	0·032	28·0	50·5	7·16	222·2	0·308	0·206	0·036	27·3	50·5	19·8	Bleach.
1888	2·17	411·8	0·309	0·188	0·037	29·8	50·2	17·31	168·3	0·300	0·209	0·037	28·9	50·3	27·5	Permanganate.
1889	3·01	395·8	0·279	0·185	0·034	36·1	51·1	8·29	182·8	0·286	0·154	0·036	36·9	51·2	28·3	,,
1890	1·78	527·2	0·351	0·197	0·037	35·7	51·3	5·36	276·4	0·383	0·300	0·045	30·7	51·3	23·8	Precipitation (partial).
1891	2·06	463·0	0·397	0·240	0·044	44·3	50·6	4·25	205·4	0·411	0·288	0·055	46·9	50·6	25·0	,,
1892	2·16	436·2	0·364	0·171	0·039	49·6	50·7	4·24	157·2	0·342	0·250	0·045	47·0	50·7	22·3	Precipitation (complete).
1893	2·72	510·4	0·345	0·123	0·032	38·6	52·0	7·48	254·0	0·391	0·227	0·042	40·4	52·8	20·1	,,
1894	2·28	442·5	0·343	0·107	0·027	41·7	52·2	8·04	179·8	0·380	0·195	0·040	43·9	52·1	26·9	,,
1895	2·92	478·9	0·351	0·125	0·025	49·0	51·8	6·20	182·8	0·366	0·201	0·034	45·8	51·8	18·8	..

TABLE III.—AVERAGE RESULTS OF THE DAILY ANALYSES OF THE WATER OF THE RIVER THAMES AT CROSSNESS DURING THE SUMMER MONTHS (JUNE, JULY AND AUGUST) OF 1885 TO 1895 INCLUSIVE.

Date.	High Water.							Low Water.							Rainfall.	Sewage Treatment.
	Total suspended Matters.	Chlorine.	Oxygen absorbed from Permanganate in 4 Hours.	Ammonia. Free.	Ammonia. Albuminoid.	Dissolved Oxygen. Percentage of Complete Aeration.	Temperature F.	Total suspended Matters.	Chlorine.	Oxygen absorbed from Permanganate in 4 Hours.	Ammonia. Free.	Ammonia. Albuminoid.	Dissolved Oxygen. Percentage of Complete Aeration.	Temperature F.	Inch.	
1885	9·59	656·9	0·231	0·104	0·035	20·6	64·5	10·14	389·5	0·278	0·127	0·037	16·4	64·5	3·49	Permanganate.
1886	8·74	434·5	0·224	0·093	0·024	22·9	63·4	8·08	224·1	0·236	0·104	0·026	21·8	63·8	4·05	”
1887	2·17	586·1	0·377	0·258	0·042	17·4	65·7	8·90	313·4	0·415	0·285	0·060	14·0	65·6	3·79	Bleach.
1888	1·82	465·0	0·343	0·186	0·036	24·7	61·8	21·45	194·8	0·359	0·248	0·038	21·3	62·0	13·83	Permanganate.
1889	3·22	458·2	0·324	0·189	0·034	35·6	63·7	9·52	207·7	0·321	0·227	0·034	28·9	63·8	5·95	”
1890	1·54	593·5	0·356	0·205	0·036	37·1	61·6	3·42	313·2	0·410	0·332	0·047	29·9	61·5	9·58	Precipitation (partial).
1891	1·88	654·3	0·365	0·261	0·036	41·4	62·3	3·75	344·6	0·457	0·368	0·063	34·7	62·3	8·07	”
1892	2·19	637·3	0·389	0·134	0·038	55·5	63·0	2·78	294·7	0·323	0·285	0·051	40·8	63·0	6·84	Precipitation (complete).
1893	2·43	633·5	0·336	0·075	0·032	35·1	65·3	8·34	421·0	0·450	0·194	0·052	38·3	65·4	5·40	”
1894	1·79	610·7	0·327	0·066	0·026	51·8	62·2	6·12	298·2	0·435	0·199	0·045	47·4	62·3	8·33	”
1895	2·47	646·2	0·336	0·058	0·023	39·7	64·4	5·50	305·7	0·466	0·198	0·040	45·2	64·1	5·72	..

APPENDIX III.

TABLE I.—AVERAGES OF DISSOLVED OXYGEN, FROM JULY, 1893, TO MARCH, 1894.

Locality.	High Water.	Low Water.
	Percentage of Max. Possible.	Percentage of Max. Possible.
Teddington	85·0	90·0
Kew Bridge	70·3	85·5
Hammersmith	55·7	78·8
Battersea Bridge	42·6	67·6
London Bridge	34·5	51·8
Greenwich	24·6	37·4
Blackwall	22·5	34·3
Woolwich	22·2	30·8
Barking Creek	24·2	30·8
Crossness	43·0	41·6
Erith	39·4	29·1
Greenhithe	38·4	25·1
Gravesend	50·7	39·5
The Mucking	83·6	72·0
The Nore	90·1	89·1

TABLE II.—AVERAGES OF OXYGEN ABSORBED FROM PERMANGANATE, FROM JULY, 1893, TO MARCH, 1894.

Locality.	High Water.	Low Water.
	Grains per Gallon.	Grains per Gallon.
Teddington	0·162	..
Kew Bridge	0·179	0·161
Hammersmith	0·197	0·173
Battersea Bridge	0·231	0·185
London Bridge	0·273	0·198
Greenwich	0·361	0·252
Blackwall	0·375	0·270
Woolwich	0·377	0·307
Barking Creek	0·381	0·349
Crossness	0·353	0·387
Erith	0·294	0·400
Greenhithe	0·198	0·302
Gravesend	0·164	0·213
The Mucking	0·101	0·126
The Nore	0·052	0·068

TABLE III.—DISSOLVED OXYGEN—MONTHLY AVERAGE PERCENTAGES OF COMPLETE AERATION.

Locality.	High Water.									Low Water.								
	1893.						1894.			1893.						1894.		
	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Teddington	89·4	87·2	82·4	81·5	88·2	80·1	84·5	91·2	93·6	91·7								
Kew Bridge	52·9	52·9	53·4	59·0	76·4	83·6	84·5	88·6	90·4	86·3	80·2	71·7	81·9	90·9	98·7	87·4	91·7	93·8
Hammersmith Bridge	34·9	31·3	34·3	33·8	62·2	77·1	76·7	83·1	83·7	73·7	67·9	64·5	71·6	83·1	88·6	85·1	89·5	91·1
Battersea Bridge	23·0	22·4	22·7	20·2	44·7	61·1	62·5	70·9	73·5	56·8	49·8	48·7	57·6	77·2	84·4	75·9	82·5	84·1
London Bridge	24·3	29·0	19·6	14·5	30·6	42·0	47·0	52·7	64·9	36·8	31·2	31·2	37·1	58·7	71·7	63·1	71·0	75·8
Greenwich	24·6	23·4	20·0	15·4	18·1	18·3	35·0	34·9	34·5	29·7	24·9	23·1	18·9	33·5	50·2	47·4	56·8	65·9
Blackwall	25·6	24·6	20·0	15·9	17·5	15·5	26·2	31·1	28·2	31·9	28·0	24·8	19·3	25·6	37·3	45·8	44·7	58·9
Woolwich	29·1	30·1	17·9	16·7	18·3	14·3	23·1	26·9	25·2	33·1	26·5	20·7	18·8	23·8	30·7	36·8	40·9	51·9
Barking	18·3	18·8	15·0	14·0	16·5	21·7	27·7	50·5	34·9	16·3	16·1	11·8	12·5	9·7	28·4	64·5	69·9	48·5
Crossness	32·8	44·7	52·3	43·2	46·2	35·8	41·9	42·9	43·1	28·9	51·8	45·6	36·2	32·6	28·5	46·5	58·8	49·7
Erith	29·7	43·3	45·4	28·2	43·4	35·5	36·2	46·1	42·6	23·4	45·0	34·9	21·3	22·6	16·7	27·5	35·5	28·1
Greenhithe	29·1	37·8	31·2	23·3	45·5	40·9	34·4	38·6	51·5	12·1	20·4	10·7	10·2	32·2	33·0	26·3	36·6	34·5
Gravesend	45·0	51·7	44·5	45·9	55·1	51·8	47·8	54·5	62·1	35·9	35·1	26·7	31·2	47·3	45·3	43·7	44·9	47·5
Mucking Lighthouse	75·8	79·8	87·5	82·9	85·2	83·1	83·7	92·9	89·5	63·1	69·8	74·7	68·1	72·1	74·5	75·3	81·3	83·9
Nore Lightship	82·7	86·1	92·0	89·4	88·2	91·3	95·9	95·5	94·8	82·9	85·5	93·0	85·2	89·6	90·4	94·1	94·0	94·6

TABLE IV.—ORGANIC MATTERS IN SUSPENSION IN GRAINS PER GALLON.—MONTHLY AVERAGES.

Locality.	High Water.									Low Water.								
	1893						1894			1893						1894		
	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Teddington	Trace	Trace	Trace	Trace	Trace	0·75	0·62	0·31	0·34									
Kew Bridge . . .	2·20	1·56	1·17	1·50	1·17	0·83	0·96	0·70	0·44	0·32	0·73	0·35	0·30	0·20	0·46	1·02	0·76	0·46
Hammersmith Bridge .	1·77	1·20	0·68	1·45	1·26	1·54	1·22	1·11	0·65	1·37	1·24	0·92	0·79	0·45	0·43	0·76	0·74	0·41
Battersea Bridge . .	1·73	0·86	0·95	1·08	1·03	1·30	2·05	1·96	1·10	2·02	2·23	2·39	2·13	1·46	0·81	1·00	0·93	0·77
London Bridge . . .	3·69	3·49	2·85	4·24	2·40	2·46	3·12	2·88	1·75	3·33	2·97	2·78	4·85	3·08	1·78	1·53	1·33	0·68
Greenwich	1·74	2·74	1·63	2·07	2·01	1·26	2·36	2·66	1·00	3·48	4·61	5·41	3·37	3·90	3·06	2·49	1·92	1·87
Blackwall	3·60	1·83	1·47	1·12	1·22	1·08	1·77	1·60	0·97	1·72	2·63	1·73	1·59	1·58	1·57	2·12	2·02	1·27
Woolwich	1·94	2·01	0·96	1·15	1·08	1·63	1·73	2·51	1·00	2·50	1·98	1·54	1·96	0·99	1·18	1·62	1·74	0·95
Barking	0·53	0·58	0·72	0·60	0·51	0·33	0·69	1·13	1·18	0·84	1·49	2·19	1·75	1·01	0·60	1·29	2·50	2·05
Crossness	0·70	0·88	0·84	0·91	0·69	1·07	1·03	0·93	0·87	2·62	2·49	2·94	1·73	2·33	1·63	3·37	3·63	1·37
Erith	1·21	0·83	1·02	0·59	0·75	0·99	1·42	1·05	1·11	0·87	1·11	1·07	0·96	1·18	0·84	0·83	1·12	0·81
Greenhithe	1·03	0·31	0·34	0·52	1·55	1·65	1·72	1·51	1·56	1·86	0·57	1·67	0·61	1·37	1·33	1·77	1·31	1·52
Gravesend	1·16	0·91	2·49	1·43	2·88	3·09	3·25	2·80	1·39	0·70	0·61	2·24	0·92	1·49	1·57	2·90	2·21	1·60
Mucking Lighthouse .	1·04	0·75	0·51	0·54	0·84	1·30	1·96	1·30	0·58	1·27	2·14	1·55	1·67	2·78	4·01	1·59	1·77	1·18
Nore Lightship . .	0·80	0·62	0·46	0·81	1·39	1·19	1·04	1·19	0·61	1·24	0·89	0·66	0·81	1·14	1·52	0·95	1·41	1·18

TABLE V.—TABULATED STATEMENT OF THE OXYGEN DISSOLVED, ABSORBED AND REQUIRED.

Section of River.	Volume of Section in Millions of Cubic Feet.	Atmospheric Oxygen dissolved in the Water.							Oxygen absorbed in 4 hours from permanganate by the organic matters in solution.		
		Maximum possible, Tons per Section.	Maximum possible, Tons per 100 Millions of Cubic Feet.	Amount actually found, Percentage of Maximum possible.	Amount actually found, Tons per Section.	Amount actually found, Tons per 100 Millions of Cubic Feet.	Rate at which Oxygen is dissolved, Tons in 24 Hours per Section.	Rate at which Oxygen is dissolved, Tons in 24 Hours, per 100 Millions of Cubic Feet.	Grains per Gallon.	Tons per Section.	Tons per 100 Millions of Cubic Feet.
					High Water.						
Teddington to Chiswick	250·8	76	30·4	77·7	59	23·5	9·0	3·6	0·170	17	6·8
Chiswick to St. Paul's Pier	678·6	206	30·4	49·1	101	14·9	86·0	12·7	0·214	58	8·5
St. Paul's Pier to Deptford	643·2	196	30·4	34·5	67	10·4	138·0	21·4	0·273	70	10·9
Deptford to North Woolwich	1,099·0	334	30·4	23·5	79	7·2	481·0	43·8	0·368	162	14·7
North Woolwich to Barking	480·3	146	30·4	23·2	34	7·1	210·0	43·8	0·379	73	15·2
Barking to Crossness	898·7	273	30·4	33·6	92	10·2	262·0	29·2	0·367	132	14·7
Crossness to Erith	1,155·0	351	30·4	41·2	145	12·6	253·0	21·9	0·323	149	12·9
Erith to Gravesend	6,543·0	1,989	30·4	42·8	851	13·0	1,432·0	21·9	0·218	570	8·7
Gravesend to Southend	34,695·0	10,547	30·4	74·8	7,889	22·7	1,898·0	5·5	0·076	1,055	3·0
Total	46,443·0	14,118	..	..	9,317	..	4,769·0	..	..	2,286	..
Average	..	..	30·4	67·7	..	20·6	..	10·3	0·123	..	4·9
					Low Water.						
Teddington to Chiswick	91·7	28	30·4	87·7	24	26·2	1·7	1·8	0·161	6	6·5
Chiswick to St. Paul's Pier	248·6	76	30·4	73·2	55	22·1	14·0	5·6	0·179	18	7·4
St. Paul's Pier to Deptford	266·1	81	30·4	51·8	42	15·8	32·0	12·0	0·198	21	7·9
Deptford to North Woolwich	504·1	153	30·4	35·8	55	10·9	145·0	28·9	0·261	53	10·5
North Woolwich to Barking	228·9	70	30·4	30·8	21	9·2	84·0	36·7	0·328	30	13·1
Barking to Crossness	429·8	131	30·4	36·2	47	10·9	124·0	28·9	0·368	63	14·7
Crossness to Erith	601·9	183	30·4	35·4	65	10·8	174·0	28·9	0·393	95	15·8
Erith to Gravesend	3,880·5	1,180	30·4	31·2	368	9·5	1,416·0	36·5	0·305	473	12·2
Gravesend to Southend	20,215·0	6,145	30·4	66·8	4,105	20·3	1,229·0	6·1	0·097	785	3·9
Total	26,466·6	8,047	..	..	4,782	..	3,220·0	..	..	1,544	..
Average	..	..	30·4	59·5	..	18·1	..	12·2	0·146	..	5·8

Discussion.

Mr. Wolfe Barry. Mr. J. WOLFE BARRY, C.B., President, said he had great pleasure in proposing a hearty vote of thanks to the Authors for their valuable contributions. The record given by Messrs. Worth and Crimp was of great value to the Institution, being, in fact, the history of a gigantic work, and forming a most worthy sequel to the contribution of the late Sir Joseph Bazalgette in 1865.[1] The account of the constructive work since Sir Joseph Bazalgette began the system of the outfalls at Crossness and Barking was a valuable addition to the Papers already possessed by the Institution on that subject. The present Papers brought the subject up to date, and the details, which had been described in a most interesting way, were full of instruction. The importance of the chemical branch of the subject had been shown clearly by Mr. Dibdin, and his Paper was a valuable supplement to his contribution in 1887,[2] also bringing the history up to date, and giving details of the success that had been attained. The purification of the water of the lower Thames was apparent to everyone who had worked on the banks of the river. He could testify to the marked improvement that had taken place during his career in bridge-building in the Metropolis since 1860. Mr. Dibdin's Paper was full of promise for the future, and removed many of the difficulties in the way of dealing with the sewage of large cities. He thought there was little doubt that the hope expressed in the Paper for greater and better results might be realized. He could speak from observation of the increase of fish life in the lower Thames; and if the same improvement continued, it was not beyond the reach of possibility that Londoners might again see salmon ascending the Thames, as they did before that noble stream was so infamously polluted as it had been in former times.

Mr. Symons. Mr. G. J. SYMONS observed that in the design of the original scheme Sir Joseph Bazalgette had adopted an estimated quantity of rainfall, and some years ago, when there were bitter complaints of the state of the Thames, a Royal Commission was appointed to inquire into the subject, and a good deal of evidence was given respecting it. He found no references to the subject in the first Paper, nor

[1] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 280.
[2] *Ibid*, vol. lxxxviii. p. 155.

indeed was anything said about rainfall, with the exception of the Mr. Symons. account of experiments carried out at Bayswater. Inasmuch as rain-water was admitted into all the sewers, and as many valuable details were given with regard to the pumps, the capacity of the drains and the like, such particulars were desirable. It was stated that heavy rains did not affect the quantity of water which reached Barking Creek. Probably not; the sewers could not carry it there, and the floods escaped by the storm-overflows, which he thought were too numerous. It was stated that the storm-water contained more suspended matter than ordinary sewage, for which reason it was very unsatisfactory that it should be turned into the storm-overflows and sent into the river without treatment. This was proved by the remark of Mr. Dibdin: "These include storm-water, which increases the average amount of suspended matters left in the effluent, as in many instances the quantity found in the dry-weather sewage is considerably lower." He should be glad of further information with regard to the cost; it was given at the date of the opening of the Crossness works, but that was evidently not the cost of the 284 miles of sewers; it was the cost at an antecedent date. The amount was then $4\frac{1}{2}$ millions. He had tried in vain to ascertain how much had since been spent, and the result was not satisfactory. It appeared about £100,000 a page all through the Paper. There were also independent amounts; steamers, for instance, had cost £431,000; Crossness, £144,000; the Isle of Dogs, £317,000. With the addition of the estimate of $2\frac{1}{4}$ millions, the amount reached a very large total, and for it something extremely good was to be expected. Again, in regard to the Effra creek pumping-station, the question of rainfall had been ignored. Reference was made to repeated complaints of flooding in 1878. In that year there were more exceptionally heavy thunderstorms than had occurred in any year since the works had been constructed. Reference was also made to a Report by Mr. Binnie and Sir Benjamin Baker as to what was necessary for the relief of flooding. He thought it should be stated how much of the necessity for that additional relief was due to the original design in regard to the capacity of the sewers, and how much was due to the development of the Metropolis, the increased area built on, and the areas taken in which were not originally contemplated. With regard to the experiments on the north of Hyde Park, it was stated, "When running full, the sewer under consideration can carry off about $\frac{2}{5}$ inch of rain per hour from the area drained by it; and on the occasions referred to was carrying about that volume, which is equal to a rate of about

Mr. Symons. 24 cubic feet per minute per acre." That amount of rain was small compared to the 1878 storm, which had led to the Effra creek development. For a short interval the actual rainfall was at the rate of no less than 12 inches an hour. The original design for the sewers allowed for $\frac{1}{100}$ inch per hour. The quantity of sewage that reached Barking was given in the Paper, but no reference was made to the population or the area that contributed it. He should like to know the quantity per head that the 205 million gallons referred to at the close of the Paper represented.

Lieut.-Colonel Jones. Lieut.-Colonel ALFRED S. JONES, V.C., thought the area of Bayswater supplied exactly the kind of data engineers had long wanted as to the collection of rainfall upon areas which had been fully built over. It contributed a clear warning to preserve and improve all natural water-courses on any land which was ever likely to be built over. His evidence before Lord Bramwell's Royal Commission[1] showed that an approach to the separate system might even yet be adopted to palliate those great evils of the storm-water overflows. He admitted that the appearance of the foreshores and water of the Thames of late years indicated that those evils had been "abated," as was anticipated by the Royal Commission, as a result of the "preliminary and temporary measures" they proposed. Such improvement in his opinion was due mainly to the careful working of the screens, filth-hoists and destructor, eliminating about 5,000 tons per annum of the most offensive refuse which used to disfigure the foreshores. Secondly, he attached importance to the sludge-barges going to sea, but he discounted the great quantity which was annually taken out by the amount of simple water. It contained 90 per cent. of water, and he computed the cost of the freight of those barges at 5*s.* 11*d.* per ton for removing about 107,600 tons of filth during the year 1894. He reduced it not only by the water, but divided the remainder by two, on account of the harmless mineral matter, which went to the bottom without injury to anybody. For the last twelve or fifteen years the working of the nitrifying organism in the pores of the soil on land irrigated by sewage had been known, and he thought Mr. Dibdin was one of the first to try to concentrate that action in a filter of more porous material than land. His experiments, like those of the Massachusetts Board of Health, had been conducted in a scientific manner, and were most valuable. The Paper rightly laid stress on the fact that the coke filter was a

[1] Second and Final Report of the Royal Commission on Metropolitan Sewage Discharge, 1884, p. xxxi.

"delicate organism," and required as much care and attention to keep it in working order as any other piece of machinery. Where, he asked, in this country had that delicate organism, that nice piece of machinery stipulation, been applied to a sewage-farm, which did the same work and in the same way, only not in such a concentrated form? He had had to reclaim a 120-acre farm, which, for fourteen years, worked most perfectly, and then for fifteen years had been absolutely neglected, so much so that it had become a nuisance, and was even now looked upon as a horrible cesspool. He was thankful to say that for the last eighteen months its wheels had been oiled to a certain extent by War Department expenditure, and if it were only given a fair chance he maintained that the farm would regain the position that it had, or even do better than it had before. That was a case of a delicate piece of machinery being absolutely neglected for fifteen years. It was stated that the material for the Barking coke filter was obtained on the spot at the very low price of 1*s.* 6*d.* per ton, and nevertheless it cost £2,000 to the acre. But the City Engineer of Manchester had estimated for precisely similar filters at the rate of £5,500 per acre. From the Table giving the averages of daily analyses, it appeared that the experimental acre had been tested at the rate of 1,000,000 gallons per day during three periods—108 days, 13 days, and 148 days respectively, making 268 altogether, with intervals for rest of 37 days and 13 days. It was also said that "the experiments were then concluded, it having been satisfactorily established that with proper care the filter was capable of continuing its work as long as it might be required at an average rate of 1,000,000 gallons a day." He thought that must be received with caution, or the sanitary authorities, leaning upon the statement that they might go on for ever working that beautiful machine, would get into trouble, and if they had not a tidal river to discharge it into, they might not know what to do with the sewage during the period of rest. With regard to the precipitation, he understood that Mr. Dibdin was content to put on his coke filters the effluent from a precipitation or deposition process, provided it had taken the suspended matter out. He would like to have some data from Mr. Dibdin as to what the difference would be by using chemicals one week and not using them another. Lieut.-Colonel Jones.

Professor Henry Robinson remarked that many years ago Mr. Melliss and he had, in dealing with the chemical treatment of the sewage at the outfall works at Coventry, utilized copperas, or iron water, as it was termed in the Paper. Their observations had shown Professor Robinson.

Professor Robinson. that the sulphate of alumina which possessed a large proportion of the protosulphate of iron had a much better purifying effect. They were glad to find in these later years that the London County Council were utilizing blue copperas at Barking and Crossness. With reference to the works at both these stations, carried out by the late Sir Joseph Bazalgette, he had had several opportunities of closely observing, not only their nature, but also the admirable way in which those works were executed, and that the outfall sewers and outfall chambers below water-level were watertight. He remembered more than 30 years ago having light refreshments with some of the officials in connection with the Metropolitan Board of Works and others in one of the large chambers much below water-level, and there was not only not a drop of water in them, but there was every indication of the splendid manner in which work of that sort could be executed. In his own practice he had often to remedy sewerage systems where the work was carried out in such a way as to cause the leakage of subsoil water into them, bringing about serious trouble and expense at the outfalls, especially where there was pumping. With reference to the general system which was now adopted at the outfalls at Crossness and Barking, when Lord Bramwell's Commission held its inquiry he had been asked to give evidence. At that time the solution of the problem, according to the Commissioners, as was stated by the Authors of the first Paper, was that after chemical treatment the effluent should be purified upon land. Many most influential men pointed to the necessity of obtaining enormous areas of land, and it was owing to that feeling that when he was asked to give evidence before that Commission, he suggested that the solution of the problem of treating the sewage at Barking and Crossness would be by a simple chemical treatment, as was now being done, which would bring the effluent up to a sufficiently high standard to enable it to be discharged into the Thames without the cost of the distribution of the effluent upon land. What Mr. Dibdin had done with filters was of great importance. He believed it was agreed by those who had studied bacteriological matters that there were two organisms which could be brought into play in dealing with the purification of sewage. In one case the organism did not require oxygen, and was called by bacteriologists the anaërobic. Its action resulted in liquefying the solid matter in sewage and bringing it into a shape more capable of the action of the aërobic germ than was possible in putting the sewage upon land or upon filters without the previous action of the anaërobic germ. The investigations of Dr. Rideal and others had pointed out those two functions of the micro-organism, and he was certain that the time had arrived when those functions had come so much within the range of practical engineering that the days of sewage-farms and the distribution and purification of sewage on large areas of land were over, unless the sewage upon land could be utilized with commercial advantage, which procedure he did not wish to under-value. But in dealing with the purification of sewage those two organisms had now come to the front to a very large extent, and he had successfully used an anaërobic chamber at sewage outfall works that he had designed. Professor Robinson.

Mr. ARTHUR ANGELL was anxious that engineers should not conclude that ordinary sewage in smaller flows could be dealt with upon the same lines as they were dealt with at Crossness and Barking. As a general rule, other things being equal, the larger the flow of sewage the more easily it would be treated. He spoke as a chemist; he knew that engineers were desirous of minimizing the daily expenses. As a chemist he watched with something like fear their anxiety to reduce their volume. He would like to have it increased almost *ad infinitum.* That could not be permitted, but at the same time he hoped it would not grow into too concrete an idea that the entire rainfall should always be separated from the sewage, because chemical difficulties occurred. Now the difficulties which occurred were not known at the works described, although he was familiar with them elsewhere. In one district the tanners had possession of the sewers, and had sent their filthy waste down, and that had to be dealt with. In another district it was the brewers who stood in the same situation; in a third it was the laundry; and in the fourth there was the wool-scourer. That proved the problem, chemically speaking, was not such a simple one as it was when the whole was put into hundreds of millions of gallons and made into a uniform mixture. Engineers must not expect to be able to obtain with the same amount of precipitants and with the same simple applications as good results as at the works described. But were those results so remarkably good? They were, inasmuch as they produced the desired effect upon the river. In Appendix I there appeared figures which were somewhat remarkable as representing the purification of sewage so far as regarded the dissolved matters. The tabulated figures represented a great number of results obtained upon the crude sewage and upon the effluent. Taking what, in his opinion, was by far the Mr. Angell.

Mr. Angell. most important column—although there was a difference of opinion as to whether the albuminoid ammonia, or the oxygen absorbed, was the most reliable measurement—taking the mean amount of albuminoid ammonia as 0·353 at the northern outfall and the remarkable effect of purification was that it was increased to 0·356. That might do, and he believed it did do, well for Crossness, but in view of the comparative paucity of the London sewage, in albuminous matters, he thought 0·3 would be looked upon as a highly noxious effluent to obtain. He was not criticizing what was being done there, except if it were put into operation or imitated elsewhere, where the flow was smaller and the river which was to receive the result was also smaller. A small flow and a great flow, chemically speaking, depended not only upon the absolute amount to be dealt with, but upon the relative amount compared with that of the water to which it was added. At the southern outfall, a purification of 24 per cent. had taken place. If it occurred in the northern outfall he did not know that he should have referred to the figures so distinctly. One of the speakers had referred to nitrification at Crossness. He had tested some of the effluents from the filter-bed at Crossness, and to his astonishment, seeing that they were styled nitrifying beds, had found no nitrates present. It thoroughly coincided with the wide experience he had had with filter-beds, namely, the non-formation of nitrates, but the formation of carbonic acid and ammonia; but he did not say there was no such thing as nitrification. He did not wish to speak against the biological force of those organisms, but at the same time another force was at work, as he had proved by taking the material fresh from a kiln and passing through sewage, sterilized by shaking it up with chloroform. In that way he had obtained a large percentage of purification where no kind of organism could possibly have existed. He was doubtful about the watertight sewers; from a chemical point of view he could not understand how such a poor sewage as that of London could contain such abnormal amounts of chlorine, running up from 10 to 17 parts per 100,000. That tended to prove, that salt water probably found its way into some of the large sewers running down near the banks of the Thames. He did not however think it a matter of great importance if it did. His great anxiety was to stay engineers from believing that they must go to Crossness or Barking for an example of what they were able to do when they came face to face with the enormous difficulties met with in the various outflows of sewage throughout the country.

Mr. G. R. STRACHAN wished to offer a word of congratulation to Mr. Santo Crimp upon two good works he had carried out whilst with the London County Council. In the first Paper the fact was modestly mentioned that by erecting head-walls in the precipitating channels at a cost of £1,890 the output of sludge was increased from 7,300 tons to 23,000 tons per week. He had also designed and constructed the coke-breeze filter which, as shown by the analyses, effected a high purification in the effluent from the chemical tank at the rate of 30,000 persons per acre. The figures were 1,000,000 gallons per day, which would work out in round figures to 30,000 persons per acre. With regard to the main sewerage question he was struck with the small provision made for London compared with the usual practice in provincial towns. As to the quantity taken to the treatment works, the main outflow sewers on the northern side would discharge 45,000 cubic feet per minute. In dry weather the amount of sewage was 13,000 cubic feet per minute, so there was a provision for the rainfall going through the treatment works of two and a half times the dry-weather flow in addition to the dry-weather flow. If such a thing were proposed for a provincial town it would never pass the Local Government Board; it would be condemned as insufficient. The overflows into the river must therefore be brought into action with great frequency. When a heavy rain-storm occurred over the whole of London the sewerage system would be practically resolved into the primitive simplicity of discharging straight into the river. He was also impressed with the meagre capacity of the treatment works. The precipitation-channels, which were not tanks in the ordinary sense, had a volume of 20 million gallons. The quantity of sewage dealt with was 117 million gallons, so that the tank-capacity was 17·1 per cent. of the dry-weather flow. He ventured to think those channels were not well adapted or designed for the continuous process. They were long and narrow, with the result that the sewage in dry weather passed through them when they were all in use at the rate of 4 feet a minute. The lineal velocity generally aimed at with sewage on the continuous principle was 6 inches per minute; and he thought that if the channels were larger and better proportioned, a better result would be obtained. The meagreness of the London system came very prominently into view when the quantities of chemicals used were examined. They might not be insufficient, but 3·7 grains of lime per gallon, and 1 grain of iron per gallon, was about as small a quantity as was used anywhere in England; two to three or even four times those quantities were generally used. As to the results

Mr. Strachan. of the treatment, in Appendix I, Mr. Dibdin had given the analyses of 4,380 samples of sewage, and the same number of samples of effluents from the Barking works on the northern side, spread over the whole year 1894. In the part relating to the northern outfall, the total suspended matter in the sewage was 29·8 grains per gallon; in the effluent it was 7·1 grains per gallon, which was a substantial reduction. The total dissolved matter in the sewage was 60·2 grains; in the effluent 63·2 grains, so that it had been enriched from the treatment. The amount of chlorine was 11·1 grains in the sewage, and 10·8 grains in the effluent. The oxygen absorbed from permanganate in four hours in the sewage was 3·124 grains, and in the effluent it had grown to 3·225 grains. The free ammonia of the sewage was 3·027 grains, and in the effluent 3·137 grains. The albuminoid ammonia in the sewage was 0·353 grain, and in the effluent 0·356 grain. With the exception of the large reduction in the suspended matters, it appeared that the precipitation at Barking in 1894 enriched the effluent. He appreciated that the liming apparatus was not in such a good condition at the northern outfall as at the southern. At the southern outfall the sewage was very much stronger, and there was a good percentage of reduction in the impurities. A sweep who came home dirty, could not be called clean if he took off 50 per cent. of the dirt. The question was, Was the effluent clean? With regard to the Crossness effluent in 1894 the amount of oxygen absorbed from permanganate in four hours was 3·115; the sewage on the north side was 3·124, so that the net result on the south side, taking the effluent (although there was a percentage of reduction in that particular item), was to bring it practically to the standard of the sewage on the northern side in that matter. Again, the albuminoid ammonia in the Crossness effluent was 0·331; on the northern side in the sewage it was 0·353. That was a reduction, but substantially it appeared that in the year 1894 on the northern side, the effluent was about as bad as the sewage, except with regard to the suspended matter, and at the southern outfall the standard of the effluent was raised pretty much to the standard of the northern sewage. By virtue of his position, Mr. Dibdin had been compelled to go to chemical precipitation for the treatment of London sewage. No other system was practicable under those large conditions, and he referred to the "costly" sewage farms. He should like to ask Mr. Dibdin, in his reply, to explain, or rather to criticize, the action of his colleague, Mr. Santo Crimp, with regard to his filter. Sewage farms had been recommended by Mr. Santo Crimp at

Shrewsbury, Waltham, Midhurst, Woking and Stowmarket, when, according to Mr. Dibdin, all he had to do was to dig a hole in the clay and put in coke breeze, and he would get almost as good a result without the cost of the sewage farm. He asked why Mr. Santo Crimp had adopted "costly" sewage farms when he had such a "cheap" method of dealing with the sewage ready at his hand. Mr. Strachan.

Mr. J. LUNT noticed that Mr. Dibdin had pointed to the conclusion that the condition of the Thames in 1887 was due to the manganate treatment having been replaced by the chloride of lime treatment. He thought there were other factors which might equally well account for the condition of the Thames in that year. Referring to Table III, Appendix II, it would be found that in 1887 the mean temperature of the summer months was the highest recorded in the river-water for the ten years which were given, and also that the rainfall for that and the two preceding years was less than at any subsequent time. Therefore there was a minimum of fresh water going into the river, and also a higher temperature, which tended to foster the putrefaction of the polluting matters both in suspension and in solution in the Thames, and so caused its bad condition. On these grounds alone, without contrasting the two processes of deodorization, the condition of the Thames in that year might easily be accounted for. Stress was very properly laid on the amount of dissolved oxygen present in the river water at Crossness as evidence of the purity of the Thames, and Mr. Dibdin had collected a large amount of very valuable material in the Tables. In Table III were a number of analyses, given for the summer months of 1885 to 1895, which were most instructive. The figures seemed to have been taken by Mr. Dibdin with some care, in order to demonstrate the purification of the Thames which had taken place during those years. He particularly referred to the figures stating that in 1887 the amount of dissolved oxygen was 17·4, and in 1894 it had risen to 51·8 per cent. of the saturation quantity. It must be admitted that previous to 1889 the process in daily use at Crossness for the estimation of dissolved oxygen was very imperfect. It had come under the notice of Sir Henry Roscoe and himself in 1888, when they thoroughly investigated the matter. The results of this investigation had been laid before the Metropolitan Board of Works in Reports of that year, and perhaps Mr. Dibdin, after that, had altered his process to one based on more accurate methods. It was certainly significant that in the year 1889 the dissolved oxygen in the Thames water had greatly increased. In the years 1885 to 1887 the figures Mr. Lunt.

Mr. Lunt. were 20, 22 and 17, and in 1888, 24. Then there was a rise to 35, 37, 41, 55 and so on. That would form a good comparison if reliance could be placed on the older figures, and if all the other figures showed a corresponding purification of the Thames. He thought those figures might well serve to show even that during the years 1885 to 1895 no purification of the Thames had taken place. For example, taking 1887 as a "notoriously bad" year as referred to by Mr. Dibdin, the total suspended matters at high water were 2·17, and in 1895, 2·47. The amount of chlorine was not of great importance, because it merely represented the amount of admixture with sea-water. The oxygen absorbed from permanganate in 4 hours was also a good indication of the amount of polluting matters in the Thames, and in the year 1885 the figure was 0·231, whereas in 1895 it was nearly 50 per cent. more, viz. 0·336. In the same way the free ammonia of 1886—when £81,000 were spent in chemicals alone for deodorization—the figure was 0·093, whereas in 1891 it was 0·261, and in 1892, 0·134. The albuminoid ammonia was also a very good indication of the amount of dissolved impurity; in 1886 it was 0·024, in 1892 it was more than 50 per cent. higher, viz., 0·038, and in 1893 0·032, and so on, so that the indications of purification given by the figures for the dissolved oxygen did not seem to be borne out by all the other figures. He asked whether, after the defects in the process used in 1885, 1886 and 1887 had been pointed out, any modification had been made in the method of estimating the dissolved oxygen, because it was previously possible to get a very high result or a very low result at will. The figures for low water might equally be read in the same sense to show that during the years given there was practically no amelioration of the condition of the river, because, taking the low-water figures for 1886, the oxygen absorbed from permanganate in 4 hours then were 0·236, and in 1895 almost 100 per cent. greater, viz., 0·466. The rainfall seemed a very important matter in the purification of the Thames. The figures from 1885 to 1887 were very low for the summer months and the temperature was higher, and those natural influences seemed to be neglected by Mr. Dibdin in drawing his conclusions as to the effects of the artificial treatment adopted.

Sir Leader Williams. Sir LEADER WILLIAMS said, in reference to what had fallen from the last speaker, it had been his good fortune to make a ship-canal in England, and his bad fortune to have it filled with sewage. During wet seasons or even during ordinary rainfall, the Manchester Ship-Canal was in a very fair state, and he did not think anyone could object to travel upon it; but when a drought, like that of the autumn of 1896 set in, and there was also a high temperature, he was bound to say it was in a bad condition. He quite appreciated, therefore, that one year's treatment of sewage could not be contrasted with that of another year under different treatment, unless the rainfall and the temperature were the same. The sewage of Lancashire was peculiar; a large variety of manufactures had to be dealt with—there were dye-works, paper-works, and chemical works, and the result of the compound was a sewage very difficult to deal with efficiently; in fact, he did not think worse sewage was to be found. He thought there was a great future before the biological treatment. He had recently been called in by the Corporation of Exeter to look into a matter connected with the River Exe, and he went with the City Surveyor to inspect the sewage works, and found the whole treatment automatic. There were cinder- or coke-breeze filters; the sewage was allowed to flow into the respective tanks full of that breeze for a time. Water was meanwhile slowly trickling into a balance-weight arrangement, which tipped over after a certain time, and the whole of the sewage passed out, and, after a time, it came back again; so that automatic tanks side by side were filled and emptied of sewage. It was a matter of experiment how long the sewage should be kept in and how much time should be given in the filters. He found the appearance of the effluent exceedingly good. There were no precipitation tanks, and the crude sewage, except for some flocculent matter and so forth, was much better than that from the Lancashire towns, and he should hardly like to say that the system would be a great success in those places. It was obvious, however, that in many towns where ordinary sewage had to be dealt with, the treatment laid down in the last Paper might be of very great value. Sir Leader Williams.

Mr. H. A. Roechling thought that as there could be no finality in matters pertaining to such a vast drainage-system as that under discussion, it was necessary that any extension of such a large network of drains should be carried out on well-defined and clearly laid down principles. If the Authors, therefore, could state whether, in their opinion, two main outfall stations would have at all times to be adhered to, or whether eventually the now united drainage-area would be split up into smaller independent drainage-areas with separate sewage-purification works, it would be of interest. The sewage of London did not appear particularly concentrated, and was not very heavily charged with manufacturing liquids. The sole difficulty seemed to lie in its vast volume. With regard to Mr. Dibdin's Paper, the system Mr. Roechling.

r. Roechling. at present adopted at the outfall works might be called a partial clarification with a sewage farm, and that sewage farm was the River Thames. The difference therefore from the former treatment was simply that a certain percentage of the suspended solids was now extracted. How long a river could be used as a sewage farm depended upon its digestive powers; but at any rate in this country, the Legislature had made it an indictable offence to set up in the river putrefactive changes which discoloured the water and gave rise to obnoxious smells. As to the partial clarification of the sewage at the outfall works, he was sorry to find from the Table for 1894 (Appendix I, Table I) that the removal of suspended solids had been comparatively small, for he found that at the northern outfall in that year only 76·17 per cent. were abstracted, and at the southern outfall at Crossness only 80·32 per cent. This was disappointing, for it meant that during that year there were discharged into the Thames at the outfalls 31,910 tons of suspended solids in a dry state; or expressed in sludge, 339,246 tons with 90·70 per cent. and 91·25 per cent. of moisture. He did not think that from 20 to 25 per cent. could be called a small percentage left in the effluent. The increase in the dissolved impurities which took place at the outfall works ranged between 5 per cent. and 9 per cent. He hardly thought that would account for leaving such a large percentage of suspended solids in the effluent. He should like to ask why the percentage of increase of dissolved impurities at Crossness was 9 per cent. and at Barking only 5 per cent., although at Crossness the quantity of lime used was 26·2 per cent. less, and the percentage of moisture slightly higher than at Barking. He was particularly struck with the very great increase of suspended solids which had evidently taken place in the tanks. In the tanks at Barking it amounted to 65·77 per cent., and at Crossness 31·30 per cent. That meant that every 100 tons before treatment had been increased at Barking to about 166 tons, and at Crossness to about 131 tons after treatment. With regard to the water in the Thames, Mr. Dibdin had given the figures for eleven years—from 1885 to 1895. For convenience of comparison those years might be divided into two periods—from 1885 to 1889, the period during which no precipitation was carried out; and the period from 1890 to 1895, during which precipitation was employed. If the rainfall was first considered, and only the months of June, July and August as the most critical months of the year, excluding the exceptionally wet summer of 1888, it would be found that the rainfall in the second period, in the years from 1890 to 1895, was considerably

Mr. Roechling

larger than in the first period—it might almost be said twice as large. The degree of dilution, therefore, in the second period for the impurities still left in the effluent must have been considerably greater than in the first period. From the contents of the river-water it would be found, as might be expected, that the amount of suspended solids in the second period was smaller than in the first period. But towards the end of the second period—in 1893, 1894 and 1895—the suspended solids had again increased. The treatment would not materially affect the chlorine one way or the other, and therefore he was not surprised that that had considerably increased. The "oxygen consumed," if the test were applicable at all, showed that in the second period, from 1890 to 1895, the amount of organic impurities held in the river-water was greater than in the first period. If the periods of high and low water were distinguished, it would be found that at high water the amount of free and albuminoid ammonia had slightly decreased in the second period. At low water, however, the amounts had considerably increased in the second period. The Tables therefore showed, especially the dissolved impurities, that a gradual deterioration had taken place during the second period, although it appeared that the degree of dilution had been greater than during the first period. It was a pity that Mr. Dibdin, though no doubt he had determined the number of germs in the river-water from 1885 to 1895, had not given them; because they, generally speaking, afforded a readier and more delicate guide in judging the character of the water than analytical figures. He observed a marked contrast between the dissolved oxygen and the oxygen consumed. From the dissolved oxygen figures a very considerable improvement appeared to have taken place; but he thought the apparent difference in the results should be explained, and how the figures had been obtained. He thought the figures supplied showed that a time would come when the stomach of the Thames would not be large enough to digest all the impurities poured into it. There was no doubt that the agents which carried on the purification of the sewage in the biological filters and on a sewage farm were the same, namely, the bacteria, but the conditions under which they worked in the two media appeared to be different. On the farm the germs found a congenial home—that provided for them by nature; they found, in short, natural conditions. In the biological filter they found the reverse—they found the home provided for them by man—artificial conditions. He had called those biological filters forcing-beds, or forcing-frames, of nature, in which nature was bid to do her work at express speed and under arti-

Mr. Roechling. ficial conditions; and he thought it was very dangerous to force the hand of nature, especially in a case where so little was known about the very intricate processes by which the decomposition of organic matter was brought about, lest in this attempt they might create conditions which in the end might prove disastrous. It was, for instance, well known that in the process of putrefaction certain highly poisonous substances such as ptomaïnes, toxins, &c., were formed, and if an effluent containing these was discharged into a small stream, which during very dry weather contained practically nothing else but this effluent, he was not sure whether they would not set up conditions which would prove disastrous lower down the stream. Then, again, there was the great number of germs in the effluent, and they all knew that they reached into millions. He did not so much object to mere numbers, but before establishing filters on a large scale, he should like to be assured that neither the life-products of those germs nor the germs themselves would be able to do any more harm further down the stream. Then, with regard to the working of the biological filters, he would like to draw attention to the remarkable words which Mr. Dibdin used towards the end of his Paper, when he said, "It must not be overlooked, however, that unless the process is carefully watched, the first sign of overwork is noted by careful analyses, and rest is given when required, great risk of failure will be incurred." That was a warning note. It meant that unless those filters were under continual, careful, intelligent supervision, and unless the effluents were frequently analysed, Mr. Dibdin would not guarantee the result. But where in practice would this continual careful supervision be obtained? It was the systematic neglect of sewage-disposal works which had brought especially some sewage farms into disrepute. He had little doubt that of the two the biological filter was the more delicate, and the farm the more robust instrument; and if through neglect, or rough usage, the more robust instrument had failed in places, he had little doubt the more delicate instrument would fail too—and that considerably sooner. If the filters were under intelligent supervision, they had, undoubtedly, a great power for good; but if neglected, they had in the same degree a great power for evil. With regard to the working expenses, Mr. Dibdin gave no figures; but the expense of having a chemical laboratory with chemists superintending the filters, and a staff of labourers, would be considerable. As to the total cost of sewage purification on these lines, there was the first cost of laying down filter-beds and their working expenses, and if to that was added the cost of erecting precipitation and sludge-disposal works, and the working expenses of these works, he was convinced that not very much more would be heard of expensive sewage farms, because, when the figures were balanced, any difference, he thought would be rather in favour of sewage farms. It would be a very interesting task to describe the various phases through which the sewage question had passed during the present century. He thought the historian would have to record that the pendulum had swung back to the position in which it stood at the commencement of the century, which was on the side of the land treatment. At that time—he believed he was right in saying—there was no other method of sewage treatment known but land treatment. Edinburgh, for instance, had used that method since 1750. Then towards the middle of the century came the boom of chemical precipitation. Chemistry and its allied sciences had made rapid strides, and this led experimenters to think there was in sewage a hidden treasure. Immediately that was hinted at, capitalists joined, and feverish energy seized each investigator to be the first to discover this wealth; patent after patent was taken out, and companies after companies were formed. Few were left to tell the tale of how much money they had spent and what small results they had obtained. This failure set scientists thinking again, and to their aid came now Pasteur's ever memorable researches into fermentation and fermentative changes; and at last it began to dawn on the scientific world that those chemical changes in decomposition were not brought about by chemical agencies at all, but by bacteria. Then Koch's discoveries furthered the investigation; and if Mr. Dibdin's experiments proved anything at all he thought they proved that the only rational and natural method of sewage purification was treatment on land. As he had pointed out the pendulum had swung back at the end of the century to where it stood at the commencement, and in future there should be no difficulty in assigning to chemicals their right place in sewage disposal. Mr. Roechling

Mr. B. Blount congratulated Mr. Dibdin on perceiving that the one thing eminently desirable in these cases was to get all the lime to be used as a precipitant in solution. The old practice of adding it as a cream was thoroughly and fundamentally bad. It was never known what quantity of lime was being utilized, and what proportion was being simply sent down as a mass of superficially carbonated particles. A similar precaution should be Mr. Blount.

Mr. Blount. observed in water-softening processes; but it was not generally realized. It was by no means universally recognized that a mere mixture of lime and water was not lime-water. He would particularly comment on the use of sulphate of iron which had been combined with the use of lime. The sulphate of iron used was ferrous sulphate, whereas ferric sulphate should be used. But, as far as he knew, ferric sulphate could not be obtained cheaply and in large quantities. Nevertheless, it was the proper material, and he thought the manufacturers should supply it. There appeared no chemical reason why it should not be made as cheaply as ferrous sulphate. The ferrous sulphate only attained its full value as a precipitant when the iron which it contained had been brought to the ferric condition. The plan of separating out the coarse solid matter by means of a rough filter and getting rid of it was good; but he dissented altogether from putting it upon land and calling it manure. He thought it was much better to burn it in a destructor. That this refuse was of small value was indicated by the fact that the percentage of nitrogen was only 0·041 per cent. and phosphoric acid 0·11 per cent., calculated on the whole quantity. Again he would congratulate Mr. Dibdin on having recognized the fact that to use the crude sewage for making lime-water and a solution of ferrous sulphate was not a proper arrangement, but that the water should be drawn from a comparatively pure source. It was futile to waste chemicals which were comparatively expensive in precipitating material which would deposit itself in any case, and it was better to use a comparatively clean river-water. It was stated that the quality of the lime was such that about 110 grains per gallon were necessary to make a saturated solution. With pure lime only about 100 grains per gallon were required, so that there was a considerable excess of lime necessary to compensate for that which was not dissolved, and that which was not lime at all; the average commercial lime which was supplied was very far from being as good as engineers had a right to expect. That was a question which was as important in another direction as in sewage, namely, the question of the purification of gas in gas works. There lime was bought and sold on a specification which usually demanded a minimum purity of 90 per cent. Anything between 90 per cent. and 95 per cent. was paid for *pro rata*, and anything below 90 per cent. was rejected. Those who had no direct experience in the matter would be astonished at the difficulty found in getting lime even of the minimum quality permitted. He would like to emphasize the remark which several speakers had made as to the methods Mr. Dibdin had used in determining free oxygen—oxygen which was actually dissolved in the water. Up to a few years ago most of the methods of determining oxygen which were extant were illusory, and it was only recently that it had been known how to determine accurately the dissolved oxygen in water. He would ask Mr. Dibdin to put on record an exact account of the methods he pursued, both in 1885 and at the present time, so that it might be made clear whether the results at the two dates were comparable. Finally, he would echo the comments which had been made on the very feeble purification which had been effected—he meant the purification as set out in Appendix I, Table I. He thought the matter could be summed up in the simplest way by saying that the function of the chemicals which were added to the sewage at Crossness and Barking was, that they acted as a coagulant of the suspended matter in the sewage and enabled the removal of this suspended matter to be effected; but he did not think they improved *per se* the character of the effluent in any important degree. Mr. Blount.

Mr. C. H. Cooper thought it was to be regretted that in the experiments on coke-breeze filters at Barking there was no record of the performance of the filters with raw sewage. At the suggestion of Mr. Crimp he had taken out the amounts of raw sewage which had been treated on a burnt ballast filter $1\frac{1}{2}$ acre in extent constructed in 1876 at Wimbledon. From 1876 to the end of 1884 this filter received the Sunday and night sewage brought by the low-level sewer, which averaged 68,000 gallons per acre per day. In December, 1884, the Sunday sewage was diverted and had not since run on to the filter, but the night sewage continued to run on till 1893; during these latter years the night sewage treated averaged 117,000 gallons per acre per day, equivalent at the rate of flow to 3,060 persons per acre. Allowance must be made for the night sewage being weak. He did not consider there could be a more troublesome method of dealing with storm-water than that known as the separate system, especially when the storm-water sewer discharged into small streams. During the dry and warm summer of 1893 at Wimbledon only two complaints of smell from ordinary sewers came under notice, whilst over thirty were received in respect of storm-water sewers. The information given in the first Paper respecting the amount of storm-water coming off the area drained by the Counters Creek sewer was very Mr. Cooper.

Mr. Cooper. instructive. Two-fifths of the rain that fell reached the sewers, amounting to 24 cubic feet per acre per minute; it was to be regretted that the rate at which this rain fell was not recorded.

Professor Corfield. Professor W. H. Corfield observed that the new artificial filters had caused some purification of the sewage, and that they had not yet become choked. The purification they had effected had been shown by the analysis of average samples of the sewage, and average samples of the water after it had passed through the filters. He asked how those average samples were taken, and also if equal quantities of sewage or of effluent water were taken at various times, and mixed together, and then a sample of that mixture taken. Although that was the usual method, it seemed not a proper one. It had been pointed out by the Committee appointed by the British Association some years ago to investigate the methods for the treatment and utilization of sewage, that average samples of sewage could only be obtained by taking samples of sewage in proportion to the flow at the time, and that it was useless to take equal samples of sewage if it was flowing at different rates and in different quantities at the times when the samples were taken. It was obvious that an average sample of sewage for analysis or for any other purpose, could only be taken correctly in that way. He would like to know if those samples were taken according to that method, but he did not mean that for present purposes it would make a great difference in the results that would be obtained or in the deductions from those results. With regard to the duration of those filters, Messrs. Worth and Crimp made the remark that the filter was "apparently capable of continuing its function for an indefinite time." That seemed a strong conclusion to draw from experiments with a filter that had only been at work for three months. It was stated by Mr. Dibdin that a 1-acre coke-breeze filter, which had worked for three months, and filtered 500 million gallons of effluent, had a quantity of sludge brought down to it during that period "equal to 2,232 tons of sludge of 90 per cent. moisture." In that sludge there were about 110 tons of organic matter. He presumed that meant dry organic matter, although it was not stated, and, therefore, that those 110 tons were really 110 tons out of 223 tons, and not out of 2,232. The 2,232 tons of moist sludge contained 223 tons of dry sludge, and he understood that of this 110 tons consisted of organic matter, the whole of which was oxidized, while the sand amounted to 40 tons. What became of the rest of the mineral matters which were, he supposed, clay and other matters likely to aid in clogging up filters, was not indicated. It was stated that 40 tons of sand had been carried into the body of the coke, and that at present there was no appearance of any danger of choking arising from that cause. If after 5 years there was no sign of choking that was certainly a strong point. However, 5 years' working did not convince him that after a considerably longer period—for after all 5 years was not a very long time in the life of a filter—choking was not likely to take place. With regard to that system the manurial value of the sewage would all be lost. It had been shown that the manurial value of sewage could be utilized just the same as that of artificial manures. The Committee of the British Association in the experiments on Breton's Farm, Romford, which were continued for 5 years, showed that an average of almost exactly 33 per cent. of the nitrogen brought in the sewage on to the farm was recovered in the crops—a result which would compare favourably with those produced by artificial manures. It was stated that by the adoption of such a system the question of sewage purification "is placed on a different footing, and the necessity of costly sewage farms is entirely obviated." He could not help thinking that that was very rash advice to give upon what he must regard as an experiment. The strongest argument, however, against the system, would be found in Mr. Dibdin's Paper where he said: "It must not be overlooked, however, that unless the process is carefully watched, the first sign of overwork is noted by careful analyses, and rest is given when required, great risk of failure will be incurred." And further: "The filter, in fact, is a delicate organism, and requires as much care and attention to keep it in good working order as any piece of machinery." With such a description as that it could hardly be a system to advise towns to adopt as against irrigation farms. He could not help thinking that if the money which had been spent in trying to purify the sewage of London, by means of precipitation and filtration, had been spent in taking it out further, as had been proposed, to the Maplin Sands, or some other suitable place, and disposing of it by irrigation, that money would have been very much better spent. He thought that would be resorted to in the end, however much money might be spent on experiments. Professor Corfield.

Dr. Dupré expressed sympathy with Professor Corfield, who had predicted that the river would be more foul after the scheme had been in operation than before. He thought a chemist who could not take a sample was not worthy of the name. It was no doubt generally believed that a sewage-polluted river Dr. Dupré.

Dr. Dupré. was injurious to the inhabitants living on its banks; but it had been repeatedly proved that that was not the case. He did not think there was a single instance to prove that a river polluted by sewage had injured any of the inhabitants living near it. That had been proved during the inquiry of the Royal Commission in London, and it had also been proved in Dublin with regard to the Liffey. He thought it had also been proved with regard to the Clyde at Glasgow, and it had been further proved with respect to the Exe at Exeter, although that river was not nearly so polluted as those just mentioned. The process which the Metropolitan Board of Works adopted was based on a long series of experiments made by Mr. Dibdin and himself. Those experiments had extended over some months on a large scale, the samples being taken by flow and not by quantity. Every process then known was tried, and the result was embodied in the report to the Metropolitan Board of Works. On that report the scheme was based. The Metropolitan Board of Works adopted the scheme, and in spite of immense opposition, stuck to their guns, and by so doing had saved millions of useless expenditure to the Metropolis. The amount of purification in the Dibdin filter was stated by Mr. Crimp to depend upon the length of time the effluent was allowed to remain in the filters, but that was a mistake. First it depended on the biological condition of the filter; and, secondly, it was absolutely essential that the filter should stand empty for a time. He might say that the so-called empty filter contained about half the amount of sewage there was in the full filter, and there was reason to suppose that the purification was proportionate to the time the filter was empty rather than to the time it was full. He asked how long the sewage must be left in the tank to allow perfect settlement to take place. He had listened to Mr. Dibdin's Paper with very great pleasure, remembering that it was only about ten years ago that the plan was called most foolish, a disgrace to civilization and to English science. The analyses had proved that all those anticipations of the opponents were entirely falsified, and he thought the conclusions of Mr. Dibdin and himself, based on the process, were perfectly justified. In his experience the amount of oxygen which remained in the river formed the best means of judging the action of the river. If the river was pure it was fully aërated; if it became foul, the fouler it was the less the amount of aëration, and it was most extraordinary how, by means of the oxygen, every foul stream that came into it could be found. When Mr. Dibdin and he were at Erith they could, after the first day, find out the hour of

Dr. Dupré.

the tide by means of the oxygen dissolved in the water, and could find out the sewage stream from Barking by means of the analyses of oxygen absorbed even before the eye noticed it. The oxygen absorbed allowed them, so to speak, to feel the pulse of the river; as long as the oxygen remained about 25 per cent. or 30 per cent. of the possible total there was no fear of any harm. No doubt the counting of the bacteria would also be very good. The counting of bacteria would take 2 or 3 days, whereas the oxygen took 2 or 3 minutes. There was no doubt that Sir Henry Roscoe had shown that the process known as Schützenberger's was not as accurate as was supposed, but the main point was that it was a process which could be performed badly and could also be performed well. Many processes used by chemists could be ill used and could be well used; but in the process as they used it there could be no doubt whatever that the oxygen examinations were correct within 1 per cent. or 2 per cent. of the total possible aëration. The process could, at any rate, show the difference in aëration between sea-water and river-water; the former absorbed less oxygen than the latter. Therefore he thought it might safely be concluded that the oxygen examinations then made were nearly correct. The process which Mr. Dibdin and he had recommended appeared to be even now misunderstood. In the first place they came to the conclusion that no chemical process which could be fairly adopted would, practically, do much more than precipitate the suspended matter. It removed sometimes 10 per cent. or 20 per cent., and sometimes only 5 per cent. of the dissolved matters, but it practically only clarified the sewage. Therefore they came to the conclusion on the next point that the minimum amount of chemicals which would clarify was the proper amount to take. That had another considerable advantage. The former evil effects, which were always found and were predicted with regard to the Thames, were due to the fact that so much chemicals were added that a large proportion remained in the effluent, and instead of doing all the action in the tank, the action went on in the river. By reducing the chemicals, all those injurious after-effects were eliminated. It was never intended to purify the effluent from dissolved matters; the effluent was to be clarified, but not further purified. The next point was that lime should be added in solution. It was only then that it would always be effective with the minimum amount. Fourthly, the natural action of the organism of the river, when once those suspended matters were removed, would effectively deal with the

Dr. Dupré. dissolved matter. Nobody at that time understood this; they had realized it and built their hopes upon it, and those hopes had not been disappointed. He might point out that the suspended matter had a much more serious effect than at first sight appeared. During cold weather there was very little oxidation of solid matter. The solid matter sank to the bottom, and partly floated about, but it was not much oxidized. When the warm summer weather came, the mud began to putrefy and rose to the surface, being also disturbed by passing vessels, and the result was that the whole of the suspended matter had to be got rid of virtually in three months. The 6 grains of suspended matter left in the sewage would be equivalent to 24 grains during the summer months, when the whole of the suspended matter would have to be disposed of. On those four points the scheme was based; and he thought Mr. Dibdin's analysis had proved conclusively that the scheme was correct, and that all the prophecies made against it had come to naught.

Mr. Binnie. Mr. ALEX. R. BINNIE rose to make a few remarks upon the Papers with feelings of considerable diffidence and trepidation. First of all he must omit those terms of courtesy in which the members generally received the Authors of a Paper. He was too intimately associated with them as his colleagues to appear to praise himself by any remarks in that direction. All who rose to speak on that important subject must feel that they were directly or indirectly criticising the great works carried out by his predecessor, Sir Joseph Bazalgette, and if they claimed for themselves any modicum of praise for what in recent years had attended their efforts, they must always remember that it was to the system which Sir Joseph Bazalgette had designed that they were indebted for the means of doing so. After seven years' association with the main drainage of London he could bear his testimony wholly and entirely first to the scheme which Sir Joseph Bazalgette had designed, and secondly to the way in which the works were carried out. Those works were the largest in the world. They had been carried out and constructed in a manner second to none in the records of the profession. They were working to-day as they had been working thirty-two years ago, when Sir Joseph Bazalgette read his Paper[1] before the Institution, and he believed they would continue to work when the whole of the present members of the Institution had passed from this mortal scene. He wished to draw a few conclusions about those

[1] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 280

works as to their extent and design. When those works were initiated, the population of what was now called the County of London amounted to, in 1851, 2,362,000 and in 1861 to 2,600,000 persons; and Sir Joseph Bazalgette had designed the works to accommodate a population of 3,500,000. That was arrived at, as could be seen from his Paper, on the estimate that the County of London would contain a little under 30,000 persons to the square mile. At present the works which Sir Joseph had designed, with the small additions subsequently made to them, were accommodating a population of 4,750,000. The cost of the works executed by Sir Joseph Bazalgette was £6,800,000. Up to date the total cost was £7,750,000, but as £3,500,000 of that had been paid off the present main drainage debt stood at £4,200,000. He wished to refer to some of the fundamental problems with which Sir Joseph Bazalgette had had to deal in designing the main drainage of London. Then, as now, he had been assailed by the desire to separate the sewage from the rainfall. He would read one sentence from the Paper referred to: "Applied to London, it (the separate system) would involve the re-draining of every house and every street in the Metropolis, and, according to a moderate estimate, it would lead to an expenditure of from 10 millions to 12 millions of money, while the interference with private property alone would render such a proposal intolerable."[1] He was afraid after the thirty years that the moderate 10 millions or 12 millions estimated by Sir Joseph would more nearly approach 15 millions or 20 millions. That scheme had been abandoned. Sir Joseph Bazalgette had had to deal, as shown on the map, with an old system of sewers along the valley lines, flowing into the Thames, the lower portions of those sewers in many cases flowing through low-lying land, tide-locked at high water, and consequently becoming sewers of deposit. Many members would recollect the state of the river caused by that system of drainage. Sir Joseph Bazalgette had elected to intercept, as far as possible, the sewage flowing down those old valley lines, and in doing so he fixed on certain fundamental quantities. He had provided for an average flow of sewage in twenty-four hours of 5 cubic feet, or $31\frac{1}{4}$ gallons, together with a $\frac{1}{4}$ inch of rainfall in twenty-four hours. But the sewers were constructed (and that was what so many people forgot) to carry one half of that total quantity in six hours of the day. All above that capacity of sewer-discharge was caused to flow over weirs into the previously existing valley lines, which drained

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[1] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 291.

Mr Binnie. the Metropolis—storm-water overflows, in fact. In that connection Sir Joseph Bazalgette said:[1] "A quantity equal to the one-hundredth part of an inch of rain in an hour, or a quarter of an inch in twenty-four hours, running into the sewers would occupy as much space as the maximum prospective flow of sewage provided for, so that if that quantity of rain were included in the intercepting sewers, the sewers would, during the six hours of maximum flow, be filled with an equal volume of sewage, and during the remaining eighteen hours additional space would be reserved for a larger quantity of rain. Taking this circumstance into consideration, and allowing for the abstraction due to the evaporation and absorption, it is probable that if the sewers are made capable of carrying off a volume equal to a rainfall of $\frac{1}{4}$ inch per day during the six hours of maximum flow, there would not be more than twelve days in a year on which the sewers would be overcharged, and then only for a short period during such days." That initiated the various principles on which Sir Joseph constructed the main drainage of London. From the Paper which he had been quoting, he had abstracted certain fundamental facts, and had put them into the form of the following Table:—

SIR JOSEPH BAZALGETTE'S DATA IN RESPECT OF THE MAIN DRAINAGE OF LONDON.[1]

Districts.	Sewage per Day of Twenty-four Hours.		Rainfall per Day of Twenty-four Hours.		Total.	
	Cubic Feet.	Gallons.	Cubic Feet.	Gallons.	Cubic Feet.	Gallons.
North of the Thames	11,500,000	72,000,000	28,500,000	178,000,000	40,000,000	250,000,000
South of the Thames	5,750,000	36,000,000	17,250,000	108,000,000	23,000,000	144,000,000
Total	17,250,000	108,000,000	45,750,000	286,000,000	63,000,000	394,000,000

NOTE.—As the rate per head was taken at 5 cubic feet per day, and provision made for a total of 17,250,000 cubic feet of sewage daily, the sewers were constructed to receive the sewage of 3·45 million, say 3,500,000, persons, and made large enough to take half the daily quantity in six hours.

Although Sir Joseph Bazalgette in 1860 had provided for 5 cubic feet or $31\frac{1}{4}$ gallons as the ultimate flow of sewage, it was remarkable that he pointed out that at that time the water-supply of the Metropolis was only between 20 gallons and 25 gallons per head per

[1] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 292.

day. The water-supply of the Metropolis had increased during the last year to $35\frac{1}{3}$ gallons per head per day. In the previous year, 1895, it had risen to a little over 38 gallons per head per day, consequently a population one-and-a-quarter million larger than that for which the works were designed was now being dealt with. The works were providing for 10 gallons per head larger water-supply than that existing at the time of their design, and they were actually coping with 4 gallons per head per day greater water-supply than the ultimate quantity for which Sir Joseph had provided. That led to the consideration of the means of disposing of the sewage. If the river were to be used as a means of disposal, it must be regarded as a stream capable of receiving the sewage. It was a tidal river, and in the summer and drier months depended for its purification and the downward passage to the sea of any matters which were thrown into it, mainly upon the upland river-water. What was found to be the case? That as regards the River Lea during the summer months not a drop of upland water passed into the tidal reaches. So far from that being the case water was pumped from the tidal reaches into the upper reaches to maintain the navigation. In the case of the Thames the same state of things existed, that the total minimum flow over Teddington Weir had fallen on one day in July last to 108,000,000 gallons a day, or only $44\frac{1}{2}$ per cent. of what the natural flow of the river would have been had the water not been abstracted for potable purposes; and during the whole of July of 1896 the total quantity flowing over Teddington Weir only amounted to an average of 188,000,000 gallons a day, or 58 per cent. of what would have been the natural flow. In the future, therefore, a continued increase of sewage poured into the river was to be looked to. Within the next thirty or forty years it might be anticipated that the County of London would contain about 7,000,000 persons and that the Greater London of the Census Commissioners would probably contain 11,250,000. Taking that large increase of population into account, with its increased water-supply, and its increased sewage, the difficulty was encountered that in the summer months the river flow due to the upland waters would be continually decreasing. He would now turn more particularly to those precipitation works at Barking and Crossness which formed the subject of Messrs. Worth and Crimp's Paper. He had no hesitation in saying at once that they were the largest engineering works of the kind in the world. They dealt daily with over 200,000,000 gallons of crude sewage, and over 2,000,000 tons of sludge were sent to sea 20 miles below

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Mr. Binnie. the Nore per annum. That was carried out by means of 1,140 I.HP. of steam, by the employment of 400 men, and six ships containing a crew of 138 officers and men; and the cost of carrying out the work of precipitation, including the repayment, interest, and sinking fund, amounted to about £150,000 per annum. The President had paid them the high compliment of speaking in terms of approbation of the effect produced on the river by their action during the past few years. He felt that what the President had said would be echoed by all who were acquainted with what the river was in the years 1880 to 1889, and what it was at the present time. When, as was anticipated the direct flow of sewage from 250,000 persons in West Ham was taken out of the River Lea, and diverted into the precipitation works, as well as the sewage which at present passed into the river from what was called North Woolwich, that island which lay between the Victoria and Albert Docks and the river, he thought a still better result would be shown. Those works which had been carried out, and the effect which had been produced, must be studied, and could only be studied by regarding the state of the river as it was up to the year 1888. The works of precipitation at Barking and Crossness were designed and commenced by his predecessor, Sir Joseph Bazalgette. Those works in their design were based very largely, if not entirely, on the data furnished by Mr. Dibdin, who had been then the chemist to the Metropolitan Board of Works, as he was now to the London County Council. At that period it was assumed[1] that the total solid matter in the sewage amounted to 27 grains per gallon, and Mr. Dibdin estimated[2] that the quantity of sludge to be dealt with would be about 3,000 tons per day. Those works, as was well known, were designed on a system of intermittent precipitation. The region of estimates and analyses had been passed; single gallons and grains were no longer dealt with, but daily millions of gallons of sewage were treated, and thousands of tons of sludge disposed of. The result was that the sewage of the south side of London discharged at Crossness contained about 34 grains of solid matter per gallon, and that at Barking there was, on the northern side of the Thames, about 38 grains per gallon. Nearly 5,500 tons on the average of 365 days in the year were now dealt with, and that without any enlargement of the works designed by his predecessor; but Mr. Crimp and he, at an early period of their association with those works, had made one important and fundamental alteration. They had found the

[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 156.
[2] *Ibid*, p. 170.

works designed to carry on the work by intermittent precipitation, Mr. Binnie. and by building weir-walls at no great expense, as described in the Paper, they converted it at once into a continuous system of precipitation. The result was that in the first week after that alteration was carried out the output of sludge at Barking alone increased from 7,000 tons to 23,000 tons per week. The result of his experience during the last seven years' study of this important problem was that it was more a mechanical than a chemical one. No one who had carefully read Mr. Dibdin's Paper could say that any great improvement, chemically speaking, was effected in the effluent water which was sent out from the precipitation works at Barking and Crossness. True, by certain processes a vast amount of suspended solid matter, both organic and inorganic, had been removed from the crude sewage, but he was rather inclined to agree with Mr. Strachan, who had pointed out that the improved effluent at Crossness was to be attributed to the fact that on the southern works the precipitation channels amounted to 30 per cent. of the dry weather flow and at Barking to only 17½ per cent., than to any improved or possible chemical treatment which the sewage had undergone. Passing from the details of those particular works to the general subject, he thought it would be admitted that since the Paper had been read by Sir Joseph Bazalgette, and since the Papers by Mr. Crimp and Mr. Dibdin had been read before that Institution ten years ago, a great change had come over the ideas of engineers. At that time, and even in the Papers then under discussion, allusions were continually seen to some chemical change produced by the oxygen in the water or in the air. Without any chemical treatment whatever, Nature would get rid of dead organic matter, whether it were passed into water or thrown on the land, and would do so without offence, provided that her capabilities were not over-tasked. It was by over-tasking her capabilities that her laws had been offended. The oxygen of the chemist of former years was now appearing quite as important as it was then, only that instead of acting in a directly chemical manner, it was the life-blood and the energy of those micro-organisms which Nature employed to do her wonderful work. From the history of that particular problem, it was found that up to 1888 or 1889 vast masses of filth, too large for Nature to cope with, were being thrown into the river; consequently, the river got into that disgusting state which was so well known. What had been done to remedy that? In the first instance, by mechanical means all the grosser solid floating particles were removed from the sewage. Those were either burnt or taken away for manurial purposes;

Mr. Binnie. they amounted to about 100 tons per week. Then daily there were removed from the sewage in the shape of sludge about 500 tons of dry matter. That was taken away by ships and thrown into the sea, where it was diluted by a large quantity of water, and brought in contact with organisms which rapidly destroyed it. The remaining portion left in the effluent was poured into the river, and, up to the present time, certainly without any great harm to the river, and which was certainly a great improvement on anything that had gone before, although not entirely satisfactory. He did not wish to be misunderstood. The final solution of the problem of dealing with sewage had not been arrived at, and probably would not for many years be arrived at. He believed that the future had in store some very remarkable and useful discoveries, but he was not inclined to go too quickly. Too little was known of the paths about to be trodden, and which were gradually leading away from the purely chemical considerations of the subject into fields of biology and bacteriology which were but unknown lands. The filters which his staff had constructed and were working, to which Messrs. Worth and Crimp on the one hand and Mr. Dibdin on the other had alluded, displayed great promise for the future, but he was not inclined to be quite so sanguine as probably those gentlemen were. He had had in past years to deal with waterworks filters, and he knew that they became clogged very often, not with organic, but with purely inorganic matter, matter which could never be acted upon by any micro-organisms, however energetic. He was anxious that those experiments should be extended on a much larger scale, and over a much longer time than had hitherto been done, lest a great expenditure should be incurred on what might ultimately prove to be fallacious data.

Mr. McDonald. Mr. A. B. McDonald asked if the difference of level between the discharge weir at Barking, and the invert of the outfall sewer, had any effect upon the retardation of flow in the sewer. There were figures in the second Paper which did not seem to agree with the relative statements made in the first. He observed in Appendix I of Mr. Dibdin's Paper that there was scarcely any elimination of the element of albuminoid ammonia from the effluent as compared with the raw sewage. That perhaps was susceptible of explanation, but it was entirely at variance with their experience in the treatment of sewage at Glasgow. The Glasgow sewage works, which were designed by the late Mr. Alsing, and which had been the subject of high encomium by every professional man who had examined them, gave to-day a result of a very different kind from anything he had been able to discover in the statements in either of the Papers. The quantity of suspended matter in the Glasgow sewage was very high, amounting to as much as 24·08 grains per gallon. It was also very intractable sewage to deal with, being largely composed of dye stuff and other industrial refuse. From the precipitation-tanks, however, before the sewage went into the filter-beds, a surprisingly good effluent was obtained. The sample he exhibited had been taken from the precipitation tanks between ten and eleven o'clock on the previous morning. It was perfectly transparent, quite free from suspended matter, and it contained only 0·203 grain per gallon of albuminoid ammonia out of an average of 0·406 grain contained in the sewage, which compared very favourably with any analysis mentioned in the Papers. It had to be remarked that this result was attained in face of the circumstance that the works were now being carried on under such pressure that the sewage only received precipitation for a period of 25 minutes, whereas the designer of the works intended that the period of precipitation should last at least 1 hour. The works were now under course of extension, and when, 6 months hence, they were put into operation, with the full period of precipitation then available, it might reasonably be expected that that 0·203 grain per gallon of albuminoid ammonia would be reduced perhaps to a figure as low as that expressed in Mr. Dibdin's analysis of the effluent of the bacteriological filter. At Glasgow the suggestion that bacteriological filtering was necessary in the treatment of sewage was looked upon with apprehension. At present he was engaged in studying the design of new sewage works for the daily disposal of 37½ million gallons at Dalmuir, 12 miles nearer the sea than the sewage works at Glasgow. There the sewage, after being precipitated in tanks, designed upon a scale sufficient to provide ample time for the operation, would be discharged into estuarial water. This effluent it was believed would be altogether innocuous, entirely free from suspended matters, and would contain an amount of albuminoid ammonia scarcely perceptible to analysis. At present in Glasgow the suspended matter was altogether eliminated—24·08 grains in the gallon disappeared. The only thing that was left was a minute trace of supernatant grease, and a little filamental matter which could be caught if desired by screens and intercepted in that way without being put through the filter at all. Only recently it was imagined that sewage sludge was an article not only of no value, but it was alleged that being mixed with

Mr. McDonal

[M]r. McDonald. matters which possessed a slight fertilizing property, it deteriorated and sterilized whatever manurial value those substances had. The manager of the Glasgow sewage works had lately adopted a system of drying the pressed sludge, and an astonishingly ready market was found for it at the price of 25*s.* per ton. Orders had come in for over 2,700 tons of it, and the Corporation had been so stimulated by the result that machinery was being constructed to produce dried sludge in large quantity. There was every reason to expect that a full market would be obtained for as much as could be produced. He looked forward with great apprehension, as he had said, to the suggestion of the filter being an essential process after effective precipitation, and he hoped that the members would sustain him, in face of the reasons which he had given, in the belief that in a position such as that chosen for the new works at Dalmuir to filter sewage which had been so effectually treated as it was now at Glasgow would be superfluous and an extremely unwise expenditure of public money.

[D]r. Woodhead. Dr. G. Sims Woodhead had had opportunities of watching, somewhat carefully, filter-beds constructed by Mr. Scott-Moncrieff, and also some filter-beds at Exeter constructed by Mr. Cameron. There could be no doubt that if all the circumstances were favourable, it would be perhaps better to use the ideal method of throwing sewage on to land, but in that matter, as in many others, it was necessary to do what was practicable and not what was ideal. In the question of filtration it might be practicable, in certain cases at any rate, to go half way with each party. He thought the extension-filter experiments had proved that the earlier laboratory experiments as regards the breaking down of solid matter by special micro-organisms had been fully borne out. There could be no doubt that micro-organisms were capable of what was called peptonizing or breaking down nitrogenous or carbo-hydrate material. There were organisms capable of breaking up sugar and substances closely allied to them, and there were also nitrifying organisms, and organisms which had the power of forming nitrous acid. In a series of experiments he had recently carried out, along with his colleague, Dr. Wood, he had taken a quantity of crude sewage from which they had obtained, by plating out, the various micro-organisms present in the sewage. They had, by means of the Pasteur filter, filtered out every micro-organism in a considerable quantity of sewage, and then had taken out those single organisms and put them back one by one into the sterile sewage matter, because it was sterile when they had taken out the whole of the micro-organisms; and in that way they had been able to prove that several of the organisms had the power Dr. Woodhead. of forming both nitric and nitrous acids. These experiments were being continued in connection with other substances, but for the present they could, by adding these organisms to the sterilized sewage, that was, sewage which had been passed through the Pasteur or Chamberland filters, produce fair quantities of both these acids, in varying proportions. They looked upon that as a very important fact, because it showed that the formation of those substances could to a certain degree be controlled. In the filters as described by Mr. Dibdin, there were undoubtedly two processes at work, and Mr. Dibdin had shown clearly that he was attempting to obtain his results by utilizing those two processes. One of the great advances recently made had been the adoption of intermittent filtration; by this means the sewage was brought comparatively slowly into contact with a very large surface of coke breeze, the substance mentioned in that special case; and as that fluid was brought into contact with the coke breeze, the solid particles, the particles which still remained in the sewage, and even some of the material in solution, were kept on the slimy surfaces exposed or presented by the coke breeze, those slimy surfaces consisting of a coating of micro-organisms. The more slowly and regularly the sewage was brought into contact with these surfaces, and the more frequently the fluid came into contact with them, the greater would be the quantity not only of solid but also of matter in solution taken out by the micro-organisms. After that had been done, it appeared, as indicated by Dr. Dupré, that the process stopped to a certain extent; the oxygen was consumed. The process of oxidation stopped there and remained stationary until a fresh quantity of air was brought into the filter, and when the filter was emptied or drained down to the bottom, the process of oxidation again went on much more rapidly, and the process of purification was continued to a higher degree than when the filter was full. Not only that, but the inflowing sewage formed a medium for washing away the products of those micro-organisms which were on the surface of the coke-breeze. This fluid, when run off again, carried with it such waste products. In his experiments with lactic acid, Pasteur had found that if he put the lactic acid organism into milk alone, the formation of lactic acid soon ceased; but if he added sufficient lime in solution to take up the lactic acid, the combined acid was rendered inert, and the organisms could go on producing lactic acid. The same result was brought about in a different way by the fluid washing away the products and leaving the organisms free to continue their work with the next batch of

Dr. Woodhead. sewage presented to them. He looked upon that as an exceedingly important point, and believed that ultimately, the purification being found to take place while the filter was empty, the filters would be slowly filled; they would then be emptied, and left as long as possible filled with air, resting, it was said, but really acting very vigorously. Of course it was not necessary to leave them any longer than the time necessary for the exhaustion of the whole of the oxygen, because as soon as that point arrived, the filter was no longer doing its work. He was not sure that ultimately lime would be used as a precipitant, in the first instance, because it appeared that almost the same results could be obtained by allowing the sewage to stand for a short time in what might be termed an exaggerated cesspool. It was well known that organisms acted in two ways. There were certain organisms which could only take their oxygen from substances which contained oxygen bound up in them, as it were. They could not take it from the free air. There were other organisms which could take oxygen from the free air. But in a cesspool changes took place in which the anaërobic organisms, or those which did not require free oxygen, were doing a very large amount of work. Although they might not be growing at a very great rate, still they were breaking down forcibly by extracting oxygen and throwing into a nascent condition very complex organic substances found in sewage. In that process, large quantities of very offensive gases were developed, but if the process went on comparatively slowly those gases rapidly became oxidized as soon as they came into the presence of oxygen, after the first breaking-up process had taken place. The great aim was then to oxidize everything which came from that tank, allowing the oxidizing organisms, or those organisms which took the oxygen from the air, to do their special work. By a process of that kind a purification, as tested by the oxygen absorbed, of about 60 per cent. had been obtained, about equal to that mentioned by Mr. Dibdin; and there was no doubt that as that process became more fully understood even better results would be obtained. He would like to mention one or two points in connection with organisms found in sewage, because they played an important part in the process of biological filtration. Even the colon bacilli, which had been vilified so greatly, undoubtedly played a part in that condition. He mentioned that because a considerable number of these colon bacilli had been found which varied considerably in their action upon organic matter. Some produced gas freely, some did not produce so much. But all colon bacilli which had a pathogenic action, as some of them undoubtedly had, died out very rapidly in water; whereas the colon bacilli, which had been accustomed to live in water remained and continued the process of purification, in which process they were assisted by other water organisms for some time after the sewage had left the filtration tank, and had been run into a brook or river. He wished to point out that the limit of the work of those filters had not been arrived at, and if the sewage had to go on to the land, as it might profitably do under certain conditions, there could be no doubt that the process of biological filtration prepared it in a very marked degree to be a much more useful product as a manure than it could possibly be as crude sewage. If the manurial products could be thrown on to the land in a form in which they were more rapidly assimilated by plants, far more could be obtained from them than when the sewage was thrown on in a crude form, clogging the soil or allowing a large proportion of the crude manurial substances to be washed away. He looked forward to the time when biological filtration and preparation would be part of the sewage-farm process, and there could be no doubt that the most perfect conversion would be obtained if the material could be first passed through a controlled filter, and then put on to the land, where a great many of the filtration products were taken out by the various bases in the soil, as had been pointed out by Mr. Warrington and others. It had also been indicated that by this filtration sewage was rendered suitable to be utilized at leisure by the plants. He believed the filters had a great future before them in places where it was impossible to get sewage farms; and in places like London, where enormous quantities of sewage had to be dealt with, there could be no doubt that these filters would come into very general use, although perhaps not immediately. The best results could only be obtained by studying them carefully on accurate biological lines. Dr. Woodhead.

Mr. Baldwin Latham observed from the second Paper that the quantity of suspended matter in the sewage, estimated in 1887 at 27 grains per gallon, had increased since that period to about 29 grains per gallon. But the large volume of suspended matter, which was actually removed from London sewage by the chemical process, differed enormously from the figures which Mr. Dibdin had given. Referring to the first Paper, it would be found that in the year 1894, the same year which Mr. Dibdin gave in his analysis of suspended matter as 29·8 grains per gallon at Barking, the actual quantity of dry matter carried to sea was 42·3 Mr. Latham.

Mr. Latham. grains instead of 29·8 grains per gallon. Both of the Papers agreed upon the question of the percentage of moisture in the sludge; but in addition to the quantity of solid matter actually carried to sea, there was the quantity which had been taken out, amounting to nearly 1½ grain per gallon, by those screens which had been passed into the destructors, or had been sold to the farmers. Beyond that there was still a quantity, which must be very large indeed, which in times of rain, when the storm-overflows came into operation, was carried direct into the Thames. Added to that the effluent itself contained 7·1 grains of suspended matter per gallon, so that there was in the sewage of London at least double the quantity of solid matter given by Mr. Dibdin as the quantity of solid matter in the sewage shown clearly by the figures in the Papers. In 1887 it had been pointed out that the amount of chemicals which Mr. Dibdin then proposed to use was too small to purify the sewage.[1] The result of the analyses in the Papers clearly proved that so far as the suspended matters in the sewage were concerned, practically no purification had taken place, certainly, on the north side of the Thames. He would like to ask Mr. Worth and Mr. Crimp to give the actual capacity of the tanks which were used, both at Barking and Crossness, as that was a very important point with regard to the removal of the suspended matter. It was stated to be 20 million gallons on the north, and 31¼ million on the south; but it was not indicated how much was used at a time. Taking the total capacity, it would be found that the speed at which the sewage passed through the tanks on the north was 3·84 hours, while on the south it was 9·3 hours, so that it was only two-and-a-half times slower on the south than on the north; yet the degree of purification which Mr. Dibdin attributed to the better solution of the lime, might not be due to that cause at all, but really was due to the much longer time the sewage was in the tanks on the south side compared with the north. It was curious that Mr. Dibdin had actually more suspended matter in the sewage on the south than on the north. But on referring to the first Paper, it would be found that that could not possibly be so; because on the north in 1894 it required 34,473 gallons of sewage to produce 1 ton of sludge, but on the south it required 39,058 gallons; showing that the sewage was much more dilute, and must have very much less suspended matter in it than the sewage upon the north. Upon the question of rainfall Mr. Binnie had made some remarks about the plan adopted for the

[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 194 *et seq.*

Metropolis; but even in the suburbs of London a much smaller amount of rainfall was allowed to be brought into the sewers than $\frac{1}{4}$ inch per day. A gauging was given of a sewer in connection with Counters Creek, which showed that in sewers it was not a rule-of-thumb quantity that had to be dealt with passed into a sewer at a given time, but it was the actual rate at which rainfall flowed off. The actual rate at which rain flowed off in that particular district in time of heavy rain was stated by Messrs. Worth and Crimp to be $9\frac{1}{2}$ inches in that time. In the design of London sewers the length had not been taken into account; and the consequence was that that length deferred the flow of the sewage. The rain which fell in the neighbourhood of the outfalls passed away before the more distant rainfall miles away had come down, so that those sewers would discharge, and did discharge, a much larger quantity than was actually calculated as so much falling upon a given area in a given time. So far as the constructive work was concerned, no possible fault was to be found with the London sewers, but they seemed to be on too small a scale, and the storm-overflows into the Thames took place at much more frequent intervals than was desirable for the purity of the river. The bacteriological treatment of sewage had occupied his attention for many years, and now it seemed to have been taken up by Mr. Dibdin and others. He had in 1883 designed a filter to carry out that bacteriological process. It differed essentially from the process now proposed, which was simply to fill a tank with either coke-breeze or burnt ballast, turn the sewage on to it till it was full, leaving the sewage in contact with the materials in the tank, and, when it had been there for, say, 2 hours, the effluent was drawn off at the bottom, supposed to be perfectly purified. In the Friern Barnet filters, which he had designed in 1883, and which had now been working for 10 years, there was a difference of design. The filtering material was burnt ballast and coke-breeze; but on the top of the filter there were 6 inches of fine sandy soil. Those filters were perfectly ventilated at all times by constructing drains and carrying air-pipes up above the water-line. The object of placing that fine material on to the filter was to restrict the rate at which the sewage passed through. The nitrifying organisms that produced the purification attached themselves to the particles of the filter. The germs did not float about in the water, because if they did, every time the filters were discharged, away went the germs; but they adhered to the particles of the filter, and the more intimately the sewage was brought into contact with the germs the more perfect the purification. In a Mr. Latham.

Mr. Latham. filter of the Dibdin type the actual capacity was about 40 per cent. of the cubical capacity of the filter; that was, the material occupied 60 per cent. and the liquid 40 per cent. But in a filter of that kind there would be large holes and drainage-channels, and consequently all the sewage would not naturally come in contact with the germ which was attached to the material in the filter. The moment the filter was filled the whole of the air was driven out. In a filter such as he had designed and had been so long successfully at work at Friern Barnet, the sewage trickled slowly through the whole of the material of the filter. The filter was never devoid of air, because it was never flooded. It had always a free movement of air through it, and the difference he found by comparing the effluent at the Friern Barnet filters dealing with the sewage of a population of over 8,000, was that the sample of effluent taken from that filter and kept for an indefinite time in a warm place was perfectly fresh, whereas the first sample of effluent on emptying a filter as described by the Author after a week was very foul. He therefore thought the question as to which was the best form of biological filter—especially after what he had heard from Dr. Woodhead—must be decided in favour of that which he had adopted for over 12 years. That was certainly much more advantageous than a filter such as had been described by the Authors, which really could not be called a filter because there was no filtration—it might be called a contact chamber, as the sewage was simply let into the chamber to take its chance whether or not it came into contact with the organisms. Such a process could never compare with a controlled filter such as those he had constructed at Friern Barnet, and which from the time they had been constructed, had never had a particle of material removed from or added to them.

Mr. Chatterton. Mr. G. Chatterton thought the great work of the late Sir Joseph Bazalgette (whose pupil he had been, and with whom he had worked many years) with regard to the main drainage of London, afforded an example to be followed by all engineers. The intercepting of the main drainage was perhaps the finest work that had been carried out during the present century. As to the purification works, he had, in conjunction with Dr. Günther, of the British Museum, made many experiments with regard to fish-life in the Thames, sinking little boxes or corves, about 1 foot 6 inches square, in different portions of the river between Greenwich and Gravesend. The result showed that in 1880 fish could not live in the river between Gravesend and Greenwich, but they could exist below Gravesend and above Greenwich;

Mr. Chatterton. they were suffocated, dying from the want of free oxygen. Greater importance had, in consequence, since been attached to the determination of the amount of free oxygen in the river. A great improvement had resulted, as shown by the fact that the London County Council were now carrying out to sea over 2,250,000 tons of liquid mud per annum, which had had a poisonous effect on the fish. The results of the processes that had been carried out were sufficiently shown by the oral testimony of the watermen, the yachtsmen, the riparian owners and the wharfingers. There could be no doubt that the Thames was an entirely different river from what it was in 1882. He thought that sufficient attention had not been paid to the report[1] of Messrs. Bidder, Hawksley and Bazalgette—one of the most remarkable reports, he thought, ever made on the subject. There was one point in it to which he should like to direct attention. In making provision for the storm-water, Messrs. Bidder, Hawksley, and Bazalgette, and Mr. Glaisher, who had been associated with them in the inquiry, had estimated it at $\frac{1}{4}$ inch in twenty-four hours reaching the sewers, or 0·4 inch falling; and that by means of sewers, since carried out, 95 per cent. of the sewage would reach the ultimate outfalls at Barking and Crossness, and only 5 per cent. would be discharged by storm-overflow into the Thames. That calculation, made probably in the dark in 1858, was one of the most remarkable ever made by those eminent engineers whose names were on the walls of the Institution. He understood that the London County Council had made the most accurate gaugings of the storm-overflows of London, showing that 96 per cent. of the total flow of the sewage of London went to the outfalls.

Dr. Rideal. Dr. Rideal thought that in regard to the purification of the Thames, the action of the Thames Conservancy, in compelling riparian owners above London to adopt improved methods for sewage disposal, should be taken into account. That had been attended by enormous expense to the local authorities, to the benefit of the London Water Companies, and the Thames at and below London. It seemed anomalous that London should have been assisted in that way by ratepayers outside the metropolitan area; and credit should have been given by Mr. Dibdin to that assistance in bringing about the improved condition of the Thames. Although sewage purification had undoubtedly been effected, also, by the chemical treatment of the sewage at Cross-

[1] Report . . . upon the Main Drainage of the Metropolis. London, 1858. A copy is in the Library of the Institution.

Dr. Rideal. ness and Barking, it should be remembered that, strictly speaking, that was not purification of the Thames, but a removal of polluting matter from the Thames area. A convenient figure, viz., 10,000,000 tons of sludge, at $4\frac{1}{4}d.$ per ton, had been stated by Mr. Dibdin as that removed by the London County Council steamships. The chief lesson to be learnt from the sludge precipitation, as practised by London, was the advantage of what might be called the homœopathic chemical treatment over the former, and, even now, in other places, the present extravagant use of chemicals. It had been shown that the cheapest chemicals, viz., lime and sulphate of iron, in minimum doses, could effect the removal of suspended matter as efficiently as chemicals at higher prices and in greater quantities. Practically no soluble matter was removed except phosphates. It was gratifying to find that the results achieved had shown the fallacy of regarding land treatment or a sewage farm as a *sine quâ non* in dealing with the sewage problem. It was to be hoped that the Local Government Board would be more ready to lend a favourable ear to those modern schemes in which land treatment was omitted now that the statistics of the largest sewage problem in this country had been summarized and made available for use by other authorities. He regarded the sewage problem as capable of division under three distinct headings, viz., (1) the removal of solid suspended matter; (2) the destruction of soluble organic matter; and (3) the removal of nuisance and smell from the effluent. The latter might be called "the finishing process," and was most important. In London, the first of these processes had been accomplished by so perfect a chemical treatment and sludge removal that no treatment of the effluent had been necessary except that occasionally a "finisher" had been used. That deodorization had been effected at various times by bleaching-powder and by manganate of soda. Credit was due to Mr. Dibdin for establishing the superiority of the latter in the face of much opposition. Except in cases like London, where a large quantity of river-water acted as a diluent and natural oxidizer, a chemically treated effluent, without other treatment, obviously required for satisfactory purification a correspondingly larger quantity of deodorant than where the chemical effluent had been further treated by land or filter-beds. Even when filters were used, a deodorant was in many cases desirable and necessary. In land-treatment and in filter-beds the oxidation was effected by atmospheric oxygen, which was obviously the cheapest chemical to employ, but acted only under the influence of bacteria. It seemed that for deodorant purposes a cheap oxidizer was wanted, and manganate of soda and bleaching-powder might not be so cheap eventually as oxidized sea-water, or ozone obtained directly from the atmospheric oxygen by cheap electric energy. The problem of deodorization therefore resolved itself into a comparison between the cost of controlling bacteria, and the cost of generating electrical energy for rendering the oxygen in air or water available. Theoretically, the conversion of free atmospheric oxygen into ozone should be cheaper than the electrolysis of water or brine; but the convenience or utilization of the procurable oxygen necessarily conditioned the economy. As a finisher, he had recently suggested in regard to filtrates from filter-beds in which the amount of soluble organic matter was small, that probably the cheapest method would be complete aeration and exposure to sunlight in a shallow tank or open water-course. A convenient name for such a finisher would be an "insolator." In this way oxidation was effected by the aid of sunlight and chlorophyl-bearing organisms, algæ, confervæ, duckweed, and possibly watercress. The latter part of Mr. Dibdin's Paper dealt with the results obtained by his well-known experimental acre filter-bed upon chemically treated sewage. He had elsewhere [1] objected strongly to the use of the term "filter" in connection with that subject, as in Mr. Dibdin's experiments the effluent had been freed from nearly all suspended matter by chemical sedimentation. The bacterial change, although called nitrification, was something more than that, as it was certain that, besides the conversion of ammonia into nitric acid, there was also the conversion of soluble organic matter into nitrites, nitrates, carbonates, and water, simultaneously going on; carbonification or production of carbonic acid, as he had shown elsewhere, took place to a very considerable extent. This he had proved by determinations of the increase of CO_2 in the effluent and in the circumambient air, whilst it was also shown by the reduction in the amount of oxygen absorbed from permanganate. The improvement in the albuminoid ammonia in the so-called filter-beds also established the fact that organic nitrogenous soluble matter was destroyed. He had been able to corroborate Mr. Dibdin's experiments that the material for such filter-beds had little effect upon the results, and in that conviction it was noteworthy that the recommendations of the Local Government Board for many years in favour of a polarite filter-bed, which it was no secret was what Mr. Dibdin called the "proprietary Dr. Rideal.

[1] Journal of the Sanitary Institute, 1897.

Dr. Rideal. material," must now be abandoned in favour of any properly constructed arrangement for ensuring the growth of the organisms which effected that change. These, as already mentioned, were not only the nitrifying organisms, but they were a variety of aerobes, living on organic carbon and nitrogen compounds in presence of air. In the experiments on the Exeter filters, referred to by Dr. Dupré and Dr. Sims Woodhead, which were similar in type to those of Mr. Dibdin, it had been shown that the bacterial oxidation took place during the period of rest, or, rather, when the filter was empty, not full. This anomaly was due to the fact that the dissolved oxygen in an effluent, even if fully aerated, was not sufficient for complete oxidation. When a filter was apparently empty, it contained, like a sponge, a very large percentage of the last dose, and the sewage matters, in contact with the air and resident organisms, were then destroyed. When the filter was full of liquid, the free oxygen was quickly consumed, so that only a short full period was necessary. Determinations of the free oxygen in a full filter-bed would indicate the time when such filter-bed should be discharged, as a longer period caused the organisms to die from drowning. By construction with sufficiently porous material, it ought to be possible to arrange a filter in which the volume of oxygen was so adjusted to the volume and strength of sewage, that by the time the available oxygen was consumed, the sewage was completely destroyed; this complete oxidation seldom obtained in practice, which necessitated insolation, further filters, land treatment and deodorant, or admixture with a large volume of river-water containing free oxygen, in which self-purification could proceed. The importance of increasing the rate of filling and shorter periods of rest had been referred to. He thought the quick removal of the liquid from the filter was wanted rather than rapid filling, and longer empty periods instead of shorter ones. The possibility of doing away with chemical treatment altogether and replacing it by a bacterial process had not been referred to by Mr. Dibdin. In a recent Report to the Sutton District Council, Mr. Dibdin had described such a process, and took credit for presenting to the community at large, in the year of Her Majesty's Jubilee, the solution of a problem, the monetary value of which he reckoned at not less than £60,000,000 sterling. He ventured to think that although the London County Council seemed apparently to undervalue Mr. Dibdin's services to them, such a boon to the nation would be appreciated by the Institution. In reference to the new process mentioned by Professor Henry Robinson, the disappearance of solid fæcal

Dr. Rideal.

matter by natural agencies was well known to take place in broad irrigation and in cesspools. When controlled and localized it seemed a rational method of dealing with such solids. Several processes had been proposed in recent years which were modifications of that idea, but in many of them it seemed to have been forgotten that the initial change or conversion of organic solids into soluble compounds did not involve oxidation. Cesspools were covered, manure was dug into the ground, so that absence of air and absence of light were favourable to the change. An upward-filtration tank filled with flints was used by Mr. Scott-Moncrieff; Mr. Cameron used at Exeter a closed tank with a very slow current of sewage passing through; Mr. Dibdin at Sutton used a ballast open downward filter identical with those he had used for oxidizing at Barking. The results in all these processes were the same, viz., disappearance of the sludge, formation of soluble organic compounds, evolution of carbonic acid, hydrocarbons, and sulphuretted hydrogen. The oxygen of such carbonic acid was not derived from the air, but was part of the combined oxygen existing in the organic matter. Open tanks were liable to smell, and therefore he was inclined to favour the closed form adopted by Mr. Cameron for practical working. In Mr. Dibdin's open form an anaerobic condition obtained below the surface, whilst on the surface there might be aerobic growth which tended to diminish any nuisance; but, as he had said in connection with his effluent oxidizing filters, it was a delicate organism, and required as much care and attention to keep in good working order as any piece of machinery. Although those questions were bacterial, the results were chemical, and could only be judged by chemical analysis. As mixed breeds of organisms did the work efficiently, their isolation and identification had only a scientific interest. Proper relation of the supply of sewage to that of air in the case of the oxidizing filters seemed to be the principal condition, while in the sludge liquefying or dissolving tank, time and absence of air were the principal factors. He had already pointed out that in many cases bacterial effluents had to be finished off before final disposal when Conservancy Boards or riparian owners below were very exacting. What was a satisfactory effluent? An increase in the amount of albuminoid ammonia might under certain circumstances be looked upon as a good sign in a partially treated sewage as it shows that the nitrogenous organic matter is in process of dissolution. Any conversion of solid nitrogenous matter into soluble forms obviously increases the amount of albuminoid ammonia in the liquid. He had elsewhere stated that he agreed

Dr. Rideal. with the contention that an effluent was good if, when mixed with sufficient ordinary water containing free oxygen, the ammonia and organic nitrogen were converted into nitrates. The percentage relation of oxidized nitrogen to unoxidized nitrogen and the amount of available oxygen in the stream were therefore the standard by which an effluent should be judged.

Mr. Ward. Mr. HENRY WARD spoke as a member of the Main Drainage Committee of the London County Council, and he should have been glad if that Committee had received severer criticisms than any that had been offered. He doubted whether any engineering work in the world had been better designed and carried out than the main-drainage system of London. He had been many times into the sewers, and the various work connected with them during the last six years, and he had never seen a bit of bad work. With regard to the design, the fact that it had been taken as an example in many other towns, not only in England, but throughout a large part of the world, said much in its favour. He thought the County Council and its predecessor, the Metropolitan Board of Works, had also been ably served by its chemists. They really appeared to have carried out the works without having made a single serious mistake. In reference to Mr. Strachan's criticisms that a larger provision was not made originally for storm-water, and that the sewers had a capacity of two and a half times the flow in dry weather, whereas most other towns had sewers of a capacity equal to six times the dry-weather flow, he would advance two points. A very large reservoir was constituted in the great length and extent of the sewers. When the London County Council first took over the works, it was found that many of the low-lying sewers had not been kept pumped down under ordinary circumstances, especially the one running along the Thames Embankment down to Abbey Mills. Larger pumping power had been installed, with the result that the main sewer, extending as it did many miles, was now kept almost dry; at any rate, it was well pumped down. Again, the storm rainfall, over the very large area of London often differed very much both in time and quantity. When it was considered that the district extended from Willesden in one direction to Plumstead and Crossness in the other, a distance of nearly 20 miles, it would be seen that there was an area in which it was quite possible to have a severe storm at one place and no storm at another, so that by extending the area they required less sewer capacity than if they had to do with a comparatively small district. Still, it was early recognized by the Council that this was their weakest point, and the matter had been referred in 1891

Mr. Ward.

to Sir Benjamin Baker and Mr. Binnie to report on. The result was that those gentlemen suggested that a further sewers should be provided at an expenditure of something like £2,000,000. That proposal had been followed only to a very small extent; but the Main Drainage Committee had in 1896 brought up strong recommendations to the Council that a very large expenditure should be made in that direction. Unfortunately, they were unable to persuade the Council of its necessity. That was largely due to the fact that the improvements in the Thames had been so indisputable that opponents again and again said that while the river was in such a splendid condition, large sums of money should not be asked for to improve it still further. As to the work of the overflows, exact records were kept of the number of hours in which each overflow worked per annum, and despite the natural increase of population, and therefore of the sewage, the number of hours that the overflows worked was less than it had been for some years past. Some speakers had expressed their doubt as to the actual purification, but he did not think that the point could be contested. There were so many authorities among those who had been opponents of the main-drainage system in times past who were now ready to recognize the greatly improved character of the river. At the site of the Barking outfall, where there was once a huge bank of mud, there might be seen, at a little below high-water mark, a considerable area of what was more or less shingle beach. That, he thought, was a sufficient proof of the state of purification. Then there were many reports as to fish being caught as high as Greenwich. There was perhaps one great difficulty which the public did not appreciate in reference to the drainage of London, namely, that so large a part of the area lay under high-water level. Along both sides of the Thames, on part of the land which had been marsh-land at one time or another, the water could only be kept out by the river wall. Under those circumstances it was difficult to get rid of the storm-water when a storm occurred at the time of high-water. The storage capacity of the sewers and, to a small extent, the pumping power had to be relied upon. There was not sufficient pumping power to deal with the whole of the storm-water; but no serious complaints had been made on that score. Under the new Building Act the Committee could prevent houses being built on land lying below high-water mark; still they had a difficulty with regard to houses built below that level in times past. The fact that the main-drainage rate all over

Mr. Ward. London was only $3\frac{1}{4}d.$ in the £ appeared to show that they could construct excellent works, pay interest on them, and also repay the capital—the whole capital would be repaid in a period of 60 years—as well as pay working expenses at a very small cost to the ratepayers. He thought many of the provincial towns would like to be able to show so low a rate as that paid in London.

Mr. Taylor. Mr. G. MIDGLEY TAYLOR noticed in Appendix I, referring to the effect of chemical treatment on the sewage of the northern and southern outfalls, that there was considerable improvement in the effluent of the southern outfall over that of the northern. That result had been attributed by Mr. Dibdin mainly to the improvement in the addition of lime-water, and Mr. Strachan had suggested that that was probably due to the increased capacity of the tanks at the southern outfall, and the opinion was corroborated by the eminent authority of Mr. Binnie. He would venture to suggest an additional reason. It would be found on p. 84, that the lime-water at the southern outfall was made with comparatively pure Thames water, and that the quantity of river-water pumped for that purpose was between 2,500,000 gallons, and 4,000,000 gallons per day, which, on the 76,000,000 gallons daily flow of sewage, amounted to about 5 per cent. He therefore thought that dilution alone would largely account for a great deal of the purification. At the same time, the river-water contained a large amount of dissolved oxygen. He would ask Mr. Dibdin if he had examined the effluent from the southern outfall, to ascertain if the dissolved oxygen had further purified the sewage, or whether it was still coming out as dissolved oxygen. In reference to the subject of upward filtration his firm had constructed filters for the upward filtration of crude sewage for some years past, and the average of three analyses of the effluent from one typical installation, made in January 1894, showed that the suspended matter was reduced to $3\frac{1}{3}$ grains per gallon; that the albuminoid ammonia was reduced from 0·44 grain to 0·3 grain per gallon, and the oxygen absorbed from 1·56 grain to 1·4 grain. The general result being, that this treatment was practically as effective as a chemical process for clarifying sewage. He agreed that a filter constituted a delicate piece of machinery. It was not every sewage works that had the advantage of such an eminent chemist as Mr. Dibdin to keep its filters in order, and he feared that if the filters were placed about the country to deal with sewage effluents for the purposes of purification without Mr. Dibdin at their head, there would be numerous failures. In regard to the cost of filtration, it would be seen that in 1894 the cost was at the rate of £2 9*s.* 6*d.* per million gallons, and in 1895 £1 15*s.* 1*d.* It was a pity that 1896 was not included; possibly the Authors might supply it. At any rate it would be seen that the process was expensive, and his experience led him to believe that when it was attempted to purify sewage at anything like the rate of 1 million gallons per acre per day, the cost became excessive. He therefore thought that unless there were very strong reasons for the adoption of that system of filtration, engineers would be well advised to continue the system of purification by land. Mr. Taylor.

Mr. WORTH, in reply, said the population contributing to the disposal works, including those outlying districts which had the privilege of draining to London under certain conditions of payments, was 4,750,000, as nearly as could be estimated, at the end of 1896. That, calculating on the dry weather flow, gave 38 gallons per head per day. The rateable value at the end of the same year, 1896, was £37,049,886, which also included the outlying districts; 3¼*d.* in the £ on the rateable value was the sum required to repay the principal and interest on the capital outlay and defray all the working expenses of the main drainage of London. The remarks of Mr. Strachan with regard to the works were correct; he was also correct in stating that provincial towns would require a larger proportion of tank accommodation to the daily flow of sewage than was provided for London. He had, however, overlooked the fact that the analogy was not quite the same, as London discharged its effluent into a tidal river. Also the discharges from the various storm-overflows were not so large or so frequent as in former times, now that the pumps at the various stations had been brought and kept in the highest state of efficiency. He could only say, in reply to Mr. Roechling, that no suspended matter was manufactured at either of the outfall works. The chemist gave it, without doubt, as he found it, but it was not as ascertained by other and more reliable means; it had now reached beyond the experimental stage into a practical one: there was the bulk to be dealt with, and that could not possibly be wrong. With regard to the chemist's results, they depended on the position that the various samples were taken in the flow of the sewage, the sample might be taken too high—*i.e.*, near the surface of the flow to get an average one and so miss the heavier suspended matters which passed along nearer the invert of the outfall sewers. He thought the samples were taken somewhat as stated by Dr. Corfield—equal samples of sewage, rather than taking them in proportion to the Mr. Worth.

Mr. Worth. volumes, because it varied considerably, both as to the rate of flow and the quantities during the day. The ratio of the samples to the flow was about 1 to 115 millions; for that was the average flow passing daily at the Barking Outfall Works. The mode adopted, which he considered a more reliable and practical one, was as follows:—Records were taken during the past three years, from 1894 to 1896 inclusive, of the output of sludge taken from the sludge-settling channels before discharging from them into sludge vessels for conveyance to sea; then, having given the sludge as above indicated, with the percentage of moisture and the quantity of sewage coming down to the Outfall Works, it resolved itself into a simple arithmetical sum to obtain the suspended matter per gallon. When this was obtained, and the number of grains that passed away in the effluent added to it, deducting the number of grains per gallon of chemicals that were put into the sewage for precipitation operations, together with a proportional increase due to the carbonate of lime. In that way during the past three years it had actually ranged between 37 grains and 40 grains of suspended matter to the gallon of sewage. That result entirely ignored the 500 tons of grit and other débris which were annually dug out of the precipitation channels, and put on the spoil bank, and also 5,000 tons annually taken from the cages or screens, representing practically another 2 grains to the gallon. Turning to the sludge vessels, they had a total capacity of 6,223 tons, reckoning the sludge at 65 lbs. to the cubic foot: this gave an average to each boat of 1,037 tons, and from actual tests carefully gauged from the overhead tanks extending over a long period, the average showed a deficiency of less than 3 per cent., so that in adopting the standard of 1,000 tons, shown in the Tables in the Appendixes, pages 74, 75, and 76, it was a deficiency of 3½ per cent., which was a fair allowance and would therefore give the maximum quantity of sludge sent away from the Barking Outfall Works, while that obtained from the sludge-settling channels gave the minimum, so that 37 grains to 40 grains, or say an average of 38½ grains of suspended matter in the sewage as coming to the outfall from the north side of the Thames could be accepted as the minimum. The difference therefore between the result of the sludge-settling channels and the sludge steamers was less than 3 per cent. He submitted on page 159 a Table of the tests of the sludge vessels taken during 1896–97 from the overhead tanks. In the admirable remarks of Mr. Binnie, which all would appreciate, were given some valuable facts and figures which left him very little to say in reply. At the Barking precipitation channels,

SLUDGE VESSELS.

Mr. Worth.

—	Bazalgette.	Barking.	Binnie.	Barrow.	Belvedere.	Burns.	Totals.	Average for each Vessel.	Adopted Standard for Cargoes.
Cubical capacity in feet . .	37,885	36,560	34,961	34,979	35,069	34,993	214,447	..	..
Tons .	1,099	1,061	1,015	1,015	1,018	1,015	6,223	1,037	
Average of ten tests .	1,083	1,012	984	991	992	986	6,048	1,008	Tons. 1,000
Deficiency, per cent. .	1·46	4·61	2·99	2·36	2·56	2·95	2·81	2·81	3·58

NOTE.—Sludge, 65·0 lbs. per cubic foot; 34·5 cubic feet to the ton.

the tank capacity to the level of the weir-walls was 3,250,548 cubic feet, and at Crossness 3,454,900 cubic feet, or practically 17 per cent. and 30 per cent. of the day-weather flow at each station respectively. He had found that about one-sixth could be taken as the proportion for those not in use during the process of decanting the effluent and removing the sludge from the floors of the precipitation channels. It must also be remembered that at Barking there was still the old reservoir which could be used as storage, having a capacity of 35 million gallons, which was provided for the purpose of enabling the sewage to be discharged into the river as far as practicable on a falling tide previous to the construction of the precipitation works. It could still be used in respect to storing the effluent after precipitation operations for a certain time before and after ebb-tide if desirable. The cost of the 1-acre filter-bed was £1,494 2*s.* 5*d.* The particulars of working at Barking for the year 1896 were as follows:—

	Gallons.		£	*s.*	*d.*	£	*s.*	*d.*	
Precipitation	45,407,471,000	cost	40,177	18	11	=0	17	8·36	per mill. galls.
Filtration .	132,942,111	,,	226	13	11	=1	14	1·25	,, ,,
	Tons.								
Sludge (land cost) . .	1,410,000	,,	11,730	11	8			=2*d.* per ton.	
Sludge (sea cost) . .	1,410,000	,,	19,832	6	0·84			=3·376*d.* per ton.	
			£71,967	10	6·84				

Mr. Worth. The following Table showed the cost of filtration of the effluent for three years:—

	£	s.	d.	
1894 . . .	2	9	6·65	per million gallons.
1895 . . .	1	15	1·39	,, ,,
1896 . . .	1	14	1·25	,, ,,

In conclusion, he thought credit was due to the Main Drainage Committee for the energetic and painstaking manner in which they had grappled with this gigantic question since the dissolution of the late Metropolitan Board of Works in 1889. Their earnest desire had been, and was, to have a purer Thames, free from all noxious substances, and the present condition of the foreshores and reaches at low water bore testimony to the success which had resulted from their efforts.

Mr. Crimp. Mr. SANTO CRIMP, in reply, thought the significance of the Table on p. 63 relating to the Isle of Dogs storm-overflow, one of the most important in London, because it was in direct communication with the invert of the northern low-level sewer, was not appreciated. It would be seen that in 1889, before the machinery at Abbey Mills was put in order, the overflow was in operation for 11 per cent. of the total time, which meant the discharge of an enormous quantity of sewage into the Thames. After the machinery had been repaired the average was $2\frac{3}{4}$ per cent. of the total time; and subsequently, when the northern outfall sewer was duplicated as far as Bromley, and the second pumping-station at Abbey Mills was provided, the storm-overflows amounted to only 0·6 per cent. of the total time. That was a matter of great importance from a sanitary point of view. Another important point was the effect of flooding in the Isle of Dogs. The poorest population of London was there congregated, many of the houses were 3 feet or 4 feet below the level of the roads, and he had seen upwards of four hundred such houses filled to the road-level with storm-water and sewage. He submitted that no work could be of greater importance from a sanitary point of view than that carried out by the London County Council for the prevention of that flooding. In order to reduce the offensiveness of the storm-overflows, the London County Council had spent £60,000, during his term of office, in constructing new inverts in the old sewers and in improving them in other respects, and the vestries had spent large sums in the same work; in fact, the whole of the old main sewers were in course of gradual reconstruction. With regard to the separate system, he thought that, so far as London was concerned, it was dead; Mr. Binnie had shown that it was impracticable. No responsible person would ever come forward with the suggestion that the separate system should be adopted in London. He had known surface-water taken from the street outside the Institution during periods of slight rainfall, when storm-overflows were not in operation, to be eleven times as rich in albuminoid ammonia as average sewage. He would ask those who advocated the separate system whether they would like to discharge that into the river under existing conditions. The sludge liquor, far from being simply water, was the essence of sewage. Filter-pressing had been tried both at Crossness and Barking with a view to reducing its bulk, but it was cheaper to take it to sea. It certainly was better from a sanitary point of view. As the bulk could not be reduced, it was useless to refer to the percentage of liquid in the sludge. Alluding to the cost of the filter at Barking, Colonel Jones had said that for precisely similar filters at Manchester the estimate was £5,500 per acre. He had had the honour of being associated with the City Engineer of Manchester in framing the estimates, and was in a position to state that the filters did not bear any similarity whatever to those at Barking; they differed in many material respects. London equalled a hundred provincial towns rolled into one, and, as a result, the conditions were very different. It was not true that when a rain-storm came over London, the drainage system would be simply resolved into its original state, and discharge straight into the river. The most important overflow was at Old Ford; 52,000 cubic feet per minute could be brought to that point, and 30,000 cubic feet per minute could be taken away. The storm-overflows were so arranged that they could not be brought into operation until the flow was increased sixfold. When it was increased seven times six-sevenths of the sewage was still going on to Barking, and one-seventh escaped at the overflow. He knew from details he had obtained in connection with the overflow that it was in operation for less than 1 per cent. of the total time, and he believed that about 99·8 per cent. of the sewage arriving at Old Ford was conveyed to Barking. With regard to the meagre tank-capacity, he confessed that at one time he had thought that the bad effluent at Barking was due to that cause. He thought that when the works at Crossness were brought into operation better results would be obtained. At Barking the tank-capacity was 16 per cent., but at Crossness 39 per cent. of the average flow of 1895, approaching in fact the tank-capacity provided in provincial towns. It was stated by Mr. Dibdin that the chemicals were applied in a better way, and Mr. Crimp.

Mr. Crimp. that was correct; but the average amount of suspended matter in the effluent at Barking for 3 years was $7\frac{1}{4}$ grains, and at Crossness $5\frac{2}{3}$ grains per gallon, and he confessed he was disappointed with the result. Mr. Strachan had asked why he had recommended sewage-farms, seeing he had had experience of filters. He had begun to make artificial filters when he was in Mr. Baldwin Latham's service in 1878, and since that time he had made upwards of 50,000 square yards of artificial filters for sewage.[1] He had not only made filters, but during the 8 years that he had been at Wimbledon, from 1882 to 1890, he had—what was more important—practical experience of their working, and working side by side with the filters was the well-known sewage-farm. It was because he had had that experience that he now recommended the sewage-farms referred to by Mr. Strachan, and had recommended upwards of thirty in addition. He did not wish, however, to say a word against filters. He had only just completed a small installation, and they were doing their work satisfactorily. He believed that both sewage-farms and filters had their own peculiar field. As to the details of the storms referred to as yielding $\frac{2}{5}$ inch of rain per hour to the sewers, on the 10th August, 0·54 inch fell in 16 minutes, and 0·60 in 34 minutes. In the first storm of the 6th September, 0·38 inch fell in 9 minutes, and in the second 0·49 in 18 minutes, and 0·56 in 26 minutes. With regard to the effect of deferred flow, there were self-recording gauges at Old Ford, and he found from one observation that he had made of a typical storm that when $\frac{9}{10}$ inch fell in less than 2 hours, the whole of the water had not run off at the end of 21 hours, when another storm occurred. The second storm ranged from 0·18 to 0·25 inch in depth, and of that only 42 per cent. had passed off at the end of 9 hours. Of that 42 per cent. 6 per cent. ran off during the 1st hour, 33 per cent. in the 2nd, 20 per cent. in the 3rd, 15 per cent. in the 4th, 11 per cent. in the 5th, tailing off to 1 per cent. in the last hour. As to the effect of length of time, he had spoken from experience, and he found that in passing the sewage quickly through artificial filters practically no purification was effected, but by passing the same sewage slowly it could be purified to practically any extent. The time the sewage must be left in the tank to allow perfect settlement to take place, depended on the amount of the chemicals used. Some suggestive information had been given in the Paper as to the effect of very light doses

[1] Minutes of Proceedings Inst. C.E., vol. lxxvi. p. 317.

at the outfalls in London. He agreed that the effect of chemicals was simply to clarify the sewage. A considerable volume of sewage at Wimbledon had been dealt with by upward filtration, constantly and not experimentally, since 1876, and he was therefore familiar with the subject. Although the capacity of the filter-tanks referred to was only one-third of the dry-weather flow—less relatively than at Crossness—the suspended matter in the effluent was really less; and there was a substantial reduction in the dissolved impurities, the process being, in fact, as effective, if not more so, than the examples before the meeting. As stated by Mr. Taylor, his firm were constructing many of these tank-filters in England. He believed the proportion of tank capacity in operation at the same time at Barking and Crossness was about five-sixths; and the proportion of sewage discharged at the outfalls now approached 97 per cent. Considering the meagre details which the engineers who designed the scheme had to work upon, they were remarkably near in their calculation. He would say, in conclusion, that knowing the main-drainage system as he did, he thought that the younger engineers who were fortunate enough to be associated with it had an extremely good field for adding to their experience; whether regarded from a constructional point of view, or from the point of view of design, he believed it reflected the highest credit on the three eminent engineers responsible for it, and formed an enduring monument to their great abilities and scientific attainments. Mr. Crimp.

Mr. W. J. Dibdin, in reply, thought the original intention in treating the sewage at the Northern and Southern outfalls, by the plan he had submitted to the Royal Commission in 1884, and clearly set out on p. 80, was not remembered by many of the speakers. The absence of any material degree of purification of the matters in solution was there explained. Certain points in regard to the Barking results especially had been criticized by Mr. Strachan, but his Paper distinctly stated that it was contemplated, after considerable discussion, to spend £60,000 on a new liming-station. On pp. 86 and 87, the comparison between the estimated and actual cost was shown, and following the table on p. 87 the comparisons of various competing schemes, which were strongly supported by Sir R. Rawlinson, Sir Henry Roscoe and others, showed that these purification works had been accomplished for an expenditure of £1,000,000 as against various proposals of between £4,000,000 and £12,000,000. With regard to Colonel Jones's observations, efficient filters, suitable for all requirements, had, at his suggestion, been constructed at Mr. Dibdin.

Mr. Dibdin. Sutton at an expense of only £1,000 per acre. Misapprehension appeared to prevail upon the question of filter construction; he had even heard it stated that a filter would do much more if it was only "properly constructed." The construction of the retaining walls would have no effect upon the amount of work accomplished by the bacteria residing in the bed, and granite walls and marble columns would make no difference. He had recently conducted experiments at the Sutton Works in continuation of those at Barking and Sutton on sewage effluent, the results of which were embodied in his Paper. In October, 1896, a filter had, at his suggestion, been built at Sutton of burnt ballast, and the crude sewage had been turned on, to ascertain how far it was possible to induce the bacteria to dispose of the solid matters or sludge. The system had been working most efficiently for the past 4 months, and he was working out improvements on the method. He was convinced the biological treatment of sewage, without the aid of chemicals, precipitation tanks, sludge presses, etc., was an accomplished fact, and he hoped soon to be in a position to invite those members who were interested, to inspect the system, which would be so designed as to practically obviate all but the minimum of working expenses. He had used iron and lime in the manner suggested for sewage treatment 20 years ago, before he had the pleasure of knowing of Professor Robinson's work in this direction. The effluents were regarded with suspicion by Mr. Angel because the matters in solution were not attacked, but earlier in his remarks Mr. Angel had said he did not know why Mr. Dibdin should go further than merely to remove the sludge. As to the presence of nitrates, he was astonished Mr. Angel should challenge the results of hundreds of analyses by that of one sample which, he was informed, had been taken just before the filter was shut off for rest, it having shown signs of over-work. Under these circumstances he should have been astonished if nitrates had been found. Unquestionably there was another force at work besides the biological one. The action, commonly called catalytic, or contact action, was well instanced in the case of solutions of alkaloids which might be removed by a suitable filter until the filter was saturated; when, on passing pure water through the filter, portions of the alkaloids would be washed out. This showed the power of a filter to remove organic matter in solution without the aid of bacteria; but when once the filter was charged with organic matter, under suitable conditions the action of the organisms would come into play and destroy that organic matter, and so act as a constant purifier. With regard to the erection of certain weir-walls at Barking, by which the output of sludge had been increased, the loss of sludge had been ascertained to be in consequence of the rate at which the effluent poured down the telescope weirs, setting up such a rapid action that it washed the sludge away. The analyses of the sewage showed approximately how much sludge should be obtained, and when this was not realized it was evident that a large quantity was escaping, although samples of the effluent taken from the tanks, when in a quiescent condition, before the opening of the telescope weirs showed a most satisfactory effluent. It was, therefore, clear that the sludge was first of all taken out of the sewage by the process, and it became perfectly clear that the whole of the sludge was not collected. When this position was clearly established to the satisfaction of the Committee, the proposals to build such weir-walls immediately received attention, and the weirs were ultimately built, with the result that since they came into action the quantity of sludge had increased to the amount previously estimated. The original telescopic weirs were of insufficient emptying capacity, and caused a rush of water to a small opening, stirring the sludge and carrying it away. The filter had been admirably built under the direction of Mr. Crimp, but he did not think the success of the biological treatment of sewage was due to the builder of the filter. After the suggestions made some years ago by Dr. Dupré and himself, nothing was heard of this method of treating sewage until the State Board of Health of Massachusetts carried out their well-known experiments, which he had further continued on a working scale, with the result that the question was now practically solved in regard to the treatment not only of effluent, but of crude sewage. In bringing about these results, he had had to depend entirely upon his staff of chemical assistants. He thought the main point at issue was—had the river been purified? If so, the more meagre their works the more economically it had been effected. The explanation of the difference of the dissolved matters in the sewage at Barking and Crossness was that the use of crude sewage and sludge liquor for making lime-water in one case and that of the use of river-water in another would increase the amount of dissolved matters. There was no doubt that objectionable effluents had been discharged from Barking. But it was to be hoped this would, in the near future, be entirely obviated, whether by the erection of a new liming-station or by what, he thought, under the conditions of present knowledge would be far more efficacious— Mr. Dibdin.

Mr. Dibdin. increased facilities for filtering the effluent or, better still, the crude sewage. It had never been proposed to entirely clean the sewage; if so, what degree would be admitted as sufficient? The effluent was clean enough to prevent nuisance when discharged into the river, and the purifying capacity of the river was quite equal to the present circumstances. It was no more than was intended. With regard to the modification made by Sir Henry Roscoe and Mr. Lunt in the Schutzenberger process, for estimating the quantity of oxygen dissolved in the water, in the Author's hands sufficiently good results were obtained to indicate those differences which practically were effective. Isolated tests under exceptional circumstances might give misleading results; but when the process was used carefully and an average of the tests taken, it could be relied upon to give very close approximations to the truth. He had, however, always relied, in his estimations of dissolved oxygen in water, upon the absolute or gasometric method. The dissolved oxygen was boiled out of the water in vacuo, collected over mercury, and the quantity present ascertained either by explosion with hydrogen or by absorption with pyrogallic acid, both methods being employed from time to time. This process was in use in his laboratory at the time Sir Henry Roscoe and Mr. Lunt were making their experiments with the Schutzenberger apparatus, and their Paper [1] upon the question had been without effect upon the results obtained before or since, as even they had to employ the gasometric method in order to standardize their new modification. The low-water value was the more indicative of the effect of the sewage in the river, and showed that in 1887 the suspended matters were 8·9 as against 5·5 in 1895. The quantity of oxygen absorbed from permanganate was regarded by Mr. Lunt as a fair measure of the quantity of organic matter. How much of that oxygen had been absorbed by the living organisms in the water? If the organisms were first killed by the process and then oxidized, the quantity of oxygen absorbed could not be taken as the measure of the dissolved impurity or actual putrifying matter in the river. He could not see why Mr. Lunt took the values in 1885, when manganate of soda was used, instead of 1887, when Sir Henry Roscoe was using chloride of lime, and when the figure was 0·377 instead of 0·231. In dealing with the free ammonia, Mr. Lunt omitted to say that in 1886 the river was kept in good condition for half the cost of the present system, there

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[1] Journal of the Chemical Society, vol. lv. p. 552.

being no cost for works, ships, &c. In 1886, with an expenditure of only £81,000 for chemicals, and no expense for works, the free ammonia was maintained at a quantity less than in any subsequent year except 1895, when the expense, including repayment of capital, was exactly double that in 1886. In 1887, the chloride of lime year, the ammonia (Table III, Appendix II) was 0·258 against 0·093 in the permanganate year, and 0·058 in 1895, the year in which the whole of the sewage was precipitated, and after the river had had several years in order to recuperate from its previous bad condition. With reference to the cost of the treatment and the satisfactory condition of the river in 1886, an expenditure of £81,000, with no outlay on works, sludge-ships, &c., to keep the river in a satisfactory condition, could not be called extravagant by advocates of an expense of £12,000,000, the interest on which alone would be four times the expense for chemicals used in that year. He had throughout fully appreciated the influence of rainfall. The Table on p. 91 showed that the annual rainfall for 1895 was the lowest on record for the previous period of ten years, being 18·83 against 19·8 for 1887. As for the summer rainfall, between 1886 and 1887, the permanganate year and bleach year respectively, there was practically no difference, being 4·05 in 1886 against 3·79 in 1887. He thought the figures in Table III spoke for themselves and required no further explanation. With reference to Mr. Roechling's remarks, he had pointed out that the increase of solids was due to the river-water at Crossness and the sludge liquor at Barking. The dissolved solids in the river-water at high tide and especially in the dry season was very much higher than that in the sewage. He thought Mr. Roechling confused the suspended solids in the river with the effect of the effluent. In order to increase the quantity of suspended matter in the river-water to the extent of only 1 grain per gallon, the effluent discharged from Barking and Crossness would have to contain as much as 200 grains per gallon, therefore slight differences in the quantity of suspended matter such as those shown in the Tables are not due to the few grains in the effluent. He had shown that the suspended matters in the river afforded but slight indication of the effect of the effluent upon the river. With reference to the question of dissolved oxygen, Mr. Roechling pointed out that in future it was not impossible that the stomach of the Thames would not be large enough to swallow and digest the impurities poured into it. This was the crux of the whole question, and the way to test this was to watch the aeration. If this was well maintained there need be no fear; but when it fell below a Mr. Dibdin.

Mr. Dibdin. certain point an objectionable condition might be apprehended. When London was double its present size, and manufactures and shipping increased, possibly the conditions might be different, and it was always well to have additional safeguards. He hoped, however, to see the whole of the sewage of London treated in the near future by the biological process, when the Thames would be able to employ itself entirely in dealing with the refuse turned into the river in so many points other than those at Barking and Crossness. He did not fear the process of forcing the hand of Nature, as Mr. Roechling termed it, in connection with the biological treatment, any more than he was afraid to endeavour to make his garden yield a plentiful crop of vegetables instead of letting it lay waste and be covered with weeds. A properly adjusted and worked biological filter was more robust than any system of sewage farming. While tens and hundreds of thousands of pounds are being spent throughout the country upon the installation and up-keep of farms, precipitation processes and schemes of various kinds—and their cost was a most grievous burden upon the ratepayer—the properly adjusted biological process, even if burdened with the expense of a few analyses, would come to the relief of the ratepayer, and would effect a settlement of the whole of this question of sewage treatment. In his Paper of 1887 he had specifically pointed out the utility of using lime in solution in the form of lime-water. Until his specification for lime to be used at Barking and Crossness was drawn up by himself some years back, so far as he was aware, no similar specification existed. It was not until he had an opportunity in connection with other work to point out to a large gas company the absurdity of their methods of buying lime, and to suggest to them that they should adopt the system which he employed, viz., to buy lime on specification, that it came into general use. He agreed it was unfortunate that in the experiments on coke-breeze filters at Barking there was not some record of what the filter would do with raw sewage. At the time that he suggested the experiments he had referred to at Sutton, he suggested the same thing to the London County Council, but so far as he was aware, up to the present moment, no stone had been turned towards a trial of the experiments; so that, while London had been sleeping, they had been working at Sutton with the most satisfactory results. He did not agree that the best possible way of dealing with sewage had not, and probably for many years would not be arrived at. His biological investigations had shown that the problem was very nearly, if not entirely settled. Water-

Mr. Dibdin.

works filters would not be used for this scheme; and if, in the course of years, they became clogged with inorganic matter (the Barking system had been working five years) the cost of re-sifting, or even of renewing the filtering material would be but a trifling item in comparison with the present system. If Mr. Baldwin Latham had been using biological filters in 1883, it was curious he was silent when, in his 1887 Paper, the biological question was pointed out and well discussed. He greatly regretted that he did not have the opportunity of meeting Mr. Baldwin Latham when he had taken a sample from experimental works under his direction. He agreed that the improvement of the Thames was largely due to the cessation of considerable sources of pollution higher up the Thames, and he felt satisfied that the evidence he had placed before the Royal Commission on Water Supply in 1892 had contributed largely to the improvements which had been made. By the direction of the Main Drainage Committee of the London County Council he had for some time an inspector under his charge, collecting samples from various factories and works on the Thames and Lea, which were carefully analysed and the results submitted in a printed report by that Committee to the Lea and the Thames Conservancy respectively. He agreed as to the definition raised by Dr. Rideal of "filter," or "bacteria bed;" he had endeavoured for some time past to get rid of the word "filter." It was applied to the process largely in consequence of the use of that expression by the Massachusetts authorities. In Sutton he spoke, for distinction, of one method as a "bacteria tank" and the other as a "coke-breeze filter," but a convenient expression to define the method, and yet not leave upon the mind an impression that it was a process of ordinary filtration, was still wanted. A word had been suggested by Dr. Rideal, but he ventured to think "carbonification" was too long and would be equally misleading. He thought Mr. Thudichum's experience in the question unique, in that he resided on the works from the time of their first being opened for some years; and in connection with the work personally measured the capacities of the various tanks. The results agreed with those of very careful observations made by himself in conjunction with his former colleague, Sir Joseph Bazalgette, and others. He regarded his estimate in 1883 of the quantity of suspended matters in the London sewage being under 30 grains per gallon as a remarkably close approximation to the truth, while those of Mr. Baldwin Latham and Dr. Tidy, of from 50 grains to 60 grains per gallon, and that of Dr. Frankland, of 110 grains per gallon, were baseless and extravagant. In conclusion he desired to thank the

Mr. Dibdin. Institution for the opportunity for discussion of the Paper which he had had the honour to place before it, and which recorded the fact that, with the co-operation of Sir Joseph Bazalgette and Mr. Binnie and their respective staffs, he had been able to bring to a satisfactory conclusion a task which, ten years ago, had been declared impossible.

Correspondence.

Mr. Fairley. Mr. WILLIAM FAIRLEY thought the Tables appended to Mr. Dibdin's Paper showed very clearly the comparative purity of the River Thames before it entered the metropolitan area, and testified to the efficient manner in which the removal of pollution from the river had been accomplished by the sanitary authorities having districts adjacent to the river, under the superintendence of the Thames Conservancy. It would appear that it was only after the river had entered into the area under the London County Council that serious pollution occurred. By Table IV, Appendix III, the organic matter in suspension, in March 1894, was 0·41 per cent. at Hammersmith Bridge, rising gradually to 2·05 per cent. at Barking; while dissolved oxygen by Table III was 91·1 per cent., and 48·5 per cent. at the same places. The removal of the suspended matter from the sewage at the Outfall Works at Barking and Crossness had undoubtedly greatly assisted in removing pollution from the lower river, and there could be no doubt that within the past few years there had been a very great improvement in its sanitary condition at all states of the tide. The effluent water discharged at Barking and Crossness, judging from the analyses given in Table I, was still sewage in the ordinary sense of the word, and would undoubtedly create a serious nuisance if discharged into a river much smaller in volume than the Thames at Barking or Crossness. The analyses showed no reduction of the organic matter in solution. This might be expected when the very small amount of chemicals added to the sewage was taken into consideration, together with the fact that the tank accommodation provided was much too small, being approximately 50 million gallons of storage to 200 million gallons of flow, or approximately 25 per cent. He understood Mr. Dibdin considered that the chemicals were only necessary to assist in the clarification of the sewage, and that no reduction of the organic matter could result from their use. This was not in keeping with experience gained in many parts of the country, Mr. Fairley.

where in numerous works by the judicious addition of chemicals, the organic matter in solution could be reduced to give purification of between 20 per cent. to 50 per cent. He had no hesitation in affirming that by doubling the present tank capacity at the outfalls, providing efficient appliances for screening and straining the sewage, and means for aeration, an effluent could be discharged into the river practically equal to that at present flowing in, without the addition of any chemicals. If an effluent were desired such as was usually required to be discharged elsewhere from tanks, by addition of chemicals in sufficient quantity, together with increased tank room, an effluent could be discharged 20 to 30 per cent. better than the present one. Judging from the last paragraph in his Paper, Mr. Dibdin appeared to think that the work of purifying the Thames, so far as London was concerned, was accomplished. He did not think this was borne out by the figures given in his Tables; much yet required to be done, although comparatively speaking, judging from what the river was in former years, the work carried out had made an immense improvement in it. With respect to the filters, coke had been much in use 15 or 20 years ago for filtration purposes in sewage-disposal works, and at the first purification works erected in the Thames Valley, namely, the works at Twickenham, the process there adopted was to properly screen the sewage, deliver it into the tanks so that the suspended matter might be deposited, and run the effluent on to filters composed of coke and gravel. These works had been in use up to the present day he believed satisfactorily; but for some time past chemicals had been added to the sewage before it entered the tanks. In this case there was a material difference in the method of working the filters. Mr. Dibdin's filter-bed was filled with effluent, and then the whole of the filtrate was discharged, in such a manner as to draw in and fill the whole of the spaces and interstices of the filter with air before admitting another charge. At Twickenham, instead of emptying the filter at every charge, the effluent was spread out in thin layers over a considerable surface, so that aeration was efficiently carried out, and the effluent carried into the filter with it a considerable quantity of oxygen absorbed from the atmosphere. For the past 6 years he had worked filter-beds composed of sand and gravel with a covering of fine sandy loam at the works of the Richmond Main Sewerage Board at Mortlake. These filters had been in almost constant use for the past few years and had had no renewals. They had for lengthened periods passed and efficiently purified effluent water at a rate often exceeding 250 gallons per yard per day, and in no

Mr. Fairley. case had analysis shown the filtrate to contain more than 0·1 part per 100,000 of albuminoid ammonia, or to require more than 0·4 to 0·8 of oxygen by the 4 hours permanganate test. In this case, however, every endeavour was made to do as much work as possible in the precipitation tanks and to reduce the organic matter by chemicals and aeration, so as to relieve the beds as much as possible. In a test made by Dr. Carter Bell of the water as it left the tanks, and before it had been filtered, the albuminoid ammonia in the sewage was 0·56, while in the effluent from the tanks it was 0·2, showing a percentage of purification of 64. This no doubt was exceptionally high, and much above what was done in daily ordinary work.

Mr. Hodgson. Mr. JOHN S. HODGSON remarked that a profitable field of investigation was opened by Messrs. Worth and Crimp's reference to the discharge of $\frac{2}{5}$-inch of rainfall per hour through a sewer draining a London area of 160 acres. The question arose, how far did this record agree with the results derivable from the Bürkli-Ziegler and other "retardation" formulas? The ultimate volume of rainfall was acquiring a new importance in the United States, after having been largely relegated to the background by the general adoption of the rigid separate system, in which not even roof- or yard-water was admitted to the sewers. These conditions could not be realized to any practical extent in England, perhaps least of all in London, and even in America their effect was being felt in the increasing necessity for specially designed rainfall conduits. The Bürkli-Ziegler formula, and some modifications of it, were widely used in this connection. If the London resultant of $\frac{2}{5}$ inch per hour carried off by the sewer be quoted as an instance of a high yield, it must still be regarded as low when compared with commonly adopted bases in Massachusetts, where moderate rainfall conditions prevailed in comparison with more westerly sections. Assuming a surface slope of 1 in 100, the London result was equivalent to an actual rainfall of 1·05 inch per hour, or, with a slope of 1 in 50, of less than 0·9 inch per hour, adopting in each case a "porosity" coefficient of 0·60. This was almost certainly too low a coefficient for any representative London area, and yet, if a higher figure be taken, the rate of actual rainfall would work out to a still smaller depth than either of those given. If, for instance, the late Colonel Haywood's[1] observations on the Irongate sewer in June, 1858, when 94·5 per cent. of a rain-storm was discharged the sewer, were accepted, it would be seen that the actual rainfall

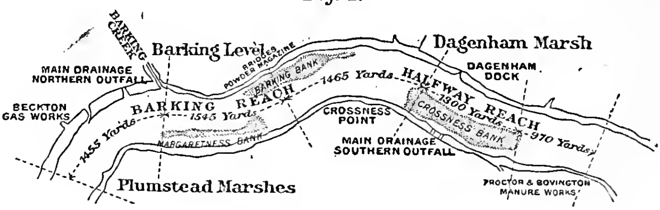
[1] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 323.

in Messrs. Worth and Crimp's recorded instance was the merest fraction over $\frac{3}{8}$ inch per hour, an amount hardly worth the prominence accorded it in the Paper, unless as a renewed demonstration of the inadequacy of the "$\frac{1}{4}$-inch per twenty-four hours" adopted by Messrs. Hawksley, Bidder, and Bazalgette. On the other hand, if the rainfall were really at a considerably higher rate, the interest centred in the proper coefficient with which to connect the two ends of this practical experiment. Mr. Hodgson.

Mr. JAMES MANSERGH, Vice-President, had in concert with Mr. Baldwin Latham and the late Mr. Peregrine Birch, been engaged with a large staff for many weeks in investigations on behalf of the Port Sanitary Authority, otherwise the Corporation of London, preparatory to the sittings of the late Lord Bramwell's Commission in 1883 on Metropolitan Sewage Discharge. He had also been engaged in 1879 with his colleague on the council, Mr. Shelford, the late Mr. Abernethy, and others on behalf of the Thames Conservancy, in the arbitration between that body and the then Metropolitan Board of Works as to the formation of banks in the river near the Barking and Crossness outfalls alleged to be due to the discharge of the sewage. In connection with these two inquiries he had had many opportunities of observing the condition of the river between Greenwich and Erith, and could bear testimony to the very great improvement which had resulted in the condition of the shores between high and low water since the works for treating the sewage at the two outfalls had been in operation. Before Lord Bramwell's Commission he had expressed the opinion that, by means of a simple method of chemical precipitation, an effluent could be produced which might be allowed to pass into the Thames at any state of the tide. Although he had always been a strong advocate of broad irrigation under favourable conditions, he never favoured the idea in the case of London. As the question of the "mud-banks" in 1880 had been discussed privately before Sir Charles Hartley, umpire, and Sir Frederick Bramwell and Sir Douglas Galton, arbitrators, the points in dispute were little known. Soon after the two outfalls had come into operation it had been noticed by the Conservancy officers and people navigating the river that banks were growing up below low water, where formerly none had existed, and that this was notably the case in front of the Crossness outfall, *Fig. 4*. At the time of the inquiry this bank was said to be 1,500 yards long, 400 yards broad, and to average 9 feet or 10 feet in thickness. Two others had also formed, one near the right bank of the river a little lower than opposite to the Barking outfall, and a third near the left bank Mr. Mansergh.

Mr. Mansergh. about a mile below that outfall. The three banks were shown in *Fig. 4.* Under the 20th and 21st sections of the Thames Navigation Act of 1870 the Metropolitan Board could be called upon to remove these banks if it could be proved that they were due to the discharge of the sewage, and if they were an obstruction to navigation. The arbitrators were appointed to adjudicate on these two points and report to the Board of Trade. He hoped he would be excused mentioning a personal episode which took place at the first consultation when the late Captain Burstal, then the energetic and highly esteemed Secretary of the Conservators, was explaining the case to the witnesses by means of a plan of the river on which the three banks were indicated. In giving the history he said that, just about the time the discharge of sewage was commenced at Crossness in 1865, the Conservators, with the view of improving the navigation, had started to dredge away certain spits and banks of hard gravel

Fig. 4.



Scale, 1 inch = 6,000 feet.

on the left bank of the river in Halfway Reach known as the Dagenham shoals, and that, when the crust had been broken with the powerful dredger, the ballast-dredgers had in a few years cleared away the whole of the rest. Upon hearing this Mr. Mansergh had ventured the obvious remark that the growth of the bank on the south side of the river might be due to the removal of that on the north. At this suggestion the Captain became very irate, and asked if the improvements effected by his Board were to be nullified by the doings of the people at Spring Gardens. He immediately set to work to examine the Conservators' complete surveys of the river, and as the result a series of cross-sections were plotted for 6 miles above and 6 miles below the middle of Halfway Reach, showing the Dagenham shoals on the north side removed but the bed of the river as it existed before the mud bank was formed on the south. The areas of these sections below low water were then plotted as vertical heights on

Mr. Mansergh.

a longitudinal section over the 12 miles, and by joining these heights it was at once evident that a bulb or aneurism had been formed by the Dagenham dredging; in other words, that the river had been made too big for its work, and that Nature was setting things right again by forming the bank on the south side. This was, in fact, the case which the Metropolitan Board made; they could not deny that the bank was constituted partly of the solids from the sewage, but they contended that the bank would equally have formed if the Crossness outfall had not existed. The Conservators did not succeed in proving the Metropolitan Board liable. He had inquired of Mr. More, the engineer to the Conservancy Board, if he had noticed any alteration or diminution in the size of the three banks in question (especially that at Crossness) since the sewage sludge had been taken away to sea, and he had been good enough to allow Mr. Mansergh to examine the survey of 1895. He believed that no appreciable change had occurred, and if the finding of the court was right, no such change was to be expected except in the material constituting the bank. Formerly, and especially after a spell of dry calm weather, there must have been deposited on the banks a capping of the sewage solids, which would be scoured off in times of flood to be replaced by any ordinary mineral matter suspended in the water. Thus, in time, these banks would become cleaner and cleaner, and there will be no floating up of black patches of filth in hot dry seasons as used to be the case. He congratulated all who had been concerned in the works of treatment which had resulted in so great an improvement in the river, without attempting to apportion the credit to particular individuals. It had never appeared to him difficult, excepting for its magnitude; and so far as his reading of the history of Sir Joseph Bazalgette's scheme was to be trusted, he believed it was proposed from the first to keep the solids out of the river. He thought the chemists engaged had acted with sound judgment in not attempting to do more than remove the solids. Under the circumstances there was no necessity to do more, for the river was quite competent to deal with the dissolved impurities. He thought, however, that the removal of solids should be carried somewhat further than it was, and he believed that an increase of tank capacity, admitting of a slower rate of traverse through them, would materially assist in this respect. He would not add anything about the so-called "biological filter." Engineers had manifestly been making and using biological filters for years without knowing it, and whether Mr. Baldwin Latham's Friern Barnet filter, or Mr. Santo Crimp's Barking filter, or Mr.

Mr. Mansergh. Dibdin's "coming" Sutton filter was to bear the palm in the future would be a matter of discussion for some time to come. He would have liked to hear something more about the £60,000,000 by which Mr. Dibdin's "latest" was going to benefit the country. Remarks had been made by engineers and others as to the frequency of storm-overflow from the London system, and it was gratifying to learn, on Mr. Crimp's authority, that, owing to alterations in the sewers of the Isle of Dogs, additions to the mains and improvements in the pumping machinery, 97 per cent. of all the liquid which flowed into the sewers was delivered at the outfall works for treatment and only 3 per cent. overflowed into the river. This was a great thing to be able to say of works which had been designed forty years ago, and amply justified the soundness of the principles upon which the designs were based. It was hardly necessary to say that works of this character could not be built for more than 30 or 40 years in advance on a rapidly-growing community because the cost would be unduly burdensome at the outset, and second because they would be too large to be efficient for the population of to-day. It was inevitable that in the immediate future very large and costly duplications of the main intercepting sewers must be made. One had only to observe how many thousands of acres of what in 1857 were open fields, contributing practically nothing to the sewers, had since been covered with roads, roofs, and other impervious surfaces, to realise at once that these sewers must now be overtaxed, and no blame whatever was to be attached to Sir Joseph Bazalgette that this time had arrived.[1] He was sure Mr. Binnie was quite alive to the fact, and the sooner the County Council set about the work the less likely were they to get into trouble on account of floodings. It was clear, too, that mere extension of storm-overflow works would not meet the difficulty—

[1] The conditions of the Melbourne Metropolitan District, for which he had designed a scheme of sewerage some years ago, did not differ greatly from those of London. The County of London had an area of 119 square miles, the Melbourne district 133 square miles. The population for which the London sewers were designed was 3,500,000, the water-supply being then reckoned at probably not more than 30 gallons per head, producing, say, 105 million gallons of sewage proper per day. For the Melbourne district the estimate of population to be served was 1,700,000, with a water-supply of 75 gallons per head per day, producing 127½ million gallons of sewage per day. In Melbourne the mean annual rainfall was somewhat less than in London, and the heavy falls in short periods were by no means so great; the open spaces were also more extensive in relation to the great area. Taking all these things into consideration the allowance he made for rainfall was not quite half that provided for London.

they must be works of interception. Even 3 per cent. of the London sewage meant that of a population of nearly 150,000 people, and this must go on increasing year by year. In conclusion he would like to say that the engineers in charge of works like those described in the first Paper had grand opportunities of getting together information of the most valuable character, and it was to be hoped that the County Council would not begrudge the cost of providing such instruments as self-recording rain-gauges, and instruments for measuring heavy falls in short periods, storm-discharge, etc., and that some of the staff would interest themselves in using such instruments to the best advantage. During the time that Mr. Santo Crimp was in charge of the north side he did good work of this character, and he trusted his successors would be equally zealous, and would have greater opportunities afforded to them. Mr. Mansergh.

Mr. J. C. Melliss had visited the outfalls at Barking and Crossness some 12 or 13 years ago, and nothing could at that time have been more unsatisfactory than the manner in which the crude sewage was discharged into the River Thames. A few weeks ago, in February, 1897, he had again visited the outfall at Barking, and found matters entirely changed. So far as the river was concerned, there seemed nothing to complain of so long as the chemical treatment was continued. It would be better if the tanks had not been covered in, and some of the buildings which were of a temporary character needed reconstruction. He had, with Professor Robinson, successfully applied the salts of iron to the treatment of sewage, and in evidence before the Royal Commission in 1884 on Metropolitan Sewage Discharge, he had recommended the treatment which was now employed at Barking and Crossness. He was not satisfied that the conveyance of the sludge out to sea would ultimately be found the best method of disposing of it. For the present it was convenient to do so, but there were thousands of acres of land, in the neighbourhood of the works, the level of which was some 6 to 7 feet below high water, and this land might be built up with the solid matter, and so reclaimed and made more valuable than at present, to say nothing of the manurial value of the sludge which theoretically was considerable notwithstanding differences of opinion as to its practical value. He thought the quantity of surface water which escaped by the storm-overflows direct to the river without treatment should have been recorded in Messrs. Worth and Crimp's Paper, because one of the most troublesome problems in designing sewers was the extent to which such water should be admitted or excluded. Mr. Melliss.

Mr. Melliss. The capacity of the precipitation tanks might be less than would be required at other places, but as the Paper referred to the sewage of London it did not follow that their capacity was too small for dealing with the London sewage. The capacity of tanks depended on local circumstances, and the degree of purification necessary, and the same degree of purity was not required in an effluent water discharged at Barking or Crossness, as would be required at some inland town discharging into a brook or small river. The filtration of a small portion of the effluent water after precipitation at Barking was a matter of great interest, though it was not essential to the treatment of the London sewage.

Sir Henry Roscoe. Sir HENRY ROSCOE observed that it was stated in Mr. Dibdin's Paper that "at Crossness, in consequence of the better solution of the lime water, there was a material reduction of the matters held in solution, and that at Barking the results are not yet so good, but this will doubtless be remedied as soon as the new liming station is erected." From Table I, Appendix I, it appeared that at Crossness the matters held in solution in the effluent were invariably increased, the average total dissolved solids being 99·2 grains as against 90·8 grains in the average sewage, an increase of $9\frac{1}{4}$ per cent., whereas at Barking the average total dissolved solids were 63·2 grains as against 60·2 grains in the average sewage, an increase of only 5 per cent. If, however, the amount of oxidizable organic matter as measured by the oxygen absorbed and the albuminoid ammonia were considered, it would appear that at Crossness there was some reduction, the oxygen absorbed being reduced from 3·709 grains in the average sewage to 3·115 grains in the average effluent, a reduction of 16 per cent., and the albuminoid ammonia being reduced from 0·420 grain to 0·331 grain, a reduction of 21 per cent. The chlorine, however, in the Crossness effluent was increased $14\frac{1}{2}$ per cent. viz., from 24·8 grains in the average sewage to 28·4 grains in the average effluent, and as the river water was pumped for the purpose of preparing the lime-water for treating the sewage, it was more reasonable to attribute the increase of the chlorine, the increase of the total dissolved solids, and the reduction of oxidizable organic matter, to the addition of the river-water rather than to the use of soluble lime. The analytical results given in Table I further showed that whilst 76 per cent. to 80 per cent. of the total suspended matter was removed by the process of precipitation, yet the whole of the objectionable oxidizable organic matter in solution remained in the effluent. The suspended matters left in the effluent ranged between 6·2 grains and 7·1 grains per gallon, or, in every million gallons of effluent discharged 4 tons to 5 tons of sludge (90 per cent. water) escaped into the river. It was therefore difficult to reconcile the statement of Messrs. Worth and Crimp that "the sewage is transformed into a clear innocuous effluent flowing into the Thames" with the analytical data given in Mr. Dibdin's Paper. With regard to the effect of the sewage discharge on the river, the deductions drawn by Mr. Dibdin from a study of the chemical results of the analyses of River Thames water at Crossness were questionable, and it was doubtful whether the state of the river in 1886, when upwards of £80,000 was spent in chemicals, was perceptibly better than in 1887 when £42,000 was spent, or even better than that in 1885 when only £29,000 was spent in deodorants. The year 1886 was referred to by Mr. Dibdin as the "manganate year," and 1887 as the "chloride-of-lime year," and the result of the use of chloride of lime was stated to be "that the condition of the river in that year was notoriously bad," the analytical figures from Table III "summer averages" being quoted in support. If, however, the actual facts of the case were looked into it was found that the river was in an extremely foul state prior to the use of chloride of lime. Comparing the river-water analyses for the month of June, 1887, when no chloride of lime was used, with the analyses for June, 1886, when manganate was freely used from May to October, and taking into consideration the fact that chloride of lime was only used from 2nd July to 26th August, 1887, it was by no means clear that the use of chloride of lime was the cause of the notoriously bad condition of the river. The results of river-water analyses were subject to the influences of changes brought about by undetermined and perhaps undeterminable causes, especially by droughts, a matter apparently not considered by Mr. Dibdin; and, as he had pointed out in his report on this subject to the Metropolitan Board of Works in 1888, either the effects of the chemicals were imperceptible or the methods of measuring those effects were imperfect. With regard to filtration, Mr. Dibdin compared the Massachusetts area of filtration required for raw sewage with Mr. Lowcock's area of filtration required for tank effluent, so that Mr. Lowcock not only had artificial aeration, but in addition a precipitated effluent to enable him to reduce the 16·6 acres to 3·8 acres per 1,000,000 gallons—a significant fact overlooked by Mr. Dibdin. With regard to the working of the 1-acre coke-breeze filter at the northern outfall, it was stated that during a period of 3¼ years the filter had passed 500 million gallons of effluent, and that "about 32 tons of nitrogen, existing either as ammonia

Sir Henry Roscoe.

Sir Henry Roscoe. or in combination with the organic matter, had been converted into nitric acid, equal in quantity to nearly 200 tons of nitrate of soda." It would be interesting if Mr. Dibdin would give the details of the calculation as to the production of 32 tons of nitrogen. Each gallon of the 500 million gallons of filtered effluent would have to contain 1 grain of nitrogen as nitrates to produce 32 tons. The average of the daily analyses showed that the nitrification effected by filtration did not approach that figure.

	Nitrogen as Nitrates.		
	Effluent.	Filtrate.	Difference due to Filtration.
	Grain per Gallon.	Grain per Gallon.	Grain per Gallon.
28 September to 23 December, 1893 . .	0·11	0·13	0·02
7 April to 9 June, 1894	0·128	0·238	0·11
3 August to 9 November, 1894	0·022	0·141	0·12
16 November to 2 March, 1895	0·396	0·670	0·27
8 April to 20 April, 1895	0·143	0·770	0·63

From Messrs. Worth and Crimp's Paper it appeared that the cost of filtering 325 million gallons of effluent in 1894 and 1895 amounted to £639, nearly £2 per million gallons. It would be of interest and value if the details of this cost could be given, as it seemed an expensive process compared with other filtration schemes in satisfactory operation elsewhere.

Mr. Sowerby. Mr. William Sowerby regarded the two Papers as most valuable records of one of the greatest works of modern times in London. It had been said that all engineering works were at the best only compromises, and this remark might be specially applicable to a great work like the drainage of London, surrounded as the project was with so many difficulties and varied peculiar circumstances, due to the contour, conformation and topography of the surface of the ground, the geological character of the locality and the surrounding district. A careful examination, however, and criticism of work when completed, though it could not be altered, might be most valuable as a future guide for the construction of similar works in other localities. It might be interesting to trace back and to record the various projects that had been brought forward to improve the drainage of the metropolis and rescue the Thames from pollution. The first agitation of the subject appeared to have begun in 1819. From that time various commissions had sat, in 1821, 1827, 1828, 1829, 1831 and 1834; and the late John Martin, the famous artist, had in 1836 formed a Committee comprising upwards of one hundred and fifty of the most eminent noblemen, statesmen and scientific men of the day, such as Duke of Rutland, Lord Euston, Daniel O'Connell, Sir E. Bulmer, Dr. Lardner, Sir C. Wheatstone, Michael Faraday, I. M. W. Turner, R.A., Charles Barry (father of the present President of the Institution), Archdeacon W. C. Mylne, Archbishop of Canterbury, the Lord Mayor, F. Giles, C.E., Joseph Buonaparte and Dr. Bowring. The result of this important Committee's labours appeared not to have passed beyond the mere discussion of the subject, till, in 1846, a company was formed to utilize the sewage of Counters Creek in the Fulham market gardens, and, as a shareholder in the company, he could speak of the results. During the first year the sewage was freely taken, the season being somewhat dry. The second year being more humid the demand fell off, and the third year, being a wet season, something like the recent rains, the sewage would not be taken at any price, and so the company was dissolved and the plant sold; but there was encouraging evidence that the sewage, though not very concentrated, was of some value for agricultural purposes; but now, nearly the whole of the Fulham garden lands being built over, it could not have been continued. The proposal of John Martin (and also of others) was to divide the metropolitan area into separate districts, according to position and the contour of the surface, and so deal with each district. To drain the mere surface rainfall from land was simple. The water found its way down various depressions and valleys to the river; but when the whole surface was built over and intersected by streets running in every possible irregular direction, and the removal of the rainfall had to be increased by the liquid and solid refuse from the houses and streets, including cess-pits, then the problem became an exceedingly difficult and complicated one; and if to this be added the idea of utilizing such refuse for agricultural purposes, then the subject became still more complicated. Where any city which had to be treated was situated in a favourable position, as to elevation and suitably low-lying lands, with proper soil for utilizing the sewage, as in Berlin and other similar places, then the matter was greatly facilitated and practicable; but in London, where the geological character of the soils were so varied, where the undulations of the ground Mr. Sowerby.

Mr. Sowerby. and levels were so different, and where the ownerships were so diversified, the question became almost impracticable. There were some localities around London, like the low-lying lands of Essex (where not already too humid), Bagshot Heath and probably several other places, where liquid manure might be utilized; but the idea of in any way utilizing the sewage of London for profitable agricultural purposes had been entirely ignored by the works which had been executed and had now been described. Perhaps the immense quantity of sewage to be dealt with and the limited area available for using it had weighed materially with those who had the preparation of the design. There were, between 1846 and 1856, a great number of schemes and projects proposed, and pamphlets written with the object of rescuing the Thames from pollution, draining the metropolis and of utilizing the sewage for agricultural purposes. The projects of John Martin included a dam at London Bridge and the delivery of the sewage below that point; it also included a grand river frontage, on the line since adopted, with convenient wharves, a railway (not underground), a promenade and a magnificent terrace and palatial buildings between Westminster and London Bridge. The scheme of the late John Murray, M. Inst. C.E., included a dam at Deptford and a broad tidal channel or water street from that point cutting across the horse-shoe bend in the Thames up to Wandsworth, thus turning the upper parts of the Thames into a half-tide basin, similar, in some respects, to his project on the River Wear at Sunderland. Among other ideas at this period was a curious one for desiccating the sewage and retaining the matters in suspension and solution for agricultural purposes. This seemed still to prevail to some extent, electricity being substituted for heat. He had, at the Royal Agricultural College at Cirencester, in 1852–53, in connection with the late Dr. Voelcker, investigated the value of sewage. There was a black ditch surcharged with sewage passing through that ancient city. Experiments led to the conclusion that the value of the residuum was about the same as ground granite or lime-stone and no more; when the water was removed, 95 per cent. of its value was lost. At Cirencester there were water meadows, evidently introduced by the Romans, like those at Taunton and Andover, which were old Roman cities. The system adopted in the London drainage was essentially a hydraulic one, no other being feasible; but such a system was not always practicable, as in India, where the habits of the people were so different, and

Mr. Sowerby.

the plague in Bombay was entirely due to the absence of a suitable system of sanitation, the condition of that city (to which he had called special attention in 1868 and again in 1878), and many more in India, being so abominable as to be quite indescribable; and there were many similar cities on the Continent of Europe in the same condition, more especially in Spain. While the system proposed by John Martin and some others was that of treating several districts more or less separately and independently, that which had been carried out had aimed at concentrating the outlet at two different points, on the north and south sides of the river. In doing this, one most important point appeared to have been forgotten, or possibly might not have been known, namely, that the offensiveness of an accumulation of filth, &c., increased as the square of the quantity; thus 100 tons was 10,000 times more offensive than 1 ton, hence it was better to deal with it in detail than in a concentrated form. There was another very important point which appears to have been almost, if not entirely, forgotten or overlooked, that was, the ventilation of the sewers; hence fatal effects of foul gases in sewers were constantly occurring. In 1849 he had prepared a plan for this special purpose, a copy of which was deposited in the library of the Institution. The plan not only provided an upcast shaft for the escape of foul gases, but also shafts with ear-shaped self-adjusting caps for catching fresh air and throwing it down into the sewers, similar to the windsails of a ship, for there should be free circulation of air in the sewers the same as in a ship or a mine. Of late years there had been shafts, nearly like lamp-posts, erected in some places for the escape of foul air from the sewers, but no means had been adopted for throwing fresh air downwards. As to the value of the sludge or powders obtainable from sewage, as had been said, it was of about the same value as ground granite or stone and no more, and if it could be utilized on some of the stiff clay lands of Essex it would be most useful in opening the pores of the soil. Like burnt lime, furnace slags, &c., most of the so-called manures simply acted in this way, and were not, as generally supposed, food for the growing plants. According to the statements in the Papers, the quantity of liquid sewage discharged in the dry weather was about 200,000,000 of gallons per day; that was nearly equal to 1,000,000 tons. This for 12 months would be equivalent to the total rainfall of something like 250 square miles, taking the rainfall at 25 inches annually; and this would be sufficient to form a lake over the whole of London about 4 feet in depth. In order to utilize this quantity of sewage it would require

Mr. Sowerby. a farm of nearly 150,000 acres, or about 15 miles square; and if the character of the soil and subsoil were considered, the undulations and varied levels of the surrounding country, together with the great diversity of ownerships, it would at once be recognised how great were the difficulties attendant upon a utilization of the liquid sewage of the Metropolis; but it would be premature to say that such a scheme was not feasible. The quantity of sludge deposited in the sea was said to be 2,169,000 tons per annum, or, say, 2,000,000 cubic yards. This would be quite sufficient to cover about $\frac{2}{3}$ square mile 1 yard deep, or in 1 century to form a bank of 64 square miles 1 yard deep. The capacity of the sea for absorbing so large an amount of solid matter was doubtless considerable; but whether this was the most suitable way of disposing of the solid refuse of London might be a question worth discussing, because such a large quantity of somewhat valuable material, if utilized on agricultural land, would doubtless have a most beneficial effect, even taken at its lowest estimated value. And when so much was heard about the waste of the old and valuable aids to agriculture, it was at least advisable that the subject should be impartially investigated. The idea at present was that the cost of utilizing such sewage would be more than it was worth. Was this so? Besides the main drains, there was much need for improved ventilation of the street drains, and especially of the house-pipes, which were being constantly choked up by the foulest matter from the houses. There was also much need for a more thorough system of flushing, more especially at such places as East Ham, for in warm dry weather the drains become most offensive.

Mr. Tait. Mr. W. A. Tait thought the present a convenient opportunity to elucidate one or two points in Sir Joseph Bazalgette's Paper,[1] to which the Author had referred. Some explanation was required as to how and when the 15-inch iron pipe shown on Plate 19 was inserted between the sump and the sewer. Again, near the foot of page 299, was it meant that the sewer trenches were excavated below foundation level in order that the stoneware pipes might be laid below the level of the permanent works? No doubt the stoneware drain once in would greatly help to dry the ground; but if laid, as it probably would be, with open joints, it might be a source of injury if sand happened to get into it as well as water.

Mr. Tapscott. Mr. R. Lethbridge Tapscott thought that, having regard to the

[1] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 280.

success already attained in treating the London sewage, it might be hoped that progress would be continued, and that the engineers and chemists would not rest satisfied until the whole of the moisture was separated from the sewage and discharged as a clarified effluent into the river, leaving the solid matter to be treated separately by some other process. When it was remembered that only about one-tenth of 2,169,000 tons of sludge taken to sea in 1895 was solid matter, averaging between 500 and 600 tons a day, it suggested the possibility of further mechanical, chemical, or bacteriological processes to still further improve the methods of disposal of the 75,000 million gallons of sewage reaching Barking and Crossness during the year. That additional works were constantly being constructed, as shown by the outlets up and down the river, for the discharge of storm-waters, and the increased pumping-power to keep the sewers free to receive storm-waters, led to the expectation that the disposal of the sludge would become simplified; and that possibly the success which had now been accomplished, in purifying the effluent by bacteria, might stimulate further attempts to treat the solid matter contained in the sludge by some method of cremation. Mr. Tapscott.

Messrs. Worth and Crimp said, in reply to the Correspondence, it would be observed from the Paper that, relatively to Barking, the tank capacity at Crossness was very large, but the results obtained did not show a corresponding superiority. The earlier filters had been used as strainers for the removal of the suspended matters remaining in the tank effluents; the Barking filter, on the other hand, removed a large percentage of organic matter in solution. The results obtained must in any case depend mainly upon the area of the filter relatively to the volume passing through it. With regard to the analysis by Dr. Carter Bell, it must be remembered that the amount of albuminoid ammonia remaining in an effluent was the main point to be considered. In reference to the rainfall, the flow referred to in the Paper was the maximum; that of the Irongate sewer was the percentage of the total fall of rain, and it was not certain that the recorded fall was of the same intensity over the whole of the area drained by the sewer. They agreed entirely with the views expressed by Mr. Mansergh as to the Barking filter. Engineers had been successfully employing filters for years past, having found by experience how best to work them, and how much work they would do. Then the chemists and biologists came upon the scene, and named the microbes, and excited much interest in the subject. But the fact remained that the filters would not do more work now Messrs. Worth and Crimp.

Messrs. Worth and Crimp. than they did before. There was a great difference between laboratory experiments, made with exactness, and the actual conditions obtaining at the sewage-disposal works of any town. If the flow were constant throughout the day, and if the quality of the sewage were also constant, matters would be far less difficult. As it was, a "factor of safety" should be adopted when applying experimental results, and in some cases as high a figure as 10·0 would not be found more than sufficient. With regard to the suggestions that the sludge might be employed in raising the level of low-lying lands, it should be remembered that the most valuable land from the agricultural point of view was the low-lying moist land which produced grass in great abundance. The cost of filtering at Barking was somewhat high in consequence of the large number of men day and night employed relatively to the amount of sewage filters. These men could easily attend to the filtration of at least three times the quantity, when the cost would be proportionately reduced. The works were surrounded by agricultural land, the owners of which were aware they could have the sludge for nothing, but they had hitherto not availed themselves of the opportunity.

Mr. Dibdin. Mr. Dibdin, in reply to Correspondence, said Mr. Fairley correctly regarded the effluent discharged from the outfall as sewage, except for the removal of the suspended matter; this was all that was intended to be accomplished by the system. So far as the prevention of nuisance in the Thames was concerned the work was accomplished, but not so in respect to the purity of the river in regard to its power of supporting fish life. As he had frequently pointed out, further work must be accomplished if this was to be done, and the best means for the accomplishment of that work was the direct biological treatment of the sewage. The position was placed in its right light by Mr. Mansergh when he referred to the non-necessity for removing more than the solids, while he thought that more might be done in this direction than was at present accomplished. It was originally proposed to treat the sewage by quiescent precipitation, but the continuous system had been adopted in consequence of the telescope weirs not permitting the effluent to be drawn off with sufficient rapidity to allow the cycle of work being accomplished; and thus, instead of the extra facilities for this emptying being arranged so that the works could be continued on the originally proposed plan, a distinct departure was made, and thus in order to remedy one defect another was introduced. He nowhere referred to the effluent as "clear and innocuous," but he had again and again pointed

Mr. Dibdin.

out that the original intention was merely to remove the solids from the sewage. With regard to the relative condition of the river, in the years 1886–87 Sir Henry Roscoe stated that the river was in an extremely foul state previous to the use of chloride of lime. As the previous winter floods had the usual effect in clearing out the river, it was difficult to see how the treatment with chloride of lime was prejudiced in comparison with that by permanganate, which Sir Henry Roscoe himself subsequently reported as being the better of the two methods, although he tried to minimise his retreat by an attack upon the methods of analysis. The significant fact with reference to Mr. Lowcock's experiment had not been overlooked by the Author, but it was not brought into prominence, as the essential feature which it was desired to point out was, that considerable progress had been made in the method of treating sewage by biological means; and that, in view of the fact that recent developments had shown the possibility of treating crude sewage by this system at a still greater rate than even that at which the effluent had been treated, the method was one which was giving great promise for the future. It was merely desired to point out the material advance which was being made, rather than to criticise the work of others. With reference to the conversion of nitrogen, existing either as ammonia or in combination with the organic matter, into nitric acid, the calculated quantity of nitrogen as nitrates, found in the effluent, did not bear out the statement, which was founded, however, upon the actual quantity of ammoniacal and organic nitrogen which had disappeared in the process of filtration. In a large number of cases the free ammonia was reduced by considerably more than 1 grain per gallon, and the statement was put forward merely to give a general idea of the work done; and, by an oversight, it was stated that the nitrogen was converted into nitric acid, instead of that nitrogen to that extent had disappeared, doubtless to a great extent in a gaseous form. With reference to the cost of the Barking filter, Sir Henry Roscoe had overlooked the fact that the cost of an experiment was not to be compared with the working cost in actual practice.

2 March, 1897.

WILLIAM HENRY PREECE, C.B., F.R.S., Vice-President, in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Member.

WILLIAM NISBET BLAIR.
CHARLES EDWARD BOTLEY.
HENRY ROBERT JOHN BURSTALL.
JOHN HENRY HOLMES.
FREDERICK WILLIAM LACEY.
HORACE JOHN MANNERING.
ALFRED HOWARD VINCENT NEWTON.
SAMUEL SYDNEY PLATT.
ADAM SCOTT.
WILLIAM ARCHER PORTER TAIT, B.Sc. (*Edin.*)

And that the following Candidates had been admitted as

Students.

SAMUEL ROBERT HARDWIDGE BEARD.
WILLIAM GEORGE BENDLE.
FREDERICK ALAN BIDEN.
ASA BINNS.
CHARLES CONNOR.
JAMES EASTON CORNISH, Jun.
WILLIAM HENRY PRYSE CRAIG.
JAMES MILLER FERGUSON.
EDWARD HAROLD GODSON.
JOHN SPENCER KILLICK.
TALBOT PEEL, M.A. (*Cantab.*)
GUY BAZELEY PETTER.
TOM ROLLS RENFREE.
JOHN ASSHETON RENNIE.
HENRY OEHLERS ROBINSON.
FRANCIS HENRY SHEPPEE, B.A. (*Cantab.*).
RICHARD FRANCIS STONEY.
GERALD SWAYNE.
CYRIL TEDMAN.
HAROLD SPENCER THRELFALL, B.Sc. (*Victoria.*)
GEORGE JOHN FREDERICK TOMLINSON.

The Candidates balloted for and duly elected were: as

A Member.

PEDRO PASCUAL DE UHAGON Y VEDIA.

Associate Members.

THOMAS JOHN HENRY ACKLAND.
EDWARD VINCENT ACTON, Stud. Inst. C.E.
JOHN WEMYSS ANDERSON.
ROBERT HAY ANDERSON, Stud. Inst. C.E.
LEONARD LUDOVIC BALDWIN, Stud. Inst. C.E.
HARRY BAMFORD, M.Sc. (*Victoria.*)
PHILIP JAMES BEVAN.
HUBERT CECIL BOOTH, Stud. Inst. C.E.
CHARLES FREDERIC BOTLEY.
RICHARD BOWER BRISTED.
REGINALD BROWN.
MARCUS STANLEY CHAMBERS.
ARTHUR COLLINSON, Stud. Inst. C.E.
STUART BLASHFIELD REA COOKE.
RALPH HENRY COVERNTON, Stud. Inst. C.E.

Associate Members—continued.

James Rush Dixon.
William James Edwards.
George Cochrane Godfrey, B.A. (*Cantab.*), Stud. Inst. C.E.
Robert Bruce McGregor Gray.
Harold Harlock.
John Joseph Hatt.
Joseph Husband.
Richard Carruthers Ivy.
Frederick Paget Lane.
William Morris Langford.
George Ernest Law.
Bernard Courtney Laws.
Francis Liversedge Lister.
Alexander McDougall, Jun.
Charles George Mason.
Frederick Michael.
Arthur William Nye.
Samuel Albert Pickering.
William Charles Popplewell, M.Sc. (*Victoria.*)
Frederick Kennerley Preston, Stud. Inst. C.E.
Hamlet Roberts.
William Higginson Schofield.
Frederic Shelford, B.Sc. (*Lond.*), Stud. Inst. C.E.
Norman Sisson, Stud. Inst. C.E.
Walter Perchard Stericker.
John Henry Tonge.
Samuel Joseph Lee Vincent, Stud. Inst. C.E.
Arthur Anderson Watkins.
Gilbert Winslow, B.A. (*Cantab.*)

Associates.

Edward Russell Clarke, B.A. (*Cantab.*), Stud. Inst. C.E.
John Hopkinson.
Walter Finch Page.

The discussion upon the Papers on "The Main Drainage of London," by Messrs. Worth and Crimp, and on "The Purification of the Thames," by Mr. W. J. Dibdin, occupied the evening.

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9 March, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President, in the Chair.

The discussion upon the Papers on "The Main Drainage of London" and "The Purification of the Thames" was continued and concluded.

16 March, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President, in the Chair.

(*Paper No. 2956.*)

"The Mond Gas-Producer Plant and its Application."

By HERBERT ALFRED HUMPHREY, Assoc. M. Inst. C.E.

GASEOUS fuel possesses certain well-recognised advantages over solid fuel; it is easily handled, and its combustion is completely under control, and causes no smoke or dirt. It is also applicable to many cases where solid fuel could not be used, and it is the fuel of internal-combustion engines. For these and other reasons the demand for it is rapidly increasing; and it is the function of the gas-producers to convert solid fuel into the gaseous state. In a Paper read before the Institution in 1886, Mr. F. J. Rowan[1] gave an account of the Wilson, Dowson, Grobe, Sutherland, Siemens, and other gas-producers which had been employed up to that time; and Papers on the application of the Dowson producer to the generation of gas for motive power have since been communicated to the Institution by Mr. J. E. Dowson.[2] The Author proposes to deal with recent advances in this department of industry.

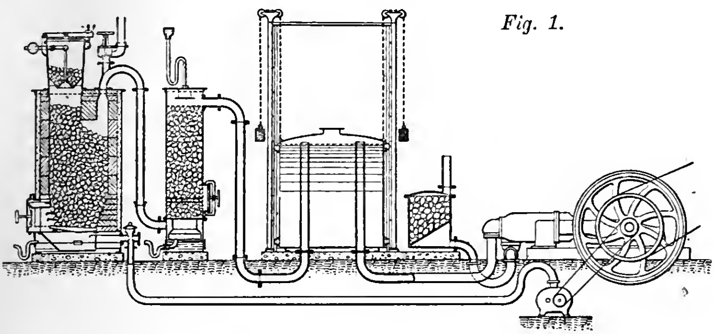
Producer gas was used for furnace work many years before its adoption for use in gas-engines; and its application to generating power, which only commenced about 18 years ago, has throughout been closely connected with the name of Mr. Dowson. His success, and the great possibilities in this field of work, led to the construction of many other producers for power gas; those of Wilson, Taylor, Thwaites and Lencauchez having achieved excellent results. The Dowson producer is adapted to use

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 2.
[2] *Ibid*, vol. lxxiii. p. 311; and vol. cxii. p. 2.

anthracite or coke, although gas has been made with steam coal, charcoal, lignite and other fuels. For gas-engine work, however, only anthracite or coke are used, and Mr. Dowson's aim is to replace some of the nitrogen in ordinary producer-gas, as used for furnace work, by an equal volume of hydrogen. To this end superheated steam is forced with the air through a considerable depth of fuel at a bright-red heat. The resulting gas is cooled and scrubbed, and its composition is that shown in Table VI, Appendix I. The principle of the other producers mentioned is the same; but no doubt certain special advantages may be claimed for each.

The Lencauchez producer is perhaps not so well known in England. It is circular in plan, and between its iron casing and the fire-brick lining there is a layer of sand, *Fig. 1.* The grate is

Fig. 1.



Scale, 1 inch = 16 feet.
LENCAUCHEZ GAS-PRODUCER.

closed and the air is forced in near the bottom by a blower driven by the gas-engine. Above the fire-door a small stream of water from the jacket of the engine enters and falls into a trough. Partial evaporation of this water takes place as it overflows or lies in the bottom of the grate, any surplus water escaping at a U-pipe. The steam thus formed passes with the air through the incandescent fuel, and the gas generated leaves the producer at the top, whence it is conducted to a coke scrubber through which it rises after bubbling through a hydraulic lute. The gas is washed by a water-spray entering at the top of the scrubber and is then ready for storing in the holder. As the latter becomes full it actuates a chain attached to the air-inlet valve on the producer and so checks the supply of air. The holder contains enough gas for starting the engine and is also used as a supply during the time the producer is idle for clinkering, a process which becomes necessary every twenty-four hours. With this producer it is found possible to use poor French anthracite or non-bituminous coal, and the success of the plant is well established in France.

From the Papers referred to it may be gathered that most producers were constructed to make gas without regard to the by-products, and that attempts to recover the ammonia had been only partially successful. No producers had been made to give good results with the cheapest slack coal, and it was only possible to obtain a gas suitable for use in gas-engines by employing an expensive fuel such as anthracite or coke yielding no by-products.

The Mond producer and recovery plant, not only employs cheap bituminous fuel, but recovers from it 90 lbs. of sulphate of ammonia per ton, and yields a gas eminently suitable for use in gas-engines, and applicable to all classes of furnace work. The difficulties in the use of bituminous slack, which have been overcome by Dr. Ludwig Mond, F.R.S., in perfecting his producer, have been numerous, involving many years of research and continuous experimental work on a large scale. In addition to the chemical problems of the preservation and recovery of the ammonia and the destruction of all tarry matter, two great troubles arise from the caking of the coal and the formation of clinker. Holes or channels are formed in the fuel and through them the air and steam flow instead of rising uniformly through the fuel, which burns unequally and varying temperatures result. The fuel also cakes into arches in the producer and the steady downward motion necessary for good work is prevented. The producer becomes blocked and clinkering is difficult; and, in spite of the bold attempts to break up the mass of fuel and clinker by a mechanical agitator, the system becomes unworkable. Even where it was desirable to use gas-coke from a neighbouring gasworks in producers of the ordinary type, Mr. Hartley, of the Britannia Engineering Works, found the producers clinker so rapidly that the working became a matter of serious difficulty, and at the close of the second day the engines had to be stopped and the fires drawn. Mr. Hartley then added mechanical means by which the attendant could detach all clinker from the lower portion of the interior of the brickwork and this gear rendered it possible to use the coke for a continuous run of nine weeks. These difficulties were emphasized by Mr. Dowson [1] in 1893; and still more recently by Mr. Delamare-Deboutteville, in the report of the trial of a

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[1] Minutes of Proceedings Inst. C.E., vol. cxii. p. 17, ll. 19 *et seq.*

large single-cylinder gas-engine,[1] in which he draws particular attention to the Lencauchez producers employed.

Experiments on gas-producers were begun by Dr. Mond in 1879, and the methods by which he had already achieved success were clearly laid down by him ten years later.[2] Besides the use of bituminous fuel and the recovery of ammonia, the Mond process is distinguished by the following characteristics: The producer is worked at a much lower temperature than usual, so that the resultant ammonia is not decomposed, and the fuel does not cake and no clinker is made. The low temperature results from, and is preserved uniform by, the large quantity of superheated steam introduced with the air, amounting to more than twice the weight of the fuel dealt with. The greater portion of this steam passes out of the producer undecomposed, but during its condensation its sensible and latent heat are utilized to produce fresh steam for use in the producer. The gas containing the ammonia is passed through an absorbing apparatus; and, although the quantity of ammonia is small compared with the volume of gas, it is so effectually treated that 70 per cent. of the nitrogen in the original fuel is recovered. The fuel is mechanically fed into the producer, and the ashes withdrawn without interfering with the regular continuous working. The amount of labour required is small, as no clinkering is necessary; and the fuel is charged in large quantities of 8 cwt. to 10 cwt. at a time. The gas generated is uniform in quality, and, as no tar is produced, the plant can be kept clean, and the gas cooled to any desired extent, without blocking the pipes and valves.

Description of the Plant.

The method of working, diagrammatically illustrated in Fig. 2, Plate 5, will be described in relation to the plant in use at the chemical works of Messrs. Brunner, Mond and Company, Northwich, Cheshire. Cheap bituminous slack, arriving in railway wagons, is emptied directly into a hopper, from which it is mechanically raised and delivered into a creeper above the row of producers. The creeper has outlets above each of the producer-hoppers, and can deliver into any one as desired. The hopper being thus filled, sufficient slack is by the simple motions of a sliding neck and two levers, allowed to fall into the measuring-hopper below to

[1] *The Engineer*, vol. lxxviii. p. 466.

[2] Presidential Address to the Society of Chemical Industry, 1889.

fill it; and, owing to the closed connection, no dust escapes. The bottom of the measuring-hopper is closed by a hood-valve held in position by a lever and counterweight, so that when the attendant has closed the upper lid he runs the weight towards the valve and allows the measured quantity of slack to drop into the producer.

The producer, Fig. 3, consists of an inner and outer wrought-iron cylindrical shell, the latter being lined with fire-brick for a portion of its height. The top is arched and is also lined with fire-brick, while the bottom tapers towards the grate; the whole producer being firmly held in position and supported by cast-iron brackets over a water-lute. For a time the freshly introduced slack is confined in the bell-shaped casting, hung from the top of the producer and surrounded by the hot producer-gas. Here the slack undergoes a process of distillation, and, as the products formed have of necessity to pass downwards through the hot zone before they can escape, the tar is destroyed and converted into fixed gas, so that the fuel has parted with all its tar before it arrives in the main body of the producer. At the bottom of the producer there is a cast-iron ring round which the upper ends of the sloping fire-bars are hooked. The lower ends of the bars lean against the inside of another ring which holds them at the proper inclination. As the bars do not reach to the centre, part of the weight of the superincumbent fuel rests upon the ashes, which form a reversed cone, filling the central space down into the water; and it is from below the water-level that the ashes are withdrawn by a spade. The mixture of steam and air has to pass downwards between the two shells of the producer on its way to the fuel, so that it is thus heated, while the inner shell is cooled. The arrangement acts also as an efficient jacket against external radiation.

The hot gas leaving the producer flows at once into the regenerator, consisting of a series of vertical double tubes of wrought-iron, so arranged that while the hot gas is cooled by passing in one direction through the inner tubes, the air-and-steam mixture is heated by its passage in the opposite direction through the annular space between the tubes. The long wrought-iron chamber, called a "washer," through which the gas is next forced, is fitted with mechanical dashers revolving on shafts at such a height above the water-level that their blades skim the surface of the water and throw up a great quantity of fine spray, completely filling the chamber. The gas and water-spray intimately mix, with the result that nearly all the heat of the gas is rendered latent by the formation of steam, or water-vapour, at a temperature of about 90° C. The steam so formed is not sufficient to saturate the gas, so that when it passes through the acid-tower, there is no weakening of the acid-liquor by any deposit of condensed steam. The gas enters the acid-tower at the bottom and in its upward course meets a downward stream of acid-liquor—a large surface of contact being obtained by means of checker brickwork arranged in the ordinary way. The acid-liquor contains only 4 per cent. of free sulphuric acid, the rest being already combined with ammonia and existing as sulphate. The bulk of the liquor is circulated continuously by a gun-metal ram pump, and its strength is maintained uniform by drawing off a small stream of the sulphate-liquor and adding sufficient acid to correspond in value. The tank at the foot of the acid-tower, Fig. 2, allows the intimate mixing of the sulphuric acid with the circulating liquor before the latter reaches the pump.

TABLE I.—VOLUMES OF DRY GAS AND WATER-VAPOUR IN 100 VOLUMES OF SATURATED GAS AT VARIOUS TEMPERATURES.

emperature.	Dry Gas.	Water Vapour.
°C.	Per Cent.	Per Cent.
0	99·40	0·60
5	99·15	0·85
10	98·80	1·20
15	98·34	1·66
20	97·71	2·29
25	96·90	3·10
30	95·85	4·15
35	94·49	5·51
40	92·77	7·23
45	90·60	9·40
50	87·90	12·10
55	84·56	15·44
60	80·45	19·55
65	75·45	24·55
70	69·40	30·60
75	62·12	37·88
80	53·44	46·56
85	43·12	56·88

The gas, deprived of its ammonia, leaves at the top of the acid-tower, and is conducted to the bottom of a large wrought-iron vessel, 12 feet in diameter, filled with wood packing of a shape to afford a large surface. The gas, containing its burden of steam, has here to meet a downward current of cold water which considerably lowers its temperature. When entering this gas-cooling tower it is nearly saturated with steam, so that as its temperature begins to fall, its capacity for carrying steam rapidly diminishes and condensation takes place. Table I shows how considerable the condensation must be, and the result is, the utilization of the latent heat of the steam condensed, as well as the sensible heat of the steam and gas, in raising the temperature of the circulating water which consequently escapes hot. On leaving the gas-cooling tower, pipe mains convey the clean cool gas away for immediate use in furnaces or gas-engines as the case may be, and in the works at Northwich, more than 24,000,000 cubic feet of this gas are used daily.

The hot water leaving the gas-cooling tower is pumped into the top of an air-heating tower, where its heat, obtained from the gas as described, is now given back to the cold air passing through on its way to feed the producer. To avoid confusion two pumps are shown in the Fig., one pumping the cold water to cool the gas, and the other pumping the hot water to heat the air; but one double-ram pump serves both purposes, and, as the capacity is the same for each of its rams, equal quantities of hot and cold water must be delivered whatever the speed of the pump. Thus the circulating waters are balanced without further regulation. Throughout the process the gas has been under pressure, furnished by the blower driving the air into the producer, and it is while on its way from this blower that the air is heated in the tower last mentioned. The chief function of the last tower is, however, to saturate the air with steam at the temperature attained, and by this means alone 1 ton of steam is carried into the producer for each ton of fuel gasified. One producer does not require a set of towers to itself as shown in the Fig., and at Northwich only two sets are required for all the producers.

The surplus sulphate-liquor formed in the acid-tower leaves the delivery of the circulating-pump at a point where the pressure is sufficient to force it over to the sulphate plant, which may be in a separate building. Here, after being neutralized, it enters conical evaporating-pans, each containing two nests of lead coils which carry steam under a pressure of about 35 lbs. per square inch. The heat given out to the surrounding liquor causes rapid evaporation and the concentration is continued until most of the sulphate has crystallized out. The contents of the evaporator are then dropped on a drainer; and, after parting with the mother-liquor, the solid sulphate is dried in a centrifugal machine and packed in bags for sale.

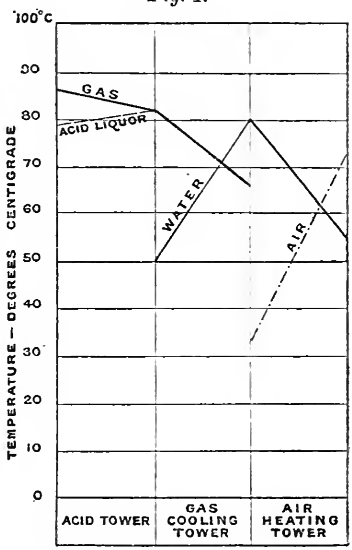
The first circular Mond producer was started to work continuously in September 1893. Up to August 1896 no repairs had been necessary, either to the brickwork lining or any other portion of the producer, except the replacement of one faulty tube in the pipe regenerator.

Tests at Winnington Works.

In the summer of 1895 the Author was invited to study the producer plant at Winnington, and to obtain all the data relating to its working necessary for a complete statement of its efficiency. With the object of affording the fullest possible particulars Mr. Charles Humfrey, the manager of the plant, organized a set of records, in addition to the ordinary hourly observations of tests, temperatures, and quantities which are regularly recorded, night and day. Three tests were made, the usual conditions prevailing throughout so far as the producers were concerned, while the gas from 62 tons, 82 tons and 94 tons of fuel per day respectively was driven through one set of towers. As would be expected, the best results were obtained from the first test when the absorbing plant had the least work, but those of the second trial were selected by the Author as more nearly corresponding with the usual conditions. Owing, however, to the very hot weather prevailing at the time, none of the thermal results are equal to those obtained under a more favourable state of atmospheric temperature.

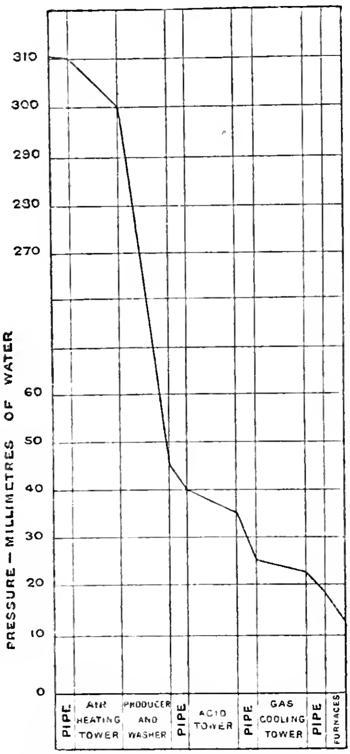
The fuel consisted of Nottingham slacks mixed in the proportion of the contract quantities and supplied in wagons to the works at an average cost of 6*s.* 2*d.* per ton. The producers were fed by charges of 8 cwt. to 10 cwt. at a time and the burnt ashes were removed from three of the six lute-holes, alternately, once in eight hours, the lutes untouched during one shift being drawn at the next. Average analyses of the slack and ashes are given in Table I, Appendix I. The density of the sulphate-liquor was kept at 35° Twaddle, equal to 34 per cent. of sulphate of ammonia by weight, so that for every ton of solid sulphate subsequently made it was necessary to evaporate $2\frac{1}{2}$ tons of water. By actual measurement of all the condensed steam from the sulphate plant it was found that 5·6 tons of steam were condensed in performing this work together with the necessary pumping.

Fig. 4.



The results of the trial, details of which are given in Appendix I, showed that for every ton of fuel fed into the producers, about $2\frac{1}{2}$ tons of steam and 3 tons of air are blown through the grate, the mixture being at a temperature of 250° C. Of this steam 1 ton is furnished by the system of regeneration, and $1\frac{1}{2}$ ton is added as exhaust steam from various engines and pumps. More than $\frac{1}{2}$ ton of steam is decomposed in passing through the hot fuel, and nearly $4\frac{1}{2}$ tons of gas are formed from 1 ton of coal, equal to about 160,000 cubic feet at ordinary atmospheric temperature. This gas has a calorific value of 81 per cent., calculated on the calorific value of the original 1 ton of fuel, and in a Babcock-Wilcox boiler gives an evaporation of somewhat more than 7 tons of water. When used in a gas-engine it is sufficient to give 2,166 I.HP. hours, being at the rate of 1·03 lb. of slack per I.HP. hour, the thermal efficiency of the engine being 23·8 per cent.; but better results have since been obtained by using the Crossley scavenging system. From Table II, Appendix I, it will be noticed that for each ton of slack gasified the plant requires a supply of exhaust and direct steam equal to 0·242 ton of slack, and this is allowed for in the statements of cost and other calculations. The efficiency of the tubular regenerator is 81·9 per cent., while the regeneration by circulating water gives an efficiency of 72·07 per cent. The balance sheet, Table IV, shows the way in which the heat quantities enter into the process, and the magnitude of the loss; and why in cooler weather better results would be obtained. The changes of temperature and pressure throughout the absorbing plant are illustrated in *Figs. 4* and *5*, the highest pressure being 310 millimetres of water. The cost of working, Table V, is affected by the market value of sulphate of ammonia, which it will be noticed is extremely low. The position which Mond gas occupies in relation to seven other typical gases is shown in Table VI. By burning it with a proper amount of air, the gas and air both being cold, the temperature of combustion, as actually observed, is 1,150° C. The theoretical temperature calculated from the calorific value and specific heats for a fixed set of conditions is shown in Table VII to be 1,606° C. The temperature realized is therefore 71 per cent. of the calcu-

Fig. 5.



lated value. When regeneration is employed to obtain very high temperatures the difference between a poor gas and a rich gas begins to disappear, and with Mond gas, used in its wet condition, it is easy to reach temperatures beyond the range of any form of pyrometer available. With a Callander pyrometer, a temperature of 1,525° C. has been observed in a flue through which burnt gases from a Mond gas-fired steel furnace were passing.

Applications of Producer-Gas.

As regards the general problem of gas-firing it should be stated that where gas has replaced slack firing, 1·1 ton to 1·2 ton of coal in the producers is equivalent to 1 ton of good slack carefully burnt by the old method. While, however, it is difficult to burn slack under the best theoretical conditions, it is always easy to regulate the burning of gas with only a slight excess of air above that theoretically required. For this reason, and because of the more regular distribution of heat when using gas, the working results of gas- and hand-firing approach much more nearly to one of equality in weights of slack. The question of decreased labour is also to be considered when comparing the advantages. Many of the furnaces in the finishing department of Messrs. Brunner, Mond and Company's Works were originally slack-fired, and, since the change to firing them by Mond gas has been made, a remarkable saving in repairs has been realized. The cast-iron pans, under which the flames pass and through which the heat is transmitted, last four times as long as formerly, and the output of a furnace during its life is more than quadrupled.

The results of firing Babcock-Wilcox boilers, by each of the two methods and at various rates of working, are given in Appendix II. To adapt the boiler, which was designed to work with the waste heat of furnace gases, to producer-gas firing, the alteration shown in Fig. 6, Plate 5, was made. Part of the inlet-flue was taken out, to allow the introduction of a 15-inch gas-main, and a perforated arch was built over the 4-foot square opening where the fire-bars are ordinarily placed. The gas was regulated by a throttle-valve, and the air entered through the annular space round the gas-pipe. The space below the arch formed the combustion-chamber, and the perforated arch served to shorten the flames and to render the combustion complete.

The manufacture of steel in the experimental steel furnace at

Winnington has recently been described by Mr. J. H. Darby,[1] who has shown that Mond producer-gas has proved a thoroughly suitable and economical fuel for use in the manufacture of the best class of steel.

The first experiments in the use of Mond gas for motive power were carried out early in 1894, on a 25-HP. Otto-Crossley engine erected at Winnington. The results of a two-hours' trial, carried out by the Author, are given in Table I, Appendix III, and, considering that no scavenging arrangements were fitted to the engine, they are among the best on record. The quantity of cheap bituminous slack at the producers per I.HP. hour was 1·03 lb., and the thermal efficiency is 23·8 per cent. Partly because the engine was not driven at full power, and also owing to the high degree of compression, the mechanical efficiency of the engine was only 71·4 per cent. in this trial. In analyzing the exhaust-gases, 0·6 per cent. of carbonic monoxide and 1·7 per cent. of hydrogen were found; but this is chiefly due to faulty governing gear which allowed occasional slipping of the governor lever which rides the gas-cam. In December, 1895, the engine was removed to another portion of the works, and erected to drive an electric-light installation, Figs. 7, Plate 5. It is coupled by a leather link-belt to a dynamo giving 300 amperes at 104 volts, and furnishes every night the current required for lighting the caustic-soda plant. The supply of producer-gas is drawn through either of two sawdust filters, 6 feet in diameter, and containing a layer of 8 inches of loose deal-dust. Since this engine started to run in its new position, it has only been necessary to renew the sawdust once in one filter; the other filter still contains the original sawdust, and the valves and cylinder of the engine have not required to be cleaned. Some figures relating to the ordinary work of this engine during the month of April, 1896, are added in Table II, Appendix III.

In consequence of the success recorded, Messrs. Brunner, Mond and Company have installed a larger engine, of 150 HP., of the Crossley-Otto two-cylinder end-to-end type. The crank-shaft is connected through a flexible coupling to the armature of a Siemens dynamo, and the whole is designed to give, when working with Mond gas, 750 amperes at 100 volts, when running at 160 revolutions per minute. It is probably the first instance in Great Britain of a large gas-engine driving a dynamo direct.

For purposes of comparison the Author has tabulated a set of figures relating to the use of Dowson gas-producers, Tables III, IV

[1] Journal of the Iron and Steel Institute, vol. xlix. p. 144.

and V, and, although under special test conditions even slightly better results may have been obtained, yet those given represent a plant working well. With the same object a summary of the trial of the famous "Simplex" gas-engine at Pantin Mills, working with poor gas generated in a Lencauchez producer, is added in Table VI.

When the difficulties of building satisfactory gas-engines of say, 500 HP. and 1,000 HP. have been overcome, they will inevitably replace steam-engines in large central electric-light and power stations, even as they are already doing on a smaller scale.

To show what might then be accomplished in the supply of cheap power, the Author takes as a hypothetical example a factory requiring a continuous power of 10,000 I.HP., with a Mond producer and recovery plant, erected adjacent to it to supply the necessary gas for the engines. Let the whole of this 10,000 HP. be utilized to drive dynamos yielding 7,000 E.HP. at the terminals. The cost of the gas-generating and recovery plant is estimated to amount to about £20,000, and the gas-engines, dynamos, exciters, switchboards, cranes, and buildings would be covered by the additional sum of £120,000 exclusive of the price of the land, which is a variable quantity. If this plant works day and night all the year round, the total expenses are estimated to amount to £35,100, which includes interest on capital at 8 per cent., giving the total cost of one kilowatt-hour as 0·184*d.*, or of one E.HP.-hour 0·137*d.* The case considered is a favourable but not improbable one, as a factory working an electrolytic process might require a continuous power far beyond the 7,000 E.HP. In most cases the mechanical power, without transformation, would be required at various points of the works, and in such cases the gas would be distributed in pipe-mains to the different gas-engine stations. The corresponding total cost would then be reduced to about 0·0865*d.* per I.HP.-hour.

It must not be overlooked that with the producer plant in excess of the power plant any required amount of gas can be furnished for heating boilers, furnaces, drying apparatus, &c., in the same works, and this at a lower cost than by the burning coal directly. In a large central station there arises a great advantage in having all the gas-engines near the producer plant, for then the otherwise waste heat of the exhaust-gases and jacket-water can be utilized. Even in the best gas-engine between 70 per cent. and 72 per cent. of the total heat is lost in these two sources of waste, and sufficient heat can be recovered from the exhaust gases alone to raise all additional steam, at atmospheric pressure, required by the Mond producers. A source of economy is thus presented which will reduce the cost per HP.-hour below the figures given, and, by effecting the evaporation of the sulphate-liquors by a direct gas-flame action, fuel would also again be saved. These are sure signs that the best possible results are not yet reached.

The transmission of power from the South Yorkshire or Midland coal-fields to the metropolis, and its subsequent distribution and supply at a very cheap rate, is undoubtedly to be looked forward to by metropolitan manufacturers, as well as by the present users of electric power. Mr. James Swinburne and Mr. B. H. Thwaite have drawn up a report of this project, and, with the assistance of Mr. Charles Brown, of Messrs. Brown, Boveri and Co., and the Oerlikon Co., Maschinenfabrik Oerlikon, they have found that a selling price to the local distributing companies of $2\frac{1}{2}d.$ per unit would leave a handsome profit after paying $7\frac{1}{2}$ per cent. interest on the capital. In making their calculations the cost of coal, after deducting the value resulting from the recovery of residuals, is taken at *4s. 6d.* per ton, whereas in the Mond process the recovery of sulphate would be sufficient to cover the cost of coal entirely. The advantages to be derived by consumers, taking power from a large central station as indicated, are not measured simply by the reduced cost per unit. Manufacturers can dispense with large and costly engines and foundations; boilers and coal-storage sheds are not required, and greater elasticity in the design of buildings can be allowed when long lines of shafting become unnecessary. In high factories the transmission of power to the upper storeys becomes simple, and isolated machines no longer offer difficulties. The dirt and nuisance arising from carting of coal and ashes and the troubles from steam-pipes under pressure disappear, together with the anxiety of a possible breakdown of the main machinery; while on the other hand an exact knowledge is gained as to the power each piece of plant consumes, and more machines can be added at will without multiplying boiler- and engine-power. The cost of repairs, interest on capital, and charges for water and lighting all diminish with the new system, but more important still is the actual reduction in the amount of power required. In several well-authenticated cases a saving of 50 per cent. of the total power has resulted after adopting electrical distribution to the individual machines.

There is no doubt that a state of things is rapidly approaching when a central supply for power will eclipse in importance the question of central stations for electric lighting, and the far-reaching effects of the movement can hardly be over-estimated.

It cannot be foretold what will be the ultimate degree of economy realized, but it should certainly be possible to supply every house in London with gas for heating and ventilating purposes, and electric current for lighting, at such prices that no householder would think of consuming coal in an open grate, or polluting the air of his rooms by burning illuminating gas. The atmosphere of London would be relieved of the smoke which makes a London fog so objectionable, for factory owners would be supplied with power at a cost which even the Niagara Falls Power Company of America cannot reach. Also the expenditure of England in nitrogenous compounds or fertilizing agents, amounting to about £2,000,000 per annum, would, as the system of gas-producers became general, be changed to an annual income arising from the sale of the surplus sulphate of ammonia in foreign markets.

The Paper is accompanied by four drawings and seven photographs, from which Plate 5 and the *Figs.* in the text have been prepared, and by designs and estimates of the cost of a plant to develop 10,000 HP.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

TABLE I.—DATA OBTAINED FROM TRIAL OF MOND PRODUCER AND RECOVERY PLANT.

Duration of experiment after conditions became constant.	three days.
Average analysis of fuel (by weight)—	
Moisture at 100° C.	7·3 per cent.
Nitrogen	1·29 „
Carbon, total	67·88 „
Sulphur	1·30 „
Ash	7·57 „
Volatile matter (exclusive of carbon) driven off at a temperature over 100° C., by difference	14·66 „
	100·00
Analysis of ashes from producer (average)—	
Ash, on dried sample, by weight	85 per cent.
Carbon „ „	15 „ „
Carbon lost in ashes, on the fuel	1·33 „ „
Carbon available for conversion into gas, on the fuel	66·55 „ „
Calorific value of fuel, per unit weight, kilogram-degree centigrade units	7,225
Kilogram-calories per 1 ton of fuel, kilogram units,	7,340,600
Average analysis of gas during trial, tested when saturated at 15° C.—	
Carbonic acid (CO_2)	16·0 vol. per cent.
Carbonic oxide (CO)	10·0 „ „ „
Hydrogen (H)	26·0 „ „ „
Marsh gas (CH_4)	2·5 „ „ „
Water vapour (H_2O)	1·7 „ „ „
Nitrogen (N)	43·8 „ „ „
Weight of 1 cubic metre of gas saturated at 15° C.	990·8 grams.
„ „ „ „ „ dry at 0° C.	1,048·5 „
Weight of carbon in 1 cubic metre of gas saturated at 15° C.	0·1448 kilogram
Each kilogram of fuel gasified yields—	
4·596 cubic metres of gas saturated at 15° C.	
4·518 „ „ „ dry „ „	
4·283 „ „ „ „ at 0° C.	
Volume of dry gas at 0° C. per ton of fuel gasified	4351 cubic metres
Calorific value of 1 cubic metre of dry gas at 0° C.	1,367·3 kilogram °C. units
Calorific value of total gas made as a percentage on calorific value of total fuel gasified	81·02 per cent.
Calorific value of 1 cubic foot (0° C.)	84·57 lb. °C. units

Water circulated through the towers, for 82 tons of fuel per day—	
Two 12-inch rams at 32 revolutions per minute.	
Theoretical quantity of water pumped per minute	1·737 cubic metre.
Actual „ „ „ „	1·59 „
Water circulated per minute per 1 ton of fuel gasified	19·4 kilograms.
Total I.HP. for blowers, engines, pumps, &c., from actual diagrams, per 1 ton of fuel gasified per day	1·38
Yield of ammonia—	
NH_3 as percentage on the weight of fuel gasified	1·09 per cent.
Calculated as sulphate (of 24–25 per cent. NH_3) on fuel gasified	4·36 „
Fuel required to produce 1 ton of sulphate	23·0 tons.

TABLE II.—ADDITIONAL STEAM ACCOUNT FOR 1 TON OF FUEL GASIFIED.

Weight of exhaust steam added to producer blast	1,583 kilograms.
Tons of fuel required to produce this steam (evaporation of eight)	0·195 ton.
Kilogram-calories in above steam at 85° C., from water at 15° C.	976,600
Kilogram-calories given to air by steam in raising temperature of air	9,016
Kilogram-calories (total) added in exhaust steam	985,616
Steam required for all purposes at sulphate plant (equal to 5·6 tons of steam per 1 ton of sulphate)	0·224 ton.
Tons of fuel at sulphate plant equal to above steam	0·028 „
Total steam used at producer and absorbing plant, &c. (this includes condensation in all pipes, &c.)	1·71 „

ADDITIONAL FUEL ACCOUNT FOR 1 TON OF FUEL GASIFIED.

Total extra fuel at producers and plant	0·214 ton.
„ „ „ sulphate plant	0·028 „
„ „ „ for combined plant, or 24·2 per cent. on the fuel gasified	0·242 „

TABLE III.—CALCULATION OF HEAT QUANTITIES FOR MOND PRODUCER AND RECOVERY PLANT.

(Kilogram ° C. units.)

PRODUCER:—For 1 ton of fuel gasified:—	
Temperature of air and steam entering	250° C.
„ gas and steam leaving	450° C.
Weight of air entering	3,165·00 kilograms.
„ steam entering	2,598·00 „
„ „ decomposed	673·20 „
„ gas leaving (dry)	4,490·00 „
„ steam leaving	1,999·00 „
„ „ from moisture in slack	74·16 „

Heat of formation of carbon gases:—		
For the actual quantity of CO_2 formed	3,063,457	
,, ,, ,, CO ,, ...	572,592	
Total kilogram-calories	3,636,049	

NOTE.—The CH_4 is regarded as a product of distillation.

Equal to per cent. of total heat of combustion of fuel		49·53 per cent.
Heat accounted for:—		
In raising 2,598 kilograms of steam from 250° C. to 450° C.	246,800	
In converting 74 kilograms of water at 15° C. to steam at 450° C.	58,238	
In the decomposition of 673 kilograms of steam (final temperature 450° C.).	2,503,560	
In heating the nitrogen of the air (250° C. to 450° C.)	118,400	
Total heat accounted for in above . .	2,926,998	
or, expressed as per cent. on total heat of combustion of fuel		39·87 per cent.
Heat absorbed by other chemical changes + heat lost at producer equals, as per cent. on total heat of combustion of fuel		9·66 per cent.
TUBULAR REGENERATOR:—		
Temperature of air and steam entering		85° C.
,, ,, ,, leaving		250° C.
Weight of air entering		3,165 kilograms.
,, steam entering		2,598 ,,
Temperature of gas and steam entering		450° C.
,, ,, ,, leaving		280° C.
Weight of gas entering.		4,490 kilograms
,, steam entering		1,999 ,,
Heat given out:—		
In cooling gas from 450° C. to 280° C.	238,500	
,, steam from ,, ,, ...	161,400	
Total heat given out	399,900	
or, expressed as per cent. on total heat of combustion of fuel		5·448 per cent.
Heat absorbed:—		
In heating air from 85° C. to 250° C.	124,010	
,, steam from ,, ,, ...	203,600	
Total heat absorbed	327,610	
or, expressed as per cent. on total heat of combustion of fuel		4·46 per cent.
Efficiency of regenerator		81·90 ,,
MECHANICAL WASHER:—		
Temperature of gas and steam entering		280° C.
,, ,, ,, leaving		90° C.

Weight of gas entering	4,490 kilograms.
,, steam entering	1,999 ,,
,, ,, leaving	2,741 ,,
,, ,, added in washer	742 ,,
Heat given out—	
In cooling gas from 280° C. to 90° C.	266,700
,, ,, steam ,, ,,	180,400
Total heat given out	447,100
or, expressed as per cent. on total heat of combustion of fuel	6·09 per cent.

NOTE.—If all the heat given out was utilized, the weight of steam added in the washer would be 829·4 kilograms instead of 742 kilograms.

ACID TOWER—

Temperature of gas and steam entering	86° C.
,, ,, ,, leaving	82° C.

The acid liquor is heated from 79° to 82° C.

Heat given out—	
By cooling gas	5,616
,, ,, steam	5,208
Total heat given out (wasted)	10,824

NOTE.—The gas is never saturated in the acid tower.

GAS-COOLING TOWER—

Temperature of gas and steam entering	82° C.
,, ,, ,, leaving	66° C.
Weight of gas entering	4,490 kilograms.
,, steam entering	2,741 ,,
,, ,, leaving	1,195 ,,
,, ,, condensed	1,546 ,,

NOTE.—In cooler weather this last would be increased.

Temperature of water entering	50° C.
,, ,, ,, leaving	80° C.
Heat given out—	
In cooling gas from 82° to 66° C.	22,450
In cooling steam ,, ,,	20,830
In condensing 1,546 kilograms of steam at 66° to water at 66°.	833,300
Total heat given out	876,580
or, expressed as per cent. on total heat of combustion of fuel	11·94 per cent.

NOTE.—Owing to the hot weather which prevailed during the trial, the gas could not be cooled to the usual extent; but supposing it had been cooled to 15° C., 767,655 more heat-units would have been obtained, equal to 10·46 per cent. on the total heat of combustion of fuel.

Heat accounted for by rise in temperature of circulating water	838,080
or, expressed as per cent. of heat given out . . .	95·6 per cent.
AIR-HEATING TOWER:—	
Temperature of air entering	33° C.
,, ,, and steam leaving	73° C.
,, water entering	80° C.
,, ,, leaving	55° C.
Weight of air, in and out	3,165 kilograms.
,, steam (natural moisture in air), approximate	11 ,,
Weight of steam leaving	1,015 ,,
Heat absorbed:—	
In heating air from 33° C. to 73° C.	30,040
,, formation of steam at 73° C.	601,895
Total heat absorbed	631,935
or, expressed as per cent. on total heat of combustion of fuel	8·61 per cent.
Heat given out by circulating water (80° C. to 55° C.)	698,400
Efficiency of air-heating tower	90·40 per cent.
Total efficiency of regeneration by circulating water	72·07 ,,

TABLE IV.—BALANCE SHEET OF HEAT QUANTITIES FOR MOND PRODUCER PLANT.

Total heat of 1 ton of fuel .	100·00	Heat of combustion of gas made	81·02
Heat added in exhaust steam	13·43	Heat recovered in pipe regenerator	5·45
Heat = work done in engines, &c.	0·29	Heat recovered in air-tower	8·61
Heat = steam condensed, &c.	1·37	Heat remaining in gas (above 15° C.)	10·46
		Heat lost	9·55
	115·09		115·09

TABLE V.—STATEMENT OF COST OF WORKING OF MOND PRODUCER AND RECOVERY PLANT.

(At Winnington, Cheshire.)

	£	s.	d.
Price of fuel per ton at works:—Weight average for contract quantities	0	6	2
Selling price of sulphate:—Price in August, 1896. Net naked at works . . . per ton	7	4	6

1 ton of sulphate is obtained from 23 tons of fuel gasified, but adding fuel for steam required the total is 28·56 tons.

Cost per ton of sulphate of ammonia made:—	£	s.	d.
Total cost of all fuel (28·56 tons at 6*s.* 2*d.*)	8	16	1
Wages at producers (23 tons at 6·4*d.*)	0	12	3
Manufacturing wages, administration	0	1	9
,, ,, labour	0	19	8
Repair wages and materials, including renewals	0	18	3
Gas for lighting purposes	0	3	11
Lubricants	0	1	8
Sulphuric acid, 0·95 ton at 145° Twaddle	1	4	4
Total for above	12	17	11
Selling price of sulphate, naked at works	7	4	6
Final works cost of 23 tons of fuel gasified	5	13	5
Or, final cost of gas from 1 ton fuel gasified	0	4	11·1
Or, the cost of 1,000 cubic feet of gas (at 15° C.) is	0	0	0·351
The gas for 1 I.HP.-hour will cost	0	0	0·02685
Or, gas for 1 I.HP. for twenty-four hours a day for a year.	0	19	7·2

TABLE VI.—ANALYSIS AND CALORIFIC VALUE OF VARIOUS GASES.

(Products cooled to 18° C.)

Volume per cent.	Mond Producer Gas from Bituminous Fuel.	Siemens Producer Gas.	Dowson Producer Gas from Anthracite.	Lencauchez Producer Gas from Anthracite.	Solvay Coke-Oven Gas.	Coal-Gas (Illuminating).	Pittsburgh Natural Gas.
Hydrogen (H)	24·8	8·6	18·73	20·0	56·9	48·0	22·0
Marsh gas (CH_4)	2·3	2·4	0·31	..	22·6	39·5	67·0
C_nH_{2n} gases	nil	nil	0·31	4·0(?)	3·0	3·8	6·0
Carbonic oxide (CO)	13·2	24·4	25·07	21·0	8·7	7·5	0·6
Nitrogen (N)	46·8	59·4	48·98	49·5	5·8	0·5	3·0
Carbonic acid (CO_2)	12·9	5·2	6·57	5·0	3·0	nil	0·6
Total volume	100·0	100·0	100·0	100·0	100·0	100·0	100·0
Total combustible gases	40·3	35·4	44·42	45·0	91·2	98·8	95·6
Theoretical.							
Air required for combustion	112·4	101·4	113·2	154·0	410·0	581·0	806·0
Calorific value per cubic foot in lb. ° C. units	85 9	74·7	88·9	115·3	284·0	381·0	495·8
Calorific value per litre in gram ° C. units	1,374	1,195	1,432	1,845	4,544	6,096	7,932

NOTE.—Where the volume per cent. does not add up to 100 the slight difference is due to the presence of oxygen.

TABLE VII.—THEORETICAL TEMPERATURE OF COMBUSTION OF MOND PRODUCER-GAS.

Analysis of Gas, Volumetric.

	Per cent.
H	27·5
CH_4	2·0
C_2H_4	trace.
CO	11·0
CO_2	16·5
N	43·0

Products of Combustion.

With theoretical quantity of air. Per 1 volume of gas burnt.

Water vapour	0·315
CO_2	0·295
N	1·303

Conditions.—Gas to be taken as saturated at 15° C.; air to be taken as half saturated at 15° C.

Cubic feet of moisture for 1 cubic foot dry gas at 15° C.	0·0168	
,, ,, air required for 1 cubic foot producer-gas	1·105	
Moisture in the air	0·00924	cubic foot.
Total moisture for mixed gas and air	0·0260	,, ,,
Weight of 0·315 cubic foot of steam formed by combustion	0·0158	lb.
,, 0·026 ,, ,, ,, present as vapour	0·00131	,,
Average specific heat of products of combustion	0·2616	
Heat-units required to raise products 1° C.	0·04002	
Gross heat-units from burning 1 cubic foot of gas	85·1	

If x = temperature of combustion above 15° C.

$$0{\cdot}04002\,x = 85{\cdot}1 - \{0{\cdot}0158\,(536 + 0{\cdot}475\,x)\} - 0{\cdot}00131\,(0{\cdot}475\,x)$$

which gives the temperature of combustion 1,606° C.

TABLE VIII.—EFFICIENCIES OF GAS-PRODUCERS.

(Tabulated from examples given by Mr. C. F. Jenkin.[1])

Description of Producer.	Calorific Power of Gas.	Figure[2] of Merit.	Cold-Gas Efficiency.	Authority.
Mond circular producer . . .	1,367	8,627	0·810	Author.
Ordinary rectangular brick producer, original form . . .	894	6,210	0·562	C. F. Jenkin.
Same producer after modification by Mr. C. F. Jenkin . . .	1,311	7,750	0·712	,,
Odelsjerna producer at Avesta, 1888, Prof. Akerman . . .	1,549	8,110	0·754	,,
Examples given by Mr. von Jüptner (1)	1,154	7,060	0·565	,,
(2)	1,044	7,060	0·468	,,
Dowson producer, using Garnaut anthracite	1,321	7,540	..	,,
Dowson; using anthracite . .	1,272	6,590	0·689	,,
Wilson producer, using slack .	1,261	7,730	..	,,
,, ,, using Durham coal	1,238	7,140	..	,,
Wilson producer, another example	1,314	7,420	0·702	,,

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 328.

[2] The "figure of merit" is the heat of combustion of the gas per kilogram of carbon contained in it. Units—kilogram and Centigrade degrees.

APPE

HAND-FIRED AND GAS-FIRED STEAM-BOILER TRIAL

(Communicated b

—	Experiments at		
	With Ordinary Fuel (1896).		
Babcock-Wilcox Boilers.			
Maker's estimate of HP.	123	123	123
Size of drum	23 feet long by 36 inches in diameter		
Number of tubes	63	63	63
Diameter and length of tubes	18 feet long by 4 inches in diameter		
Grate-area in square feet	26·5	26·5	26·5
Total heating-surface . . . square feet	1,411·0	1,411·0	1,411·0
Fuel.			
Kind of fuel	slack	slack	slack
Quality	good	good	good
Colliery	Black-well Main	Boston Pit	Boston Pit
Weight in tons per twenty-four hours	5·08	4·69	6·9
,, lbs. per hour	474·0	437·0	644·0
Lbs. per square foot of fire-grate per hour	17·9	16·5	24·4
Method of firing	hand	hand	hand
Water.			
Temperature of feed-water . . . ° C.	30·0	31·0	50·0
Water evaporated in tons per twenty-four hours	32·6	29·6	44·0
,, ,, ,, lbs. per hour	3,044·0	2,762·0	4,106·0
I.HP. at 30 lbs. per I.HP. per hour	101·0	92·0	137·0
Steam pressure . . . lbs. per sq. inch	82·0	82·0	83·0
Evaporation.			
Lbs. of water per lb. of fuel (actual)	6·42	6·31	6·3
Equivalent evaporation from and at 100° C.	7·49	7·35	7·1
Lbs. per square foot of heating-surface . per hour	2·15	1·95	2·9
Flue Gases.			
Temperature leaving boiler . . . ° C.	315·0	370·0	398·0
Analysis by volume with fires in average condition and doors shut: CO_2 per cent.	15·0	14·8	14·2
,, CO ,,	0·8	0·8	0·5
,, O ,,	3·0	5·0	5·7

DIX II.

EXPERIMENTS WITH BABCOCK-WILCOX BOILERS AT WINNINGTON.

Mr. C. Humfrey.)

Winnington Works. With Mond Producer-Gas (1896).				Manchester Steam Users' Report, 1895.	
159	159	159	159	(given for comparison)	
23 feet long by 48 inches in diameter				20 feet long by 42 inches in diameter	
81	81	81	81	54	54
18 feet long by 4 inches in diameter				18 feet long by 4 inches in diameter	
	33·5 if bars were in				
1,827·0	1,827·0	1,827·0	1,827·0	24	24
Mond producer gas. The weights given are those of slack fed into producer				Burgy clean wet	Burgy clean dry
..	..	..	..	Worsley	
5·3	5·5	6·9	8·7	7·3	6·1
494·0	513·0	644·0	812·0		
..	..	..	..	24·4	23·8
	see Fig 6, Plate 5.			hand	hand
44·0	40·0	42·0	55·0	6·0	9·0
32 5	35·7	44·4	53·2	45·3	40·1
3,034·0	3,337·0	4,144·0	4,969·0	4,232·0	3,612·0
101·0	111·0	138·0	166·0	141·0	125·0
84·0	84·0	83·0	80·0	85·0	78·0
6·13	6·50	6·43	6·12	6·11	6·49
7·00	7·46	7·36	6·83	7·41	7·82
1·66	1·82	2·26	2·72	2·32	
209·0	213·0	224·0	282·0		
15·4	16·3	14·0	15·0		
3·6	3·1	4·2	3·6		
0	0	0	0		

APPENDIX III.

TABLE I.—TRIAL OF A 25-NOMINAL-HP. GAS-ENGINE (CROSSLEY BROTHERS) WORKING WITH MOND PRODUCER-GAS.

Date, 5th July, 1894.

Conditions:—The trial was conducted by the Author with the assistance of Mr. Bradley (Messrs. Crossley Brothers' representative). The engine drove a 200-ampere dynamo (100 volts), and the power was absorbed by iron wire resistance-coils. An hour's preliminary run was made to get all conditions steady. Some of the indicator diagrams (taken at five-minute intervals) were obtained with a Richards indicator, the others with a new Crosby gas-engine indicator purchased for the occasion.

Duration of trial (3.30 P.M. to 5.30 P.M.), two hours.

Average Analysis of Gas during Trial—Mond Producer-Gas.

CO_2	12·9	volume per cent.
O	0·0	,, ,,
CO	13·2	,, ,,
H	24·8	,, ,,
CH_4	2·3	,, ,,
N	46·8	,, ,,

NOTE.—Some gas escaped into the exhaust due to occasional slipping of governor lever.

Calorific value of 1 cubic foot of gas (lb. °C. units, see Table)	85·9
Mean speed of engine, revolutions per minute	191·4
Number of explosions per minute	47·8
Pressure of explosion	226·1 average lbs.
,, at end of compression	107·4 ,, ,,
,, at opening of exhaust	38·4 ,, ,,
Mean effective working pressure	67·3
Indicated HP. calculated from diagrams	38·71
Gas used per hour, as measured by meter, saturated at 26·6° C. and 764·5 millimetres	3,051 cubic feet.
Gas per I.HP. (dry at 0° C. and 760 millimetres) per hour	69·70
Slack used at producer per I.HP. hour	1·03 lb.
Heat-units developed by actual quantity of gas used per minute (lb. °C. units—products cooled to 18° C.)	3,861
Heat-units accounted for by indicator diagram per minute	919
Thermal efficiency	23·8 per cent.

TABLE II.—STATEMENT OF COST FOR ELECTRIC LIGHT AT THE CAUSTIC-SODA PLANT OF THE WINNINGTON WORKS.

This installation consists of incandescent-lamps and arc-lamps, the latter in pairs, all on a 100-volt circuit. The dynamo is driven by a 25-nominal-HP. Otto gas-engine using Mond producer-gas.

Time run during month of April, 1896	320 hours.
Total Mond gas used, measured by meter, April, 1896	920,035 cubic feet.
Equivalent weight of slack into producers	5·75 tons.
Power—	
Average pressure at switchboard	100·0 volts.
,, current ,, ,,	184·0 amperes.
,, work	24·5 E.HP.
,, ,, including power for driving fan	37·7 I.HP.
Gas—	
Cubic feet of Mond gas (wet at 15° C.) per electrical HP.-hour (calculated)	117·2
Ditto Ditto per I.HP.-hour (calculated)	76·18
Cost—	£ s. d.
Slack at producers (without deduction for ammonia)	2 0 3
Gas-engine oil, renewal of carbons and lamps	4 10 6
Labour at engine, one-third of man at 4*s.* per eight hours	2 13 0
Total cost	9 3 9
Number of Board of Trade units at switchboard	5,888
Cost per unit (1,000 Watt-hours)	0·394*d.*
Cost as compared with illuminating gas—	
To furnish the same amount of light, 17,040 candle-power with illuminating gas at 2*s.* per 1,000 cubic feet, and allowing 3½ cubic feet per 16 candle-power-hour, total illuminating gas required	1,192,640 cubic feet.
Cost for illuminating gas	£119

NOTE.—The engine-driver in charge had two other engines to attend, less than one-third of his time being taken by this installation. Seven, and sometimes eight, pairs of arc-lamps were in circuit. Half the cost of the oil is charged, as this oil was used over again on other engines.

TABLE III.—DOWSON-GAS PLANT. FIGURES FOR A PLANT OF NOT LESS THAN 100 BRAKE-HP. UNDER ORDINARY WORKING CONDITIONS.

	Per Brake HP.
First cost of Dowson plant, including ash-pit for generator, foundations and erection—	
For 80 brake HP. size	£4
,, 500 ,, ,,	£2

Fuel used—	
Anthracite in producer	1·0 lb.
Coke in steam boiler (17 per cent. on total)	0·2 lb.
Total fuel	1·2 lb.
Fuel lost per hour when plant stands idle	0·2 lb.
Gas—cubic feet of gas required	80–95
Water used in boiler per hour	1·0 lb.
,, ,, for washing gas per hour	1·4 ,,
,, ,, for cooling	60·0 ,,
Cost—Total cost of fuel	0·1*d.*
Total cost, including fuel, water, oil, wages, repairs at 3 per cent. and depreciation at 10 per cent. on prices erected (estimated by Mr. Dowson)	0·37*d.*

	Per 1,000 Cubic Feet of Gas made.
(Gas made per ton of anthracite, about 190,000 cubic feet.)	
Fuel required—	
Anthracite	10 lbs.
Coke	2 ,,
Total	12 ,,
Total water for gas-making	32 lbs.
Steam accounted for in gas	8 ,,
Volume of air required to mix with gas	1,400 cubic feet.
Cost of producing gas	$2\frac{1}{2}$*d.*

TABLE IV.—DOWSON-GAS PLANT.

Clerk of Works Report on Dowson-Gas Plant at Gloucester County Asylum.

(This plant has been in use twelve years.)

Estimated cost of production during the year ending the 31st of March, 1895.

	£	*s.*	*d.*
Anthracite, 125 tons at 21*s.* 2*d.* per ton	132	4	10
One year's repairs at 6*d.* per day	9	2	6
Gasman's wages at 21*s.* per week	54	12	0
	195	19	4

Total gas made, 25,496,700 cubic feet.

Cost per 1,000 cubic feet, exclusive of slack used at boilers, $1\frac{7}{8}$*d.*

The above figures were kindly given by Mr. Dowson to the Author in August, 1895.

TABLE V.—COMPARATIVE COST OF MOND PRODUCER-GAS (WITHOUT RECOVERY PLANT) AND DOWSON GAS.

If a Mond producer is worked without any plant for the recovery of ammonia, then for 1 ton of fuel gasified the extra fuel for steam is	0·20 ton.

	s.	d.
Total cost of fuel (1·20 ton at 6s. 2d.)	7	4·8
Wages at producer	0	6·4
Total cost of gas from 1 ton of fuel	7	11·2

Quantity of gas from 1 ton (measured through wet meter at 15° C.)	165,994 cubic feet.
Cost of fuel and labour for 1,000 cubic feet	0·507d.
Corresponding cost of Dowson gas per 1,000 cubic feet	1·8d.

TABLE VI.—TRIAL OF A 320-I.HP. SINGLE-CYLINDER "SIMPLEX" GAS-ENGINE WORKED WITH LENCAUCHEZ PRODUCER-GAS, AT THE PANTIN FLOUR MILLS, FRANCE.

Quantity of fuel used during trial	10,000 kilograms.
Duration of trial	194 hours.
Kind of fuel used—dry coal of the Anjou mines.	
Cost of fuel per ton (estimated at Brussels)	20 francs.
Engine—	
Diameter of cylinder, 0·87 metre, equal to	34·5 inches.
Length of stroke, 1 metre, equal to	39·37 ,,
Maximum I.HP. (French) during trial	280
Maximum brake HP. (French), calculated	220

The engine was run on a steady load, driving mill machinery.

Producers.—Two Lencauchez producers coupled together, but arranged to work independently during the clinkering of fires.

Conditions.—The producers were filled before starting the experiment and left full at the end of the trial, the fuel used being taken from a separate weighed quantity of 10,000 kilograms and used until exhausted, when the length of run was found to be 194 hours.

Consumption of fuel—grams per French I.HP. hour . . 368

equal to 0·803 lb. per British I.HP. hour, or to 1·043 lb. per British brake-HP. (calculated).

Jacket cooling water	6,100 litres per hour.
Water for washers and producers	3,000 ,, ,,
Total water consumption per British brake HP. hour	58·3 lbs.
Estimated cost of fuel ,, ,, ,, ,,	0·067d.

Discussion.

Mr. Wolfe Barry. Mr. J. Wolfe Barry, C.B., President, in moving a hearty vote of thanks to the Author for his interesting and suggestive Paper, said that it opened up a subject which might have a great and important future, and he hoped it would be discussed in all its bearings.

[H]umphrey. Mr. H. A. Humphrey remarked that since the experiments tabulated in the Paper certain changes had been made, and the working of the producers had been improved in several respects. A typical gas from Mond circular producers now contained 40·6 per cent. of combustible gases; the analysis in volumes per cent. being:—hydrogen, 28·0; carbonic oxide, 10·8; marsh gas, 1·8; C_nH_{2n} gases, traces; carbonic acid, 16·6; and nitrogen, 42·8. From daily samples of the gas taken during the month of February, 1897, the average calorific value, as determined by the Junker calorimeter, was 1,352 kilocalories per cubic metre. To show the regularity in the heating properties of the gas, it might be mentioned that the highest calorific value during that month was 1,403 and the lowest 1,322 kilocalories, giving the maximum variation between 3·77 per cent. above, and 2·2 per cent. below the average. The average analysis of dried samples of slack used in the producers showed, during February, 10·82 per cent. of ash, 69·60 per cent. of total carbon, 1·30 per cent. of nitrogen, and 18·28 per cent. of volatile matter, other than carbon, driven off at a temperature above 100° C. The calorific value of the fuel now employed was always below 7,000 Centigrade heat-units per unit weight, as determined by the Berthelot bomb calorimeter, in which the fuel was burned in oxygen compressed to 24 atmospheres. The remarks in the Paper regarding the immunity from repairs of the first circular producer erected still held good. The Mond gas-producer and recovery plant was not, at any rate for the present, applicable to installations where less than about 20 tons of fuel were used per day. On any smaller scale the recovery plant would be expensive in proportion to the output.

[Mr]. Dowson. Mr. J. E. Dowson congratulated Dr. Mond upon the thorough manner in which he had attempted to grapple with a difficult subject. He might not agree with all Dr. Mond's conclusions, but he could at least admire the skill and care with which he had designed the plant. It was well known how much engineers were

Mr. Dowson. indebted to the late Sir William Siemens, for his work in connection with gaseous fuel, and it was gratifying to know that a distinguished countryman of his was following in his steps and was giving the matter close attention. He gathered from the Paper that Dr. Mond's first generator was made in 1893; and it was striking that that gentleman should have there and then built a generator capable of converting as much as 1 ton of fuel in the hour. He remembered that many years ago, when he had first dealt with the subject, his little generator was capable of converting only 20 lbs. or 30 lbs. of coal per hour; and even if he had then had the means at his disposal, he did not think he should have had the boldness to attempt such a size as 1 ton per hour. In Appendix I, Table I, he observed that the average amount of carbonic acid in the Mond gas was 16 per cent. In another Table it was given as 12·9 per cent.; he need hardly say that both were exceptionally high for producer-gas. Yet in Table VIII a figure of merit was adopted for the Mond producer which placed it at the top of a list of various other producers. He thought the basis of calculating that figure of merit—taken from a Paper[1] by Mr. C. F. Jenkin—misleading for producers which were worked by steam. He had determined the efficiency of a producer from the heat value of the gas in relation to the carbon in the fuel gasified, and that, doubtless, was right where the gas was produced with an air-blast without steam; but where both steam and air were sent through the fire, hydrogen was added to the gas produced, and the steam consumed for that purpose, which represented an additional coal-consumption, should be taken account of. In Dr. Mond's process an exceptionally large quantity of steam was used; and he thought it was wrong to give a supposed efficiency to the gas-producer alone without taking into account the steam required to carry on the complete process of making the gas—apart from the recovery of the ammonium sulphate. He thought the Author would probably find that Table VIII needed correction on that account. In Appendix III, Table I, it was stated that the gas consumed by the engine was measured by meter, and that the slack used at the producer was 1·03 lb. per I.HP. hour. Seeing that the producer was gasifying nearly 1 ton of coal per hour, that the engine consumed only 3,051 cubic feet an hour, and that the engine trial lasted only 2 hours, he would ask how the fuel consumption for the engine alone was arrived at, even to two places of decimals. Would the

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 328.

Mr. Dowson. Author also state whether this allowance included the fuel equivalent for producing the steam used in the production of the gas? In Table III the Author appeared to have included in the cost of the gas 60 lbs. of water per brake HP. per hour; but actually that water was used for the cooling of the engine only and had nothing to do with the cost of the gas. He was surprised to find that Table V supposed the recovery plant was not used, while the whole of the Paper seemed to deal with the recovery of the sulphate of ammonium as an integral part of the process. It seemed that the cost of Mond gas made on the scale of some 2,000 I.HP. should hardly be compared with that of a small plant of 150 HP. only, working for only 8 hours or 10 hours per day, and charged with the usual stand-by losses. In the large plant, the work was going on continuously night and day, naturally under certain advantages in that respect. It seemed that it would be as correct to compare the working-cost of large steam-engines and boilers on board a vessel running continuously night and day, with a small stationary engine on land, the boiler fire of which was banked 14 hours or 16 hours per day. In some districts the use of bituminous coal would no doubt be cheaper than working with anthracite or coke; but in many places the prices were practically the same. The generators he had designed were now made to work with small anthracite costing between 6*s.* and 7*s.* a ton at the pit in South Wales, or at pits near Glasgow, when bought in single truck-loads. Bituminous coal cost about the same in those districts; so that for the South and West of England, and for many parts of Scotland, the cost of the coal delivered would be practically the same in each case. For those districts, therefore, if there were no recovery of the ammonium sulphate, which was the case in the particular Table he was referring to, there did not appear to be any gain in the Mond process. For the Midlands and the Northern Counties the case was different, and there it would be advantageous to use bituminous local coal where it cost appreciably less than coke, provided that the first cost of the plant was not excessive. With regard to furnace work with Mond gas, he was disappointed at the statement in the Paper to the effect that more coal was used for the gas-firing than by the ordinary system. That loss, he supposed, was partly due to the fact that the gas contained such a high percentage of carbonic acid, and that some of the hydrocarbons had been washed out. He wished to know more precisely if that loss were compensated by the recovery of the ammonium sulphate, and also what was the initial cost of the plant required to carry out that process. Some years ago he had had occasion to design a furnace, for the Projectile Company at Wandsworth, for heating billets of steel before they were compressed into shells. When the furnace was fairly at work, the Company had made an independent 12 hours' trial with the gas furnace, in comparison with another furnace of exactly the same size and doing similar work, but heated with a fire in the ordinary way, each furnace having its own gang of men and its own machine. The result showed that the new gas generator consumed 765 lbs. and the old system 1,276 lbs. of coal, or a saving of 40 per cent. in weight of coal in favour of the gas-fired furnace. It appeared that the Mond producer was not intended to work on such a small scale. On the supposition that there were several such furnaces to be heated, requiring 5 cwt. or 6 cwt. each per hour, or any other figure that the Author considered fair, he would ask whether it was cheaper to work such furnaces with producers of well-known types or with the Mond recovery plant, with its 16 per cent. of carbonic acid and with all the hydrocarbon vapours removed. Mr. Dowson.

Mr. G. L. ADDENBROOKE noticed from the Paper that the amount of ash was taken at 7·3 per cent., but the Author now appeared to be using coal with 10 per cent. to 11 per cent. of ash. From a Table giving the moisture, ash, and combustible matter in Welsh, Scotch, Staffordshire and other slacks, or coal dusts, he found such percentages of ash as 17, 12 and 18, though one was as low as 6·4. Some Staffordshire dust gave as much as 28 per cent. Breeze-dust had 16 per cent., coke-breeze 24 per cent., and so on, so that apparently the majority of the fine slacks referred to by the Author had a larger percentage of ash than the particular fuel used by Dr. Mond, though the word slack was used in a very elastic sense. He would ask whether the Author thought that an additional quantity of ash would affect the work of the furnaces. The question of long-distance transmission, say from the Midland Counties to London, was a point to which he had given a good deal of attention three or four years ago, when power had been transmitted from Schaffhausen to Frankfort. In that case the distance of transmission was 112 miles, or about the same as from the Midland coalfields to London; consequently if it could be done in the one case it could be done in the other. The first conclusion at which he had arrived was that the only gain would be the difference in the cost of carriage of the coal from the pits. The cost of the conveyance of coal from the Midlands by the London and North Western Railway Company was about 5*s.* 10*d.* Mr. Addenbrooke.

Mr. Addenbrooke. per ton, including truck hire. If a central station were erected near the collieries on such a large scale as mentioned in the Paper, it would not be possible to depend on one colliery, and therefore something would have to be paid for transmission even in this case. Subtracting 10*d.* on this account, 5*s.* a ton was left of difference between taking the coal and turning it into an electric current in the Midlands and employing it in London. He had no doubt that the figures given by the Author were correct if current could be sold at 2½*d.* a unit to supply companies in London. But the supply companies in London were already making current for themselves for less than 2½*d.* per unit, so if they wanted a supply from the outside of current at all they wanted to get it at about 1*d.* a unit. Under those circumstances he was doubtful if such a scheme would be successful. Further, although he thought the other difficulties would be conquered in time, there were still important points, such as the power of insulators to resist high pressures, which were by no means satisfactorily settled at present. The problem had been dealt with some years ago by Messrs. Swinburne and Thwaite who intended to use gas-engines, and the Author referred to it now as one which could be carried out still better by Mond or producer gas; it appeared, however, that the Author's argument was much more against it. He observed that 1 lb. of slack produced 77 cubic feet of gas, and that was about what was required per HP. in a gas-engine; but from Appendix II, the results of using gas under the Babcock-Willcox boilers, 1 lb. of slack would evaporate between 7 lbs. and 7·36 lbs. of water; therefore 10 cubic feet of gas would evaporate 1 lb. of water, which needed about 1,000 British thermal units. Consequently, taking 14 lbs. of steam per I.HP. as the best that could be obtained in practice with a steam-engine, nearly 160 cubic feet of gas fired under the boiler were required; but the tests in the Paper showed 1 brake HP. hour with a gas-engine for about 73 cubic feet or 80 cubic feet; therefore by using a gas-engine only half the amount of coal used for a steam-engine would be required. So that if in the first case there was an advantage in sending current from the coalfields it was very much reduced by using gas, only half the coal being required, and therefore only half the carriage. Supposing, notwithstanding that a central station were erected in the Midlands to supply power, the railway companies charging 5*s.* 10*d.* per ton, and another rival station was erected just off one of the main lines outside London, if they could get cheap carriage; it would not be likely that the railway company would allow all that carriage to pass out of its hands. The coal would be probably delivered a train-load at a time collected from a single colliery; it would be cheaply managed, and would go straight into the central station sidings; under these circumstances was it not likely that the railway companies might be induced to reduce their rates to about one half? Looking at these uncertainties he thought it would have been better to have omitted the point of transmitting power to a great distance from the Paper; on the other hand, he thought there was a great opening for the transmission of power over moderate distances. He had considered the question carefully, and his idea of the economical limit of electrical transmission, unless there was a waterfall in one part and a town in another, under ordinary circumstances was between 8 miles and 10 miles at the outside. Certainly if Dr. Mond could make gas-engines work on anything like the basis stated in the Paper, there was a wide field for their use, but he was afraid the opening did not lie in the direction of long-distance transmission. Mr. Addenbrooke.

Mr. T. Parker had, four or five years ago, investigated the subject under discussion with the then means of producing gas for gas-engines for the purposes of applying power, and again in another case for a large electro-chemical application. In those cases he found that the gas and the gas-engines available at the time were not so cheap and handy as steam, and he was therefore compelled to recommend steam-engines. He was glad to see from the Paper that the application of bituminous coal for producing power in gas-engines was within reach. He observed that Dr. Mond was able to produce 1 HP. of work with 1·03 lb. of bituminous slack, and at the same time produce a product which would be very valuable in the shape of sulphate of ammonia. He thought it would be better to apply the figures to some means by which they could be continuously worked, such as an electrolytic or electro-chemical application. With regard to producing power for transmission on a large scale, there was also great scope for its application. He thought the figures assumed by the Author with regard to the capital outlay of a plant capable of yielding 10,000 HP. excessive, and would not do justice to the possibilities of the case. It might be reasonably expected to run such a plant of 10,000 HP. for 8,000 hours per annum; that would give a margin of 760 hours per annum for any attention that might be required upon the plant; and, comparing that with water-power, the time would be reasonable. That number of hours would yield about 80,000,000 HP. hours per annum, and give 1 HP. year for the cost of 16*s.* with 7 per cent. for depreciation. Any smaller number of hours would proportionally affect that figure. There was an unlimited amount Mr. Parker.

Mr. Parker. of slack coal, as suggested in the Paper, to be obtained at the rate of 500 tons per day at 2*s.* 6*d.* per ton, and this could be used in the neighbourhood of the colliery. Allowing $1\frac{1}{4}$ lb. per HP., brought it out at 10*s.* per HP. year, making a total cost per HP. year of 26*s.* for coal and depreciation of plant, or about $\frac{1}{25}$*d.* per HP. hour. Those were results which he expected to see realized, and which he had long ago thought possible and probable. He hoped they would soon be put into practice, because the field of electrical application would then be unlimited. He had a number of applications for plant that could be put to work at such a price, to say nothing of the ammonia products, which should balance the whole 26*s.*, and would give power for practically nothing, except attendance, oil, and the like. The figures he had referred to placed the prospect of electrical industry in a very hopeful light, and he expected real results to follow the Paper. With regard to sulphate of ammonia, it would need special attention, but he felt that that could be left to Dr. Mond.

Mr. Preece. Mr. W. H. Preece, C.B., Vice-President, called attention to the marvellous and rapid growth of electrical industry, and to the advantage which that industry must experience by the introduction of such processes as that which Dr. Mond had brought forward. To illustrate that growth he might mention that only that day he had been inspecting an installation which two years ago was thought to be gigantic, when he suggested that a plant of 375 kilowatts should be installed. In the short space of two years the question had to be considered of exactly doubling that plant. If it progressed at that pace, and there was no reason why it should not, in another two years it would double itself again. It seemed almost a rule in most of the electric-light installations that were started under good conditions, that they doubled themselves at a marvellous rate. There was one striking fact coming out in all those additions and enlargements of electrical industries, to whatever purpose they were applied, viz., that the cost of production was diminishing with the magnitude of the output. If, in addition to that natural reduction in the cost of output, there was introduced, with the assistance of able chemists, such as Dr. Mond, a process also of reducing the cost of production, the result would be, as the electrical industry grew, that the cost of production would diminish almost as the square of the output. If there were any truth in that deduction, it was certainly something that should make not only those who were interested in gas manufacture think seriously, but it was one of those things that applied to all, whatever their occupation might be and in whatever direction power was applied. In the case, for example, of the Post Office, Mr. Preece. wherever large new post-offices were being built electrical plant was being applied to all kinds of purposes. It was not alone used for electric lighting, it was used for lifts, for air-pumping engines, for pneumatic tubes, for working folding machines in the savings bank, and even for melting wax, an enormous quantity of wax being used for sealing registered packets and parcels generally. The more the cost of production was reduced, the more the use of that form of energy was applied to the useful purposes of mankind, and therefore engineers should hail with satisfaction the introduction of any processes, whether Mr. Dowson's or Dr. Mond's, which reduced still further the cost of production. The main feature of Dr. Mond's process—the process by which bituminous coal could be applied to gas production—was a feature distinctly in the right direction. He had heard even of a better case than the cost of 2*s.* 6*d.* a ton referred to by Mr. Parker, that of a large coal-owner, who said he could supply 500 tons a day at the pit mouth, of slack, at 1*s.* per ton, which could be converted into gas. It was all very well to supply coal at 2*s.* 6*d.* or 1*s.* per ton, but it had to be taken away from the mouth of the pit. The questions were (1) whether it was more economical to transport the coal in bulk from the pit's mouth to the place where it was to be consumed, (2) to conduct the results of distillation, namely, the gas in pipes, to the point of usage, or (3) to transport the energy produced at the pit-mouth by the combination of coal converted into gas and there and then utilized for the production of electrical energy, and thus transported to great distances. He did not go so far as Mr. Addenbrooke, who had limited the distance to a very short one. But from calculations he had made, he had found it was much cheaper to transport fuel in bulk from the colliery districts to London than to attempt to transport it in the form of electrical energy. How far, with coal at 1*s.* a ton, it would be remunerative to transport gas to London was another question. The whole of the Chicago Exhibition in 1893 was lighted, and power distributed, by gas brought about 130 miles, from Pennsylvania. The results were very satisfactory and certainly economical. He had said that the larger the output the cheaper the cost of production. There was another and most important point in connection with the cost of production; the output must not only be large but must be continuous. He had already mentioned in that room that, even with present knowledge, with the use of coal, with economical high-pressure engines, it was possible with a large output, used continuously, as, for instance, in the case mentioned by Mr. Parker

Mr. Preece. of electrolytic depositions of copper and the electro-chemical deposition of phosphorus, to produce energy continuously and easily in great magnitude for less than $\frac{1}{4}d.$ a unit. The great hope inspired by the Paper was that that could be even reduced. It was pointed out that by taking 10,000 HP. it could be produced at practically $\frac{1}{6}d.$ per unit. When it was possible to develop a kilo-watt-hour of electricity, viz., $1\frac{1}{3}$ HP., continuously for an hour, at $\frac{1}{6}d.$, there was no other available form of energy which could compete with it. All workshops would utilize that form of energy, and it would be possible to remove those noisy and uncomfortable shaftings that were so disfiguring. The force could be applied, too, where it was wanted and when it was wanted, and, to a certain extent, many of those industries could return to the home instead of being concentrated under the tyrannous rule of Trades Unions in large workshops. Then there were possible combinations in the towns of electric lighting and tramway working. The experience of America and the Continent, and, on a smaller scale, in England, as in Bristol, Dublin, Leeds, and other places, showed that of all the systems of working tramways there was none so comfortable or so promising, and none so economical, as that of the application of electricity; however much or little the tramway working might cost during the day, it would cost less when the power was utilized for a longer period during the night for lighting. Looking at the growth of the industry, therefore, from all points of view, with its innumerable applications, such a process as had been invented by Dr. Mond and brought forward by Mr. Humphrey, led engineers to expect that in the very near future electrical energy was going to walk away with all other forms of power, and that the production of electricity for every purpose—many other than those to which he had alluded—was certain to become, not only practical, but economical.

Mr. Jenkins. Mr. H. C. Jenkins thought Dr. Mond had demonstrated the possibilities of regenerating at low temperatures. He had been able to pass an enormous quantity of steam through producers and thus keep the temperature down without losing the heat he otherwise would. He had also overcome the difficulty of clinkering, and recovered the ammonia. This was accomplished at the expense of having a larger amount of carbon than usual in the ash, and the hydro-carbons of the C_nH_{2n} series were lost; but apart from that, Dr. Mond obtained a good gas. Although, as Mr. Dowson had pointed out, an enormous quantity of carbonic acid was present in the product, he should look also at the very large amount of hydrogen. In the present case, Dr. Mond had obtained a large amount of hydrogen at the expense of some carbon monoxide. It was obvious the plant could not be used on a small scale on account of the capital cost and the trouble the apparatus involved. With regard to the proposals for obtaining energy in an electrical form in the Midlands and bringing it to London, he would ask were not still risks being run from strikes. In the distribution he would also suggest that shafting could not be eliminated. The cost of motors to each and every machine would be prohibitive, and it would be necessary to have a certain amount of shafting and belting, although factories were supplied with electrical power. The Author appeared to have chosen good general conditions under which to burn the gas when he adopted the firebrick combustion-chamber to his boilers. He would suggest, however, that its use had not been highly successful. There was an enormous quantity of carbonic oxide in the flue gases, and no free oxygen. Was not that a reversal of the usual order? Air was cheaper than producer-gas, and would it not be better to use more air and have a slight excess of oxygen? It was true the carbon monoxide could not be completely burned; still it could be reduced certainly to some much smaller figure than 3½ per cent. The combustion-chamber appeared to be too small, and the maximum amount of gas had been put through it in order to raise sufficient steam in the boilers. The temperature of the flue gases was very low, a result due to the clean state in which the boilers could be kept when using the gas, rather than to any efficiency of the gas-firing. The efficiency of the gas itself did not seem to be quite what it might be made. The gas-engine was by far the most important motor now to be considered, and some of the benefits might be expected in it that must be derived from using a thoroughly washed gas. He would ask the Author whether the use of the sawdust-filter was compulsory or whether it could not be altogether dispensed with by having more washing-towers? He should be glad to know, too, what kind of meters were used in the tests of the gas-engines, and whether they were standardized before use. The Author had referred to the economy that would result if gas-engines could be run in conjunction with the plant, because of the increased heat efficiency of the whole plant. It would be interesting to see how far economy could be carried by such means. For metallurgical purposes the gas seemed to be very good, in spite of the large amount of carbon dioxide and the small amount of water vapour. That small amount of water vapour could of itself be of no harm, provided the regenerators for the furnaces were large enough. The thorough washing of the gas would enable use to be made of certain kinds of slack that would be otherwise objec- Mr. Jenkins.

Mr. Jenkins. tionable on account of sulphur, the plant offering special facilities for the elimination of this element. Some account of the capital and interest charges would be of interest to show the minimum limits of size and the output per day.

Mr. Head. Mr. JEREMIAH HEAD thought the process described in the Paper was of the greatest importance to all engineers. He felt especial interest in it in connection with the iron and steel industries, which were becoming more and more dependent on gaseous fuel. It was only recently that English steel manufacturers had been alarmed by the competition of the United States. The steel sent to England came from Pittsburg, where one of the advantages in making it cheaply was the use of natural gas. It would be seen from Table VI, p. 208, that Pittsburg gas contained nearly double the amount of combustibles that producer-gas contained. There were enormous advantages to the steel-melter and the steel-heater in having a gas of that kind which contained heat in so concentrated and easily-dealt-with a form. In meeting that competition in future, it was of the greatest importance that the methods of making gas for application to metallurgical processes should be improved. Better and cheaper gas was required, if for no other reason than that of helping to meet foreign competition. The process described in the Paper was extremely interesting, as it appeared to enable more power to be obtained out of the coal burnt than by any other way, something like one half as much again as was obtainable in the very best engines and boilers of which he had any experience. The question had been asked whether the apparatus could not be worked without the recovery process. It had been shown distinctly that the apparatus could be perfectly well worked in that way, and if that was done, the saving of the coal over gas produced in any other way was reckoned at 25 per cent. Another advantage of using this system, even without the recovery plant, was that clean gases were obtained—gases that could be conveyed to almost any distance without risk of deposition in the pipes or flues. It also diminished the sulphur and the cost of labour. He wished to point out what he thought had not been sufficiently dwelt upon, namely, the extreme regularity of the process. With self-acting conveyors and elevators the fuel passed into the producers, and the ashes were withdrawn at the bottom with the utmost regularity, so that it became a continuous process resulting in the gases being of an exceedingly equable and reliable kind. That was of great importance, indeed some of the more delicate processes could not be carried on without gas of that kind. He understood from the Paper that Dr. Mond considered that the value of the ammonium sulphate was equal to the cost of the coal; so that either the gas or the ammonium sulphate was obtained for nothing. That was really one of the great advantages and compensations obtained from that somewhat costly apparatus. He agreed to the desirability of knowing the cost of the apparatus. He was somewhat disappointed to find that the slack used was estimated to cost 6*s.* 2*d.* when delivered to the producers. It certainly must have been slack of a very superior kind, or it must have had a very high cost of carriage upon it. He agreed that slack could be obtained in quantity in certain colliery districts in England at 2*s.* per ton at the pit. Very large quantities had been shipped at the Tyne in times past for 1*s.* a ton; indeed, thousands, if not millions of tons had been put in heaps at the collieries and allowed to go to waste altogether. Anything that turned slack into useful gas must be a national advantage. One of the great advantages of Dr. Mond's system was that, by previously lowering the temperature, a great deal of the moisture which would otherwise go forward was condensed and taken away. Those wet gases were very bad for metallurgical purposes, but the gas when cooled and therefore dried, as in the present case, was perfectly good for melting steel. Nothing had been said in the Paper about the by-products other than ammonium sulphate. He supposed that as the tar was retained they were retained with it; therefore the only by-product was the ammonium sulphate. In carrying the system out to the almost unlimited extent contemplated by the Author, it had occurred to him whether the demand for ammonium sulphate was unlimited. He hoped it was, in order that the system might thrive in that way, and also that the depressed agriculture might derive benefit from an unlimited supply of almost the best manurial substance that existed. He understood that it was of special importance because it was so good for grass, and it was well known that latterly more and more agricultural land had been laid down in pasture. Mr. Head.

Dr. H. E. Armstrong considered the Paper gave an account of the first moral process which had been put forward for producing gas—the first attempt to recover a by-product that should not be sacrificed. He thought ammonia was one of those things that it was not right to throw away, considering its great value from an agricultural point of view, and one of the important features in the Paper was the necessity of taking care not to waste any of the ingredients in fuel which were commonly wasted. Hitherto an enormous proportion of valuable material had been sacrificed, but Dr. Mond had explained how to do the work in a moral way. Dr. Armstrong.

Dr. Armstrong. The percentage of carbon dioxide in the gas was extraordinary in comparison with that present in most producer-gases, and he could not help thinking that considerable improvement might be effected in the quality of the gas in that direction. If a diminution in the percentage of carbon dioxide could be brought about, the fuel would undoubtedly be a more valuable one. He asked whether the experiments on the use of the gas for firing, not boilers or evaporating vessels, but high-temperature furnaces, had been sufficiently numerous to bring out the value of the gas? The point which had been brought into special prominence by Mr. Frederick Siemens—the great value of carbonaceous matter in fuel used in high-temperature furnaces—was one to which attention had to be directed in considering the value of the Mond gas; the gas in question appeared to be particularly free from hydro-carbon constituents. It might be thought that the gas would not lend itself so well to steelmakers' use, not only on account of the presence of a large amount of carbon dioxide, to which Mr. Dowson had referred, but also on account of its freedom from constituents which would give rise to the separation of carbon in a condition to promote radiation at high temperatures.

Mr. Bauerman. Mr. Bauerman thought Dr. Armstrong, in his remarks about carbonic acid in the gas, had rather missed the point—that in gasification at a low heat (which appeared to be the essence of the whole matter) the production of carbonic acid in quantity was a necessary consequence, with a large development of sensible heat which was taken up by the most effective regenerator—a large quantity of water. With regard to the use of Mond gas in regenerative furnaces, it appeared from the data given by Mr. Darby,[1] that in the preliminary heating in the regenerator reconstitution of the gas took place, though the mutual reaction of carbonic acid and hydrogen gave rise to water and carbonic oxide with some increase in the thermal value per unit volume of the gas before it was burnt in the Siemens furnace. Although it was a "poor" gas as compared with water-gas made by the intermittent process, it proved perfectly efficacious for steel-melting, and, apart from the ammonia recovery, another advantage was to be found in the freedom from dust of the fuel-gas obtained. He thought the Paper showed a most remarkable example of what might be called low-temperature regeneration. The four up-and-down pipes, and the towers, contained the essence of the whole thing. It was a remarkably beautiful process, and he was ex-

[1] Journal of the Iron and Steel Institute, vol. xlix. p. 144.

ceedingly glad that it had been so fully and completely brought before the Institution. Mr. Bauerman.

Mr. HUMPHREY, in reply, said that Dr. Mond's experiments dated from 1879; and when, ten years later, he described his system to the Society of Chemical Industry, a large plant of square producers was at work. It was from the experience gained with these producers that he was enabled to at once build a circular producer of the capacity stated. In Appendix III, Table I, given simply in connection with a gas-engine trial made a year previous to the other experiments, the gas was not a pure circular-producer gas, but was mixed with that from square producers, the supply being drawn from a main common to both. The higher figure for CO_2 was the correct one for the producer described. The reason the gas, containing as it did so much carbonic acid, headed the list with the best "figure of merit," was to be found in the large quantity of hydrogen present, which had been chiefly raised at the expense of that portion of the carbon burnt to form CO_2. To introduce into Table VIII such a correction as that proposed by Mr. Dowson would make the Table misleading, for in the Mond plant the steam used was partly that recovered by the regenerators, and the remainder was exhaust steam which would otherwise be wasted. On the other hand, the Dowson plant used steam which had to be generated purposely and supplied under pressure. Suppose, however, that no exhaust steam was available, and that the producers were worked for the sake of the gas only, then the Dowson and Mond plants both required about the same proportion of additional fuel for steam-raising, as might be clearly seen from Appendix III, Tables III and V. The 1·03 lb. of bituminous slack per I.HP., as recorded in the gas-engine trial, was obviously not measured directly, but the point was important because great accuracy was required in determining such figures. From a large amount of experience the exact volume of gas obtainable from a given quantity of coal was known, and the most reliable means of verification were to be obtained from a balance-sheet of carbon quantities, taking account of the carbon in the coal, the carbon in a measured quantity of gas, and that lost in the ashes. This meant systematic and careful analyses, and at Winnington a special laboratory was devoted to the work. In the engine trials the gas was measured by an ordinary type of rotary wet meter of ample capacity, and then calculated back to slack actually fed into the producer, no allowance being made for extra fuel for steam-raising, because in a large gas-engine plant such extra fuel would be replaced by the hot exhaust gases. A Mr. Humphrey.

Mr. Humphrey. large Crossley-Otto engine, of the two-cylinder end-to-end type, capable of developing 150 I.HP., had been recently erected at Winnington to work with Mond gas, and, as might be expected from a larger and more modern engine, better results had been realized than those given in Appendix III. As complete experiments were to be carried out on this engine, it would suffice to say that on the official trial the fuel consumption was 0·92 lb. of slack per I.HP. hour, and the thermal efficiency 26·85 per cent. To insure accuracy, a meter with a capacity of 20,000 cubic feet per hour was used to measure the gas. In Appendix III, Table V, it was intended to place the case of the Dowson plant in as favourable a light as possible, for in no instance he had investigated had he found a plant regularly making 1,000 cubic feet of gas for the sum mentioned; also the cost of the extra fuel at the boiler had been purposely omitted. In the corresponding figures for the Mond plant, this extra fuel had been included. If the locality of suitable pits was to be chosen, the cost of bituminous fuel for the Mond process would be considerably lower than that given in the Paper. As regarded furnace work with gas-firing, it was true that this method required a larger consumption of coal when compared with careful hand-firing carried out under favourable circumstances. Nor did it appear possible that it should be otherwise, for, although the balance of advantages remained in favour of gas-firing, some heat must be lost in converting the fuel to the gaseous state, no matter what producer was adopted. The comparison instituted by Mr. Dowson, in which a saving of 40 per cent. was shown in favour of gas-firing, would indicate that the particular example was either not suited for direct-firing, or that the hand-firing was badly carried out. In any case where gas-firing was adopted, and when leaving out of account the recovery of ammonia, that producer was the best which yielded the greatest number of heat units in the total gas made from 1 ton of coal. Table VIII provided a clear answer to Mr. Dowson's question on the subject. As to the suitability of slacks for use in the Mond producer when they contained a large percentage of ash, his experience showed that a heavy ash did not involve difficulties in working; but he had no experience of such percentages as 28 and 34, which must be regarded as exceptional. When generating power by gas-engines using Mond gas, a given HP. could be obtained for a given time with an expenditure of half the fuel required by the best steam-engine, and at a still greater reduction in cost, whether the central station was in the Midlands or in London. The costs quoted by Mr. Parker might be possible, but those in the Paper were given with a margin on the safe side. The large sulphate-of-ammonia plant at Winnington, with its regular supply to the market, was a standing proof that the ammonia question was no longer in the problematic stage, as Mr. Parker's remarks would almost indicate. With regard to the valuable remarks of Mr. Preece, and his important suggestion to transmit energy by distributing Mond gas through pipes, Professor W. C. Unwin had made[1] calculations which showed that large powers could be transmitted in this manner by comparatively small pipes and with very little loss of energy, due to the pumping power required to put the producer-gas under sufficient pressure for distribution. He had the best authority for stating that the cost of motors was not prohibitive, as stated by Mr. Jenkins, at any rate for new factories, for in such cases the saving in first cost had been conclusively proved. In the performance of Mond gas burnt under a Babcock-Willcox boiler, and showing, in Appendix II, a proportion of unburnt CO, some of the flames had been extinguished by the comparatively cold tubes before combustion was complete, so that it would have been possible to have an excess of oxygen, and yet some unburnt gas. The difficulty had been overcome by shielding the portion of the tubes closest to the perforated arch, and by enlarging the combustion-chamber. It was quite possible to burn all the combustible gases under proper conditions. When Mond gas was applied to a gas-engine, the sawdust filter might be desirable, but was not necessary, as was shown by such a filter running for more than a year without being disturbed. The total cost of a plant in connection with the 10,000 HP. central station was £20,000. This sum included the fuel handling plant, the producers, towers, regenerators, sulphate plant, and all blowers, engines, pumps, tanks, and machinery erected and in working order. In reference to the cost of slack, viz., 6*s.* 2*d.* per ton, Winnington, which was close to Northwich, in Cheshire, had been chosen for Messrs. Brunner, Mond and Company's works because cheap salt and brine were obtained there, and not on account of cheap fuel. All the important coal districts were at a distance, and the cost of carriage was a considerable item. The demand for sulphate of ammonia could not be called unlimited; but it may be regarded as nearly so. In a recently published work,[2] Mr. Legrand estimated that England consumed Mr. Humphrey.

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[1] "Development and Transmission of Power," 1894 ed. p. 262.

[2] "L'Ammoniaque, ses nouveaux procédés de fabrication et ses applications," by P. Truchot. Paris, 1896.

Mr. Humphrey. $\frac{1}{66}$th of the quantity of nitrogenous manures which could be advantageously and economically used for agricultural purposes. Also the amount of nitrogen in sulphate of ammonia was 21·21 per cent., against 16·47 per cent. contained in nitrate of soda, and as the unit of nitrogen was of equal value in both forms, there was good reason to believe that sulphate of ammonia would replace nitrate of soda for mixed manures, in spite of the splendid organization of the nitrate trade. Dr. Armstrong's inference that Mond gas would not be so useful where very high temperatures were needed was found to be contradicted by practical results. Without going into the curious change which took place when the gas passed through a high temperature regenerator, and which had been dealt with in Mr. Darby's Paper, another interesting fact might be recorded, namely, that this clean washed gas, which burned at lower temperatures with a pure transparent blue flame, became intensely luminous at high temperatures, and apparently the radiant effect valued for steel furnace work was fully realized. The steel furnace at Winnington was carried on as long as there was anything to learn from the experiments, and the results proved beyond all doubt that the gas was in every way suitable and economical for making the best qualities of steel. He thought the presence of so much CO_2 could not be regarded as detrimental while the equivalent in hydrogen was present. It did not in any way limit the useful application of the gas, and if this gas contained more heating value than could be obtained by using any other producer, this seemed, after all, to be the most important point. As to starting, stopping, and working a producer at different speeds, if the circular producer was to be started for the first time, a preliminary drying of two or three days was necessary. In any case, if the producer had been emptied, and was starting cold, it was advisable to proceed to heat slowly, the fire being lighted with shavings and wood, and fed with coke, the bottom and top of the producer being open, and the combustion regulated to prevent too high a temperature. When the wood was all burnt, the bottom lute was filled with water, and only a very small amount of blast was used. Coke was employed until there was a depth of 6 feet in the producer, then the attendant began to add slack. The gas formed was wasted until it tested 30 per cent. of combustible gases, when the conditions could be quickly brought to the normal state. This process should not be necessary more than once a year, because when once started, there was no need to entirely stop a Mond producer. Its output could be regulated by the blast within wide limits, and, if desirable, it could be shut down for a fortnight, with the fire in it, without requiring attention during that time. The method was as follows: The producer was cooled by a good charge of fresh slack, then the blast was reduced as the first regenerator pipe was being luted with water, the gas blowing away through the ball-valve on the producer. Finally, as the gas generated diminished to a very small quantity, provision for its escape was made by placing the hole in the ball-valve in a vertical position, so that the pressure inside and outside the producer was maintained uniform. A producer stopped in this manner retained enough fire in its mass of fuel to be started at short notice any time within a fortnight. Mr. Humphrey

Correspondence.

Mr. E. Delamare Deboutteville, of Rouen, was gratified to find that the difficult problem of the utilization of rich coal was about to be at length solved, and that the progress of the gas-engine would no longer be hindered by the unfortunate consideration of the choice of fuel. The new gas-producers, with their very complex apparatus, would be but little applicable to small powers, but with such powers as 150 HP. or 200 HP., it was possible to realize greater economy than had hitherto been possible. As the Author had justly pointed out, electrical transmission to a distance, with the establishment of large central power-stations to distribute the energy to a spreading district would involve economy superior to the best which could otherwise be realized in practice. Such cheap power could not be obtained with steam, for the results now realized nearly approached the possible limit, and could certainly not be greatly improved upon. But in the case of gas, however great the advance during the last few years, a large margin still remained for increased economy. Steam-engines, in the present state of knowledge, had, with the exception of perfection in details, achieved almost the highest efficiency that could be expected from them; but gas-producers were still imperfect, in the sense that they had not been able to utilize rich coal for the production of power-gas. When this barrier had disappeared, and cheap coal from whatever field could be utilized for the production of power-gas, large installations of gas-power plant would arise on all sides, and the great progress which had been shown to be possible would be an accomplished fact. Having made many experiments with various apparatus, and with rich coals from numerous districts, he Mr. Deboutteville.

r. Debontte-lle. appreciated the difficulties of their utilization, and he viewed with gratification the fact that the new producer took them into account and successfully overcame them.

ssrs. The smotoren brik Deutz. Messrs. THE GASMOTOREN FABRIK DEUTZ, noticed that the Mond gas-producer was principally adapted for production on a large scale; for generation on a small scale the apparatus was too cumbersome and expensive, and had the disadvantage of requiring careful supervision, in particular in those parts in which the gas was purified and the ammonia extracted. It was therefore probable that the simple apparatus would retain its old position for the treatment of anthracite and coke. So long as one gas-engine unit did not exceed, say, 200 HP., they could not but regard one simple generating apparatus, working with either coke or anthracite, as the most advantageous generator, owing to its extremely simple arrangement and low cost. Anthracite and coke were obtainable in abundance, and thus obviated the necessity of a large compound cleansing apparatus, which, as shown by the working of the Mond apparatus, was inseparable in the case of other kinds of coal. In small plants the price of the fuel was a matter of secondary importance; in large plants, on the contrary, the question of procuring and utilizing the cheapest fuel was of the foremost moment. In a plant installed at Basel,[1] the coke was supplied by the municipal gasworks and showed very satisfactory results, so much so that an additional engine of about 200 HP. was now being erected. They had recently tested a 16-HP. gas-generating plant and found the consumption of fuel to be 0·62 kilogram per brake HP. per hour; and, in the case of a plant for 100 HP., 0·49 kilogram. Of this 85 per cent. was anthracite consumed in the generator and 15 per cent. coke consumed in the steam boiler.

Mr. Holgate. Mr. THOMAS HOLGATE remarked that the problem of how to obtain in the form of ammonia the nitrogen of coal or coke, without loss of heating-value of the fuel, had occupied many experimenters, notably, with successful results, by Messrs. Beilby and Young,[2] in dealing with shale in the oil-works of Scotland. He was impressed with the results obtained by those gentlemen (who had improved on the method of Dr. Hubert Grouven, of Bürgerhof), and had in 1891 investigated the system to discover its suitability for the Halifax Corporation Gasworks. The material available was the coke from an inferior Cannel to the extent of 10,000 tons per annum, and

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[1] Sonderabdruck von Vortrag Meyer, Wasserwerk Basel; Sonderabdruck von Schöttler, Heizgas.

[2] Journal of the Society of Chemical Industry, vol. iii. p. 216.

containing 50 per cent. of ash. It was tested and found to be a material that could thus be utilized, but the estimated cost of the necessary plant for so small a yearly output, and the low price of sulphate of ammonia, left no prospect of profit sufficient to justify the expenditure. From Table V, in Appendix I, it appeared that the net cost of 1 ton of fuel, in the form of gas, was 80 per cent. of the cost in the solid form; but this was exclusive of interest on the capital. Further, the charge made for sulphuric acid would apply only inside a works where that substance was manufactured; in other works the charge would be 50 per cent. higher than that adopted by the Author. Adding the necessary items thus indicated, it appeared that the total net cost would not be much less than the raw fuel. There would remain the advantage which pertained to facility of regulation of a gas for heating purposes, which might be described as a minimum when employed for boiler-heating, and a maximum when employed for heating the cast-iron pans referred to. The greatest advantage appeared, however, to be due to the use of the fuel-gas in the newest type of gas-engine, instead of in the wasteful cycle of a steam-engine. The Author's proposal to distribute this gas from a gasworks or other central station, would thus be most suitable for users of motive power, and that within a reasonable distance from the generating station. No information was given as to the capacity or cost of gasholders for storing, and of mains for distributing this gas, but it was evident that these expenses must be considerable in comparison with coal-gas. The fuel-gas contained but 40 per cent. of combustibles, having a calorific value of 85·9 against coal-gas containing 98·8 per cent. of combustibles, and having a calorific value of 381. The heat wasted in raising the temperature of the 60 per cent. of incombustibles, would make the useful effect of coal-gas fully five times that of the other. It was eminently desirable that a gas to be distributed should not be burdened with useless and wasteful constituents such as CO_2 and nitrogen. It was evident that Dr. Mond's arrangements for the utilization of heat had been carefully devised, and with the proposal to utilize the jacket-water from the gas-engine still better results would be accomplished. In one respect, however, the method appeared capable of a substantial improvement by means that were readily applicable to the plant as now working, and which, whilst saving a large proportion of the steam used for evaporating the sulphate of ammonia liquor, would enable the percentage of CO_2 in the fuel-gas to be very materially reduced. At the Halifax gasworks there was in operation a plant for the re- Mr. Holgate.

Mr. Holgate. moval of CO_2 from crude gas by washing with purified ammoniacal liquor, and this could be applied so as to form sulphate of ammonia in an ordinary saturator, or to give nearly pure gaseous NH_3 and CO_2 separately, as might be desired.

Professor Robinson. Professor HENRY ROBINSON thought particulars of a gas-producing plant he had recently erected for the Leyton Urban District Council might be of interest. The plant was for the purpose of an electricity station, and consisted of Dowson gas-producers to supply gas to four Wells gas-engines, each of 55 brake HP. These drove (by belting) four dynamos of 35 kilowatts capacity each. The works represented the ordinary condition of an electricity-supply station, where the current had to be available throughout the twenty-four hours. It was a 150-volt continuous-current supply, on the three-wire system, with 300 volts between the outer wires. On the completion of the first half of the work, in October, 1896, he had had a trial run with one Dowson gas-producer serving two engines. The result showed that 280 Board of Trade units were generated in 5 hours 35 minutes, with a fuel consumption as follows:—

	Lbs.
Anthracite	448
Coke	52
Total . . .	500

equal to 1·783 lb. per Board of Trade unit.

The cost was thus only $\frac{1}{4}d.$ per unit for fuel. The engines were running at about five-eighths their full power, at 160 revolutions per minute, having fifty-two explosions per minute out of a possible eighty. This quantity of fuel did not include anything beyond what was put into the producer and boiler during the test, finishing with the fuel at the same level as at the start. In ordinary working the amount used in raising gas to the proper quality had to be allowed for. The plant was now in regular work, supplying electricity to the Leyton district, and the Resident Engineer, Mr. H. Collings Bishop, had supplied him with the coal-consumption as follows:—During February the current sold amounted to 5,660 Board of Trade units. The fuel-consumption was 3·92 lbs. per unit sold, costing 0·506*d.*; so that the fuel-cost was only $\frac{1}{2}d.$ per unit sold. The price of the anthracite coal was 24*s.* per ton. In March, 1897, a third engine had been finished and set to work at full load, when about 90 kilowatts were generated, using only 2·01 lbs. of coal per unit generated, and this was a fair sample of the permanent conditions of running. This led him to the opinion that the fuel consumed per unit sold would be less than 3½ lbs., and therefore less than ½*d*. This compared very favourably with the published figures of fuel-cost at other electricity stations throughout the country, and was better than any stations in or near London. The Westminster Electric Supply Company was the nearest to it, with 0·57*d*. for coal per unit sold. The provincial stations in the coal districts obtained their fuel at low prices, but out of forty-eight only ten had a lower coal-cost than that at Leyton. Professor Robinson.

Mr. F. J. Rowan observed that the large majority of the users of gas-producers had not space for, even if they had the means otherwise of using, the extensive plant which the Author had described. In the future a large development of the central supply-station plan might be applied to the distribution of gas or of electric energy for power purposes; and in such works, as in large chemical works, such as those at Northwich, elaborate gas-producing and treating plant would find a fitting home. Such works must, however, be necessarily few as compared with the bulk of users of power—at any rate, for a long time, and the many would not be greatly helped by the interesting details of plant for the recovery of sulphate of ammonia from producer-gas. The apparatus described in the Paper had undoubtedly shown itself economical in working, but it did not present any features of novelty which called for special remark; in fact, the tube-regenerator described seemed to have been anticipated by Mr. Fichet in the Muller-Fichet plans, judging from his remarks in the discussion[1] of the Paper on gas-producers which he had had the honour to present to the Institution in January, 1886. That the combustion of fuel for the production of gas with recovery of the nitrogen as ammonia should be carried on at a low temperature, with the use of abundance of steam, was plainly stated in the discussion referred to, although Messrs. Young and Beilby, following Dr. Grouven, of Leipzig, had for some time strenuously worked at and continued to advocate the high-temperature method. The low-temperature method had since been verified in the later shale retorts of Mr. Norman Henderson, of the Broxburn Oil Company, and in the Mond producers described by the Author; but where condensation and washing of the gas were inconvenient or impossible, and the maximum quantity of hot gas was wanted for heating purposes, producers would in all probability still continue to be worked at higher temperatures with air or steam Mr. Rowan.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiv. p. 83.

Mr. Rowan. blast. As there seemed to be three systems of gas-supply from producers used for gas-engines or central-station work and in competition with one another, viz., the Dowson, the Lencauchez and the Mond systems, it would be interesting and useful to have a close comparison of the three as to first cost and working expenses for an installation of a given size.

Mr. Tapscott. Mr. R. LETHBRIDGE TAPSCOTT thought that having regard to the economy of using fuel gas made from the cheapest coal, and the ease and convenience in conveying and utilizing it at a distance from the producing plant, it was gratifying to find that a waste-product had been recovered during the process, which of itself had a commercial value. Owing to the large scale on which the gas could be produced, its low temperature and absence from tar recommended it for use in place of coal, besides being free from some of the objections inherent in conveying steam about extensive works. He presumed that the storage in large quantities under pressure would require gasometers.

Mr. Thwaite. Mr. B. H. THWAITE took exception to the suggestion that the producer bearing his name was similar to the others mentioned. The effective principles of his system, both in structure and operation, were distinct, more so than in the process described by the Author, from other systems in daily use. On p. 192 it was implied that no gas-producers had been made to give good results with the cheapest bituminous coal. One of his systems had for many years permitted the worst fuel refuse, even common peat, with or without hydro-carbons in its constitution, to be used for driving gas-engines, and with excellent results.[1] There was no proof that the difficulties referred to at the Britannia Works were intrinsically associated with the use of coke. Generators had been designed, and were in daily use, that successfully dealt with this fuel. He could not reconcile the reference on p. 193 to the advantages of the low-temperature working conditions of the Mond plant with the statement on the following page that the products of distillation had to pass downwards through the hot zone, by which the tar was destroyed and converted into a fixed gas. To volatilize hydro-carbons and afterwards to convert such products of volatilization into a permanent gas, involved the establishment of the following conditions:—The volatile gases from the distillation of the hydro-carbons must be compelled to flow through and in intimate contact with 2 feet to 3 feet of fuel, in a condition of

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[1] *The Times*, December 25, 1894, and March 30, 1895. *The Journal of Gas Lighting*, vol. lxv. p. 1191. *The Engineer*, vol. lxxx. p. 3 *et seq.*

bright incandescence, otherwise the products of tar volatilization would recondense. As far back as 1885 attempts had been made to compel the volatile hydro-carbons to pass downwards through the fuel in a single-vessel generator. All such attempts had proved failures, because the fuel above the lower edge of the drop-curtain wall was at a comparatively low temperature, and also because the heated gases were diverted from, and did not pass through the fuel above the lowest edges of the drop-curtain wall, the volatile gases only passed through this comparatively cold fuel and escaped under the edge of the drop-curtain wall into the outlet flue, so that the volatile products were not exposed to contact with incandescent fuel in such a way as to effect the fixation of the volatile gases. The drop-curtain of the Mond producer was identical with the original arrangements introduced with this object, but working under higher temperatures than were maintained in the Mond plant, so that the Mond apparatus was even less capable of dealing with a highly hydro-carbonaceous fuel. If an average character of hydro-carbonaceous, or so-called bituminous fuel, were utilized (containing say 20 per cent. to 25 per cent. of volatile hydro-carbons) in the Mond apparatus, working with the low-temperature conditions resulting from the use of such large volumes of steam, the tar would perhaps be vaporized, but the vapour would certainly not be fixed but would recondense. The arrangement of utilizing the generator-shell radiant heat was satisfactory, but it was one of the features that characterized his own generators, and had been used in his plant for many years. The method of treating the gases on their emission from the gas generator constituted whatever novelty there existed in the Mond arrangement, and where agricultural fertilizers were in great demand, and water was pure, abundant, or cheap, the question of adding such an expensive auxiliary to the plant might be worthy of serious consideration. With regard to the report of the trials, the test giving the critical figure of fuel expenditure to produce 1 I.HP. of energy was unreliable, extending as it did over a period of only some 120 minutes. The test should have extended over eight hours at least. There was a considerable difference in the two figures of volume consumption per I.HP. hour—in one instance 76·18 cubic feet was given, and in the other 69·70 cubic feet, as the factor of expenditure. His own best results with bituminous coals showed 1 E.HP. hour for an expenditure of $1\frac{1}{3}$ lb. of fuel[2] burnt in an Otto-cycle engine; with the commonest bituminous Mr. Thwaite.

Report by George Cawley, *The Engineer*, vol. lxxxii. p. 320 *et seq.*

Mr. Thwaite. slack coal, unfit for steam raising, the expenditure had been equal to 2 lbs. per E.HP. In the Thwaite system neither the generation of gas nor the recovery of ammonia involved the employment of a steam-boiler. The statement at the foot of page 200, that the engine there referred to was the first instance in Great Britain of a large gas-engine driving a dynamo direct, was incorrect. He had tested an engine of the vertical inverted type, made by the Acme Gas Engine Company, Limited, Glasgow, in 1895, which engine was providing the light and power of an installation that involved an output at the rate of 108 E.HP. Gas plant on his system for using the cheapest kind of steam coal was either being constructed or was in operation in England, the Colonies, and in various parts of the Continent. A single unit plant, on the Thwaite system, both of engine and gas plant, of 500 E.HP., was being constructed in England; this was the largest single unit of gas-power station that had yet been constructed. The result of a long and varied experience on the generation and employment of gaseous fuels had brought him to the conclusion that for power and heat-producing purposes generally, and, except where high local temperature effects were required, carbon monoxide was to be preferred to hydrogen. A $\frac{\text{volume}}{\text{weight}}$ calorific comparison, and extended to calorific and the sequence of power possibilities, and using Berthelot's specific heat at high-temperature factors, showed there was little to choose between the two gases. There was no latent heat absorption to be taken into account in calculating with the CO factor, and there was no trouble with the water resulting from the oxidation of hydrogen—both advantages favouring the use of carbon monoxide. The Table of comparative efficiencies, at p. 210, was ingenious, but it is misleading. The figure of merit should be multiplied by the proportion of the incombustible in the fuel used; this would correct the variation in the calorific value of the solid fuel used in the generator. The same gas generator, working with two different kinds of anthracite, would give a greater difference of thermal value than was shown between one kind of generator and another. A simple measure of efficiency of a gas was the percentage of the carbon dioxide constituent. Whatever the quality of the fuel, the volume of the CO_2 should not exceed 6 per cent. Reference had been made to his project of generating power on the coalfields and transmitting it electrically to the Metropolis and to the industrial centres of Lancashire, Yorkshire and the Midlands, which had formed the subject of a Paper read before the Manchester Association of Engineers on the 12th November, 1892.[1] The first

[1] Minutes of Proceedings of the Manchester Association of Engineers, 1893.

Mond producer, as described, had commenced work in September, 1893. The scheme had been described more recently in his article in the *Nineteenth Century*.[1] In the preparation of the report associated with that scheme he had Mr. James Swinburne as a collaborator, and the assistance of reports from Mr. Huber, of Oerlikon, and Mr. C. E. L. Brown, of Baden. The project embodied all that was described in the Paper, and long before the Mond plant described by the Author was erected. In regard to the estimate of a plant to supply gas-engines of 10,000 I.HP., the structural simplicity of the Thwaite Power Gas Plant would enable a plant of that power to be erected for at least 50 per cent. less than the Mond plant. It was stated in the Paper that by using the Mond apparatus the recovery of the sulphate would be sufficient to cover the cost of the coal entirely. He was glad to hear this was the case; but if so, why did Messrs. Brunner, Mond and Company continue to employ ordinary coal for raising steam in their main battery of boilers? Great credit was due to Dr. Mond for having doubled the weight of sulphate of ammonia obtainable from 1 ton of coal, but the cost of evaporating the immense proportion of water made this excess a decided drawback to the application of the system, independently of the great complication and extent of the combination of the plant. Mr. Thwaite.

Mr. C. Humphrey Wingfield thought that the intersection of the curves of temperature in *Fig. 4*, would convey the idea that at some part of the tower the temperatures of the gas and water, for instance, were equal, while to the right of this point the water appeared hotter than the gas from which its heat was derived. In Table III this was clearly shown not to be the case, and he thought that by reversing the direction of the lower lines the relative temperatures of the respective media would be better indicated. It would then be seen that the difference in temperature between the gas and the acid was nearly constant throughout. The near approach of the water- to the gas-line in the second column would show that the water was not in excess—a desirable feature, since its temperature should be high in order to heat the air efficiently in the third column. In the latter the air-line kept well away from the water-line, showing, again, that the ratio of water to air was not too large to allow of a large part of its heat being taken up. Mr. Wingfield.

Mr. H. A. Humphrey, in reply to the Correspondence, was glad to find his opinions supported by so eminent an authority as Mr. Mr. Humphrey.

[1] "Electricity from the Coalfields," *Nineteenth Century*, December, 1894.

Mr. Humphrey. Delamare Deboutteville, whose long experience and great success constituted him one of the first authorities on all matters relating to gas-producers and gas-engines. He thought the Gasmotoren Fabrik Deutz might be congratulated on the excellent results achieved; but it should be mentioned that where anthracite and coke were used the quantity of ammonia present was not considered worth recovering, and this source of revenue was therefore lost; also common bituminous slack must always be the cheapest of the three fuels. The charge for sulphuric acid given in Table V, Appendix I, was correct, the chamber acid being delivered to the works in tank steamers at the price stated. No gasholders were used, or considered necessary, even when the output exceeded a million cubic feet of gas per hour. The presence of CO_2 and nitrogen seemed to be a stumbling-block to many who had not had experience with a gas of low calorific value. That the presence of these gases in a gas used for heating purposes was not to be commended might be granted, unless great uniformity of temperature and absence of local heat was the chief desideratum when they might be of actual advantage. But the point requiring emphasis was that they exercised no such serious detrimental effect as was often believed, for although the heat absorbed by the incombustible gases during combustion of the other portion tended to limit the temperature attainable, yet this heat was not lost if the products were properly cooled. In spite of the CO_2 and N present in Mond producer-gas, the available heat from 1 ton of coal gasified was greater for Dr. Mond's system than for others, and in these days when the principle of regeneration was so well understood, the gas in question was in every way suitable for very high temperature work. What was really required by those who used gas for heating, was that the final cost of a million available heat-units should be the minimum, and that was exactly where Dr. Mond's system had proved the most successful. Mr. Holgate's suggestion to remove the CO_2 by washing the gas in ammoniacal liquor could not, he believed, be recommended as an addition to Dr. Mond's plant, chiefly because the bicarbonate of ammonia which would be formed was volatile and unstable, even at comparatively low temperatures, and this would lead to a loss of ammonia; also a calculation of the quantities involved showed a discouraging result. Such figures as those given by Professor Robinson proved the advance in economy where gas-engines were employed, under suitable conditions, instead of steam-engines. In the present communication an endeavour had been made to satisfy such a want as that expressed by Mr Rowan by giving a full and detailed statement of the cost of the producer plant at Northwich. He thought Mr. Thwaite had construed the opening statements of the Paper to mean more than was stated, and that recognised authorities would have to plead the same ignorance of the system which permitted "the worst fuel refuse, even common peat, with or without hydro-carbons in its constituents, to be used for driving gas-engines, and with excellent results." Mr. Dowson's and Mr. Delamare Deboutteville's statements in 1893 and 1894 respectively, showing the contrary, had already been referred to. Even so late as 1896, before the results contained in the Paper were published, Mr. D. Clerk[1] had written:—"Mr. J. E. Dowson's producer is the only one at present in existence giving suitable gas, and it requires the special fuel anthracite. The use of ordinary fuel has not yet succeeded." He regarded Mr. Thwaite's experiments as inconclusive, but hoped to see his efforts rewarded with a well-deserved success. The dust, carried over by the gas from the producer, of which a sample drawn from the bottom of the regenerator tubes had been placed on the table, consisted of fine particles of slack, and was so free from tar that it would run through an open cock in the same manner as fine dry sand. No better evidence, perhaps, could be given to satisfy Mr. Thwaite's doubts of the solution of the tar difficulty. The difference between the volumes per I.HP. given in Tables I and II, Appendix III, would be expected, when it was considered that one was a trial figure and the other was obtained by ordinary running during one month and in charge of unskilled hands. In Mr. C. F. Jenkins' Paper[2] proof would be found that the "figure of merit" was calculated on a sound scientific basis, and took due account of the incombustible in the fuel used. He had elsewhere corrected the impression that the first Mond producer was started in 1893. Dr. Mond's square producers utilizing the same principles were much older; his numerous producer patents dated back to 1883, and his experimental installation was older still. The reply to Mr. Thwaite's question, as to why Messrs. Brunner, Mond and Co. still employed ordinary slack in raising steam in their main batteries of boilers, had been anticipated by Mr. Holgate, when he deduced the cases for maximum and minimum advantages of gas-firing. The boilers in question were not specially suitable for use with gas, and were at present working with mechanical

Mr. Humphrey.

[1] "The Gas and Oil Engine," 6th edition, p. 267.

[2] Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 328.

Mr. Humphrey. stokers, also as fast as the producer plant at Northwich was extended the extra capacity was appropriated for work where the advantages of gas-firing are more keenly felt. The meaning of the curves, *Fig. 4*, became clear when it was stated that for any of the three towers the temperatures on the left of a vertical column were those of the liquid or gas entering, while those on the right were for the liquid and gas leaving.

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23 March, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President, in the Chair.

The discussion upon the Paper "The Mond Gas-Producer and its Application" was continued and concluded.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2983.*)

"Inland Navigation in the United States."

By Smith S. Leach, Major Corps of Engineers, U.S. Army.

Relief and Drainage.

The relief of the United States may be resolved into three main divides, with their foot-hills and sequent plains, namely, the Atlantic, Pacific, and lake divides. The first and second are mountainous, the third is not. The Pacific divide is formed by the Cordilleran, or Rocky Mountain range; and the country west of this divide is mainly an elevated, semi-arid plateau, the central part of which has no drainage to the sea. The northern and southern parts drain through the Snake and Colorado rivers respectively, but without sufficient flow for navigation. The plateau is limited on the west by a coast range, down the west flank of which short precipitous rivers reach the Pacific. In central California, a peculiar elongated basin is so deep that the tide flows up the Sacramento and San Joaquin rivers which drain it; and at the north, where precipitation is greater, the Columbia and its tributaries, and the streams which flow into Puget Sound are navigable. The eastern slope of the Rockies is deficient in rainfall, nearly to the Mississippi. Many of its streams are dry beds during part of the year, and incapable of improvement. All the western tributaries of the Mississippi are navigable for a certain distance from the main stream, generally to the western limit of adequate precipitation, at about the ninety-seventh meridian.[1]

The lake divide is an upland plateau of relatively low relief. From the western tip of Lake Superior it sweeps in a broad arc, concave to the north and east, round the lower end of Lake Michigan, follows the south shore of Lake Erie, and east of the latter joins the Atlantic divide. At Chicago there is so great a

[1] "United States," Encyclopædia Britannica, 9th edition, vol. xxiii. p. 804. The chart of mean annual rainfall shows this change in precipitation very clearly.

depression, that the summit-level of a canal which crosses it is fed from the lake. East of Lake Erie, the elevation of the crest decreases; and the Erie Canal, crossing the Niagara escarpment near Buffalo, and following the rim of the Ontario Basin, crosses the divide between Syracuse and Rome at a level lower than its source.

The Atlantic divide is formed in great part by a series of mountain ranges known as the Appalachians, or less correctly the Alleghenies, a name which properly belongs to one of the principal ranges. This divide, starting in the peninsula between Saint Lawrence Bay and the Atlantic, runs south-west in a long double curve, concave first to the south-east and then to the north-west. The ranges composing the Appalachians are of various lengths, but are all nearly parallel to the local trend of the system. Complex as they are, they may be generalised as two parallel ranges, from 60 to 100 miles apart, and enclosing a long, narrow valley. The ranges, and the floor of the valley between them, gradually increase in elevation from north-east to south-west. In New England, the summits are 2,000 to 4,000 feet above the sea, and the valley 400 feet or less. In western North Carolina, the mountains rise 4,000 to 6,000 feet, and the plateau to 2,000 feet above the sea. Here the elevations being to diminish; and the ranges gradually fade away into two low ridges, the one on the Atlantic side sweeping round through Northern Alabama, Western Tennessee, and Kentucky, to the junction of the Ohio and Tennessee rivers, forming the divide between the Mississippi and Gulf basins. The ridge on the inland side follows an interior arc to the same locality, but becomes a secondary divide, separating the valleys of the Tennessee and the Cumberland, both tributaries of the Ohio. In the upper part of the Atlantic divide, there are two interruptions, so complete as to present practicable routes for deep-water transportation. They both connect the lake and Saint Lawrence system with the Atlantic Ocean, by way of the Hudson River. The Champlain valley pushes the divide down towards the sea, and the Hudson and the Mohawk immediately drive it back on the lakes; and inland navigation has connected the Atlantic and lake basins by both these routes.

The great Appalachian valley extends from southern New York to south-western Virginia, and is a trough with both ends closed. The actual divide is along the western range. The valley itself belongs to the Atlantic basin; and its rivers break through the eastern rim in large volume and at low elevations, forming "gaps," with cascades and rapids which are complete interruptions of navigation. At the lower end of the valley, the divide crosses to the eastern range. For some distance further the drainage is still lateral, but in the opposite direction, the small streams collecting in the New River which, breaking through a high gap in the western rim, finds its way by the Great Kanawha to the Ohio. Then the drainage takes a longitudinal direction, through the streams forming the headwaters of the Tennessee.

These three divides mark the boundaries of the principal drainage systems of the United States, namely, the Atlantic slope, the Gulf slope, the Mississippi basin,[1] the lake basin, and the Pacific slope. The Atlantic slope presents a varied conformation. The northern part is a series of south-trending ridges, with main drainage lines nearly parallel to the coast. The coast plain is narrow, and the descent to it abrupt, so that the rivers of this section are generally unnavigable above the tidal limit. Long Island Sound and three large bays, Narragansett, Delaware and Chesapeake, are the main features of the natural inland navigation. South of the Chesapeake, the coast-line becomes more regular, the coast plain widens, the drainage lines become normal to the coast, the range of tides is low, and the larger rivers have non-tidal portions susceptible of improvement. From Boston to Wilmington, and from Charleston to Fernandina, the coast is so deeply or so frequently indented that it is possible, with a few short artificial links, to create a chain of 7 to 9 feet navigation along the coast, sheltered from the open sea, and secure, except at a few points, from hostile forces. This inside route lessens the distances between some important ports; and from New York to Richmond, greater depths than 9 feet are practicable.

The Gulf slope is distinguished from the Atlantic mainly by its rivers being non-tidal, the tides of the gulf being very low and occurring but once a day. The two slopes are mitred together on a line from Atlanta to the middle of the Florida peninsula. The terrace formation of the South Atlantic slope is modified along the gulf, and the streams are navigable for greater distances.

The Mississippi basin, the largest and most important, is a low flat plain, with gentle and very regular slopes. From the great falls of the Missouri, above Fort Benton, to the mouth of the Mississippi, a distance by channel of 4,000 miles, there is no point where the fall is so great as to interrupt open navigation. On the Ohio, there is but one such point, and on the Mississippi, above the Ohio, only one, with a second where canalization is desirable

[1] The separation of the Gulf slope and the Mississippi basin is arbitrary.

but not necessary. The principal tributaries of the Mississippi are great rivers; many of its sub-tributaries are important streams; and not a few of its minor feeders supply the demands of commerce.

The lake basin within the United States is generally narrow, and is drained by creeks rather than rivers. Apart from the streams connecting the lakes, the Fox is the most important.

River Regimen.

The climate of the United States, east of the ninety-seventh meridian, shows only two marked variations; one a change from coast to inland conditions in crossing the Appalachian ranges, the other a gradual transformation of the temperate aspect of the northern portion into the mildly sub-tropical climate of the gulf coast; but, as regards precipitation and drainage, the whole area is under substantially uniform conditions. The annual rainfall over the area averages about 42 inches; it is somewhat less in the Mississippi basin, a little more on the Atlantic and eastern gulf coasts, and considerably more on the western gulf coast. Its distribution among the seasons is not easily averaged; but there is a distinct tendency to excess in winter, and deficiency in autumn. The proportion the discharge of streams bears to the total precipitation is from 24 per cent. for the larger, to 40 per cent. for the smaller, with exceptional cases much higher, the Yazoo, for example, giving 90 per cent. The Appalachians have but little regulating influence upon the discharge of streams. The isotherms crossing them are deflected southward through 6° of latitude and 12° of temperature. The total area within the loops of the curve of 48° F. round the higher ranges does not exceed 10,000 square miles. The mountains are generally covered with a thick soil derived from the disintegration of local rocks. The breaking up of the frost is nearly simultaneous throughout any single drainage basin. The few days' delay in the hills is partially set off by their greater declivities, which send the water forward more rapidly after it is released. The absorptive soil holds back the water in the dry season; and the net effect of the mountain drainage is to increase the freshets and diminish the low-water volume; and the tendency of the low-land drainage is the same. In the spring, the rains melting the snow cause excessive flood discharges. In the summer and fall, the increased absorption by the large areas of cultivated land, and the greater evaporation under higher temperatures, reduce the low-water volume to a relatively small figure. In the main trunk of the Mississippi, the maximum flow is twenty times the minimum; in the Ohio, at Cincinnati, eighty times; in the Arkansas and the Great Kanawha, sixty times; and in the Savannah, one hundred and twenty-five times. On the shorter and steeper streams, the freshets are of short duration. On the larger rivers they take the form of long flat waves, moving slowly down the channel and causing prolonged high stages.

As a rule American rivers are very tortuous, long distances by channel being 50 to 100 per cent. greater than the corresponding distances in the river's general direction. Average inclinations of 2 feet to the mile are rare in streams which admit of improvement. In their upper navigable portions, all the large streams which unite in the Mississippi have slopes approximating closely to an average of 1 foot to the mile. The slopes gradually diminish in descending the streams, on the Missouri very little, on the others more. The short rivers of the western Appalachian slope have inclinations but little greater, and sometimes less. The Great Kanawha, one of the most important and also one of the steepest, has a fall of 45 feet in 15 miles at its head; but its total fall to its mouth is 107 feet in 96 miles. The Savannah, on the South Atlantic watershed, has a slope of 6 inches to the mile in its navigable portion. The rivers of the Gulf slope, east of the Mississippi, are flat in their lower and upper portions, and steeper in the middle where they cross the terrace. The Black Warrior, a tributary of the Tombigbee, has a fall in its upper half of less than 1 foot to the mile, and in its lower half, which crosses the terrace, a fall of nearly 3 feet to the mile. The Tombigbee, below the junction of the Warrior, has a fall of less than 2 inches to the mile. The Alabama and its tributary the Coosa show the same sequence of slopes, and also the Apalachicola and the Flint. The prevailing slopes and variations of discharge produce large oscillations of water-surface. On the Lower Mississippi, the vertical range from extreme low-water to extreme flood is 54 feet at 300 miles from its mouth. On the Ohio at Cincinnati, the range is 70 feet; and on the streams of all sections, the prevailing ranges are 30 to 60 feet. The beds of the rivers are usually erosible, some slowly, others rapidly. Even the rivers in which rocky shoals are frequent have their navigation obstructed at other points by deposits of detritus. The caving of banks and their frequent overflow bring into the stream large numbers of trees, stumps, and logs. Almost every project of river-improvement has included the removal of sunken obstructions of this character; and on many of the rivers a considerable annual expenditure is required to remove the new ones as they arrive, several specially-equipped vessels being kept for that purpose. All the rivers carry sediment at high stages, and few are clear at any time. The western tributaries of the Mississippi are the most persistent silt-bearers, the Missouri especially carrying large quantities, even at its lowest stages. Nevertheless, the possibility of effecting extensive channel corrections by induced silting is the exception rather than the rule.

Extent of Inland Navigation.

The length of the navigable rivers of the United States on which some measure of improvement has been undertaken exceeds 26,400 miles. The geographical distribution is: Atlantic slope, 5,300 miles; Gulf slope, 4,200 miles; Mississippi basin, 15,100 miles; Lake basin, 300 miles; and Pacific slope, 1,500 miles. The Great Lakes have, in the United States, a developed shore-line of 4,700 miles, along which are seventy-six harbours, improved or artificially created; while the bays and sounds of the Atlantic coast have 3,600 miles, and those of the Pacific, not including Alaska, 1,900 miles, making a total of 10,200 miles of shore along which goods might be embarked for water transportation. Of the 26,400 miles of navigable rivers, 19,500 miles have been improved for open navigation, distributed as follows: of 3 feet depth or less, 7,941 miles; of 4 feet depth, 3,373 miles; of 5 feet depth, 3,200 miles; of 6 and 7 feet depth, 2,799 miles; of 8 to 10 feet depth, 1,559 miles; of 11 to 20 feet, 280 miles; and of more than 20 feet depth, 246 miles.

Besides this open navigation, projects have been approved, and work completed or begun for 2,400 miles of slack-water navigation, with locks and fixed or movable dams. These projects will require 193 locks, with a total lift of 1,850 feet. Ninety-two locks have been constructed, and are now in operation, with a total lift of 820 feet, which give 1,085 miles of navigation of 4 to 7 feet depth.

There are 32 miles of lateral canals in operation to avoid rapids on the St. Mary's, Mississippi, Ohio, and Tennessee rivers; and on the latter stream 11 miles more are under construction. There are also 31 miles of "cut-off" canals in operation, providing shorter and safer routes; and another canal of this class, 50 miles long, from the Mississippi to the Illinois, is under construction. All these are owned by the United States, and are free. In addition, 4,665 miles of canals have been built by States and corporations, comprising both of the classes named, and a third class which may be called connecting canals, uniting two separate drainage-basins having no natural inland water communication, Appendix I. Of these, 2,215 miles have been abandoned, leaving 2,450 miles in operation, with 987 locks aggregating 9,722 feet lift. The canals in operation average a lock to 2·6 miles. Of those abandoned, 483 miles had 502 locks; and a ratio of a lock to the mile would probably be a fair average for all of them.

The Erie Canal has been almost constantly in course of enlargement, first by doubling its locks and then by lengthening them,[1] which latter work is now complete except at the flights. Under a new project of enlargment just adopted, the Erie Canal will be deepened to 9 feet, and the Champlain Canal to 7 feet. Probably hydraulic lifts will replace the flights at Lockport and Cohoes, and possibly elsewhere. Other important projects in progress are the Hennepin Canal, connecting the Mississippi at Rock Island with the Illinois near Lasalle,[2] and the Chicago Drainage Canal, which will ultimately replace the Illinois and Michigan Canal. Surveys are being made by the United States to determine the feasibility of a modern canal across Ohio. Surveys have also been made for a ship-canal from Pittsburg to Lake Erie.

The total expenditure on works of inland navigation has exceeded $450,000,000,[3] one-ninth of which is represented by the abandoned canals.[4]

Design and Construction of Canals.

From one of the early locks, 90 feet long, 12 feet wide, with 3½ feet depth of water on the sills, to the new lock at St. Mary's River, 800 feet long, 100 feet wide throughout, with 21 feet on the sills, is a considerable advance. Yet this progress depends mainly

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[1] Very complete information about the Erie Canal, and some other navigation works, is given in "Notes on some of the chief Rivers and Canals of the United States and Canada," by G. T. Walch, Madras, 1877.

[2] "Report of the Chief of Engineers, U.S. Army," 1890, p. 2581.

[3] The Index to the "Reports of the Chief of Engineers," vol. 3, p. 503, gives a statement of Federal appropriations including 1892.

[4] Subject of "Canals" in tenth and eleventh censuses of the United States.

on the increase of the width of the lock-chamber. The greater widths of trunks and locks, as compared with European canals, are the leading characteristic of American designs. For nearly every other feature of the latest locks, a precedent may be found in very early practice. The highest lifts of locks under construction, or actually designed, are 24 feet at the Cascades of the Columbia, and 25 feet at Bee Tree Shoals, Tennessee River. A lock with 30 feet lift was in operation on the Lehigh Canal seventy-five years ago. The earliest locks were filled through sluices in or round the lift-walls, and emptied through openings in the lower gates, a practice which still generally prevails. The present, and the new locks at St. Mary's River, however, are filled and emptied through wooden culverts under the floors, which avoids the difficulties experienced on the Ottawa Canals, where, in much the same climate, wall-culverts were so injured by frost as to cause their abandonment and the substitution of gate-wickets. The culverts rest on the solid rock, to which they are anchored by bolts, and carry the floor of the lock across their tops.[1] The Cascades lock on the Columbia is filled and emptied through culverts in the side walls, each communicating with the chamber through eleven branches. A lock now building at Herr Island on the Allegheny is detached from the shore for commercial reasons, and is filled through transverse culverts in the river-wall, and emptied through similar openings in the land-wall. The lock last designed for the Ohio is to be filled and emptied through the outer wall. The valves for controlling the flow through culverts and sluice openings are, with few exceptions, of the "butterfly" type, with a flat disk rotating on an axis usually central, although a slight preponderance is occasionally introduced. Similar valves were used in the first locks at the Falls of the Potomac; but the latest ones are many times larger, are of cellular construction in iron and steel, and are operated by direct-connected hydraulic engines. A ring gate, operated by hydraulic pressure, has been adopted for the culvert openings of the Hennepin Canal.

The earliest locks were of brick or wood, both of which proved so short-lived as to cause their abandonment; and when the Erie Canal was begun, massive ashlar masonry had become the accepted standard. For locks of secondary importance, a composite type was adopted, consisting of a wooden trunk supported by retaining

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[1] Drawings of the 1881 lock were published by the Engineer Department in 1884. Some features of the new lock are described and illustrated in *Engineering News*, New York, 26th Sept., 10th and 29th Oct., and 28th Nov., 1895.

walls, sometimes of dry rubble. Concrete is rapidly coming into use for facing as well as backing. The Herr Island lock will be built wholly of concrete, and also the remaining ones on the Coosa.[1] On the Hennepin Canal, concrete is adopted for all classes of masonry, including culverts, weirs, and the piers and abutments of aqueducts and bridges.[2]

The first result of the increased dimensions of lock gates, mainly in length, has been the abandonment of all types of gate except the mitred. For the upper ends of the earlier locks, drop-gates were much in vogue, consisting of a single plane leaf revolving on its lower edge. Single-leaf sliding gates were also used, and are advocated for the Erie Canal locks, only 18 feet wide, to afford a longer available chamber. Gates of this type, but which are caissons rather than leaves, were adopted for the lock at Davis Island Dam, Ohio River, on account of the great length as compared with the height. These gates are 120 feet in length, closing an opening 110 feet wide. The lower one is 15 feet high and 14 feet wide, formed of horizontal Howe trusses and vertical posts, planked on both sides and decked. The gates are run on tracks into recesses behind the land-wall by a chain and steam-driven drum.

The wickets in the large gate are connected to the piston-rod of a hydraulic cylinder, and are operated by a single stroke of the piston. The valves which control the inlets from the filling-culvert, are operated in the same way. As yet, the prevailing practice for locks of moderate size is to operate by hand. The leading power installations are at the Keokuk Canal on the Mississippi, the present lock at St. Mary's Falls, and the new lock at the same place. The Keokuk plant, put into use in 1877, was the pioneer,[3] consisting of nine hydraulic cylinders, connected with a single distributing valve, which place each leaf of each gate, each set of culvert gates, and the sluicing gates which regulate the pool-level, under the control of one operator. A similar plan was adopted for the lock of 1881 at St. Mary's Falls, with the substitution of water-power for steam, and with variations in detail, especially as to the transmission of the power from the pistons to the gates. This design will also be used at the Cascades lock. The machinery of the new lock at St Mary's River differs from

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[1] *Engineering News*, 20th Feb., 1896.

[2] "Report of the Chief of Engineers," 1894, p. 2165; and *Engineering News* 14th Feb., 1895.

[3] "Report of the Chief of Engineers," 1876, p. 664.

that of the present lock, mainly in the substitution of a hydraulic winding engine to operate the gates.[1]

Wood is strongly preferred as a material for lock gates; and its use is only given up when its strength is insufficient, or its life abnormally short. Its advantages are buoyancy, elasticity, the facility of making emergency repairs, and, as yet, its economy. The last consideration is rapidly losing its force for large gates, and may soon disappear. Typical designs include the straight and bow-string girder, simple and trussed, and the arch.[2] The prevailing types in wood are the simple straight girder and the trussed bow-string. On the Hennepin Canal, gates 20 feet long and 16 feet high have 12-inch by 12-inch horizontal timbers 10 to 23 inches apart, mitred into quoin and heel posts, and a diagonal suspension rod. On the Kanawha, gates 30 feet square have each horizontal composed of two 12-inch square timbers, side by side, and dowelled together. These gates are peculiar in having no quoin or heel posts, the spaces between the ends of the girders being filled with blocking, firmly bolted together. The gates of the Kampsville lock, 44 feet wide and 23 feet high, and of the present St. Mary's lock, 35 feet square, are of the bow-string type. The former are trussed by iron rods from quoin to heel post, passing over a saddle girder on the middle of the back of the gate, the triangle formed having 41 feet base and 3 feet 4 inches altitude. Rollers under the outer ends of gates, to prevent drooping, have been abandoned, on account of the obstructions which get on the track; and it has been found that, by careful construction, a gate can be carried from the heel post.

Metal gates of moderate size are in use on the Muscle Shoals Canal; and large ones have just been finished for the Cascades and the new St. Mary's locks, presenting a contrast in design. The Cascades gates, 36 feet, 40 feet, 46 feet, and 54 feet high, by 53 feet developed length, are designed with horizontal frames 30 inches apart, and a single skin. They are estimated to weigh 130 tons in air, and will be wholly suspended from the anchorage. The gates being subject to rapid changes of water-level, and sometimes to complete submergence, air-chambers and water-boxes would require more manipulation than is desirable. The St. Mary's gates, 43 feet high, each leaf having a developed length of 59 feet, have horizontal frames spaced 30 inches, intercostal ribs in the lower cells, and a double skin with partitions forming air-

[1] *Engineering News*, 28th Nov., 1895.

[2] "Professional Papers, Corps of Engineers, U.S. Army," No. 26, 1892.

chambers and water-boxes. The fluctuation of level here is relatively small and slow. The surfaces of the gate are nearly parallel cylinders, the thickness at the quoin being 31 inches, and at the heel 36 inches. The rise of the gates is one-fifth of the span, which is also the ratio for the Cascades gates.[1]

At river locks, a movable dam is placed across the head bay to provide against accident to the lower gates. At the St. Mary's Canal, the movable dam is operated at regular intervals to make sure that it is in condition for instant use. The new lock has intermediate gates just above the lower ones, to enable it to be worked with reduced length in case the lower gates are wrecked.[2]

For locks of moderate widths, on unyielding permeable soils, cross timbers, imbedded in concrete and carrying a double-plank floor, form the bottom of the lock and the footings of the walls. In yielding soils, piles capped with longitudinal stringers are used to support the cross timbers, the heads of the piles and both sets of timbers being imbedded in concrete. For wide locks, there is a difficulty in making the floor stiff enough to resist the upward pressure when the chamber is dry. Concrete floors of sufficient thickness to meet the pressure by dead weight are very costly, and have not, as a rule, been employed. On the Hennepin Canal, this difficulty will be avoided by sheet-piling across the head- and tail-bays, and laying under drains with their outfalls at the point where the sump would be located if the lock were to be pumped. At the Herr Island dam, on the Allegheny River, the material for 24 feet below the floor of the lock, making a cofferdam difficult if not impracticable, has been dredged off, and a thin floor of concrete laid on better material at the level indicated. From the edges of this floor, concrete walls have been carried up to the lock floor. The concrete box so formed will be filled with sand and gravel, which will load the bottom sufficiently to enable it to withstand any hydrostatic pressure which can be developed under it. Round the upper edge of this box, a cofferdam will be built, within which the lock will be constructed.[3]

The early standard type of aqueduct was a wooden trunk on masonry piers. A metal trunk was adopted for an aqueduct on the Muscle Shoals Canal. The design for the Hennepin Canal is composite, consisting of a metal skeleton and a wooden skin.

Persistent efforts have been made to relinquish sliding sluice-

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[1] "Report of the Chief of Engineers," 1891, pp. 3343–3361.

[2] *Engineering News*, 26th Sept., 1895.

[3] "Report of the Chief of Engineers," 1895, p. 2411.

gates for regulating levels. Several forms of the Stoney sluice-gate have been used at different times and places. The last and most elaborate, designed for the Chicago Drainage Canal, has the train of live rollers thrown in and out of bearing by a serrated wedge-bar resting against a series of counter-wedges.[1] The new Taintor gate consists of a segment of a cylinder, convex upstream, revolving on a horizontal axis, whose mounting is eccentric, the centre of the figure being slightly above the centre of motion, which gives a small component of the pressure to set off a part of the weight. The gate is manœuvred by a winch, with chains attached to the periphery.[2]

The "bear-trap" gate is an old design with an indifferent reputation; but in its renaissance, so many variations and improvements have been made that great hopes are entertained of its future. Its valuable principle was practically neutralized by the cumulative influence of numerous defects. A weir of this form, 52 feet long, is, however, in successful operation at Davis Island dam. The first advance was the form known as the Parker gate, Fig. 1, Plate 6. This met most of the difficulties, but not the existence of a re-entrant angle, in which drift is apt to lodge and prevent the lowering of the gate. The next step was the Lang gate, Fig. 2, where the upper fold of Parker's upper leaf is replaced by chains, and the re-entrant angle is suppressed by an "idler" hinged to the crest and sliding on the upper leaf. By introducing a second chain, Fig. 3, Colonel Jones has made the gate reversible, but for a less head than on the direct side.[3] A Lang gate, 80 feet long, is in operation under a maximum head of 16 feet, which works perfectly, and can be raised, lowered, or held at any intermediate point, by one man turning a hand-wheel. The Jones gate is in operation, for sluices and locks, in connection with the reservoirs at the headwaters of the Mississippi. In the form designed by Major Marshall, Fig. 4, there are two re-entrants, each masked by an idler. This gate has a position of equilibrium corresponding to any head of water, which it will take without shock. Fig. 5 shows an adaptation of the bear-trap to a sluice-opening of 160 feet on the Chicago Drainage Canal. As the leaves are to be of metal, counterweights are provided to set off a part of their weight.[4]

In the application of bear-trap dams to navigable passes, a

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[1] *Engineering News*, New York, 12th Dec., 1895.
[2] "Report of the Chief of Engineers," 1890, p. 2366.
[3] *Engineering News*, 6th Feb., 1895; and *Engineering Record*, 16th Feb., 1895.
[4] *Engineering News*, 12th Dec., 1895.

difficulty, as yet unsolved, is the absence of head when the gate is to be raised. If buoyant, the gate will not lie flat on the bottom; if the reverse, it will not rise from that position. Intermittent buoyancy is an obvious remedy; and air-chambers, flexible and rigid, have been proposed. A large surplus power is available in lowering the gate; and it is not improbable that a practicable way of storing a part of it, to be used in starting the gate up, may yet be found.

Canal trunks are of very simple construction. The demand for width induces a tendency to carry the trunk in embankment as much as possible. Linings are sparingly used, as moderately porous soils soon become fairly impervious by filtering the silt out of the water which first leaks through them. On the Hennepin Canal, a muddy stream, which is to be excluded from the canal, will be turned in at first, to supply silt for stopping leaks. In very coarse gravels, a lining will be made by sprinkling cement and sand on the surface, rolling it down, and allowing it to set by finding its own moisture. The same method is to be tried for paving which is necessary to permit high speeds.

Slack-Water Navigation.

Locks having been considered, only the dams remain to be described under this head. Fixed dams consist generally of timber cribs filled with stone and backed with earth. The crest is near the upstream edge; and the top, below the crest, is formed in steps, each having a tread of about three times the rise and tightly decked. This form facilitates construction, and is also efficient in baffling the overfall. The top above the crest is formed on a slope, which, as well as the upper vertical face, is planked to reduce leakage. On permeable foundations, the cribs are usually placed in a shallow trench; and when necessary, sheet-piling is driven to cut off underflow. The latest dams on the Illinois[1] were constructed without coffer-dams, and with only a few days' interruption of navigation.

The use of the Chanoine wicket for movable dams has been almost exclusive. The 40-foot bear-trap lock-gates at the Sandy Lake dam, Minnesota, and a needle dam now building for a location where the low-water flow will not supply the leakage of a wicket dam, are the only exceptions. The foundations are of concrete, in the top of which timbers are embedded and held by anchor bolts.

[1] "Report of the Chief of Engineers," 1889, p. 2122.

To these timbers, the wicket-sills and cushions, the hurters, and the sill- and trestle-boxes are attached. The concrete foundation is usually faced with stone, partially or completely. For the weir-aprons on the Kanawha, which are laid at the original low-water line, wood is only used for the wicket-cushions and upper guard-sill. The wicket-sills are of timber faced with cast-iron. The trestles, aprons, horses, and props are of wrought-iron; the hurters, wicket-, trestle-, and sill-boxes of cast-iron. The largest movable dam, at Davis Island, on the Ohio, has a navigable pass 559 feet wide, and weirs 148 feet, 52 feet, 212 feet and 204 feet wide. The 52-foot weir is a drift-gap, closed by the bear-trap gate already noticed, which was added after accumulations of drift had carried away one of the service bridges and otherwise impeded the operation of the dam. No other drift-gap has been found necessary as yet, but recent locks are provided with sluices for passing drift round the chamber to avoid locking it through. At Davis Island, the sills of the pass and weirs reproduce, substantially, the original cross-section, to reduce the high-water engorgement to a minimum. The pass was designed without a service bridge; and the weir-bridge, which was carried away by drift, has not been renewed. The wickets are lowered from a manœuvring boat working below the dam, by means of a spar and tackle pushing the top of the wicket upstream sufficiently to disengage the prop. The lock is 110 feet wide and 600 feet long, with 6 feet depth of water on the sills and 6 feet lift.

On the Great Kanawha, there are two fixed and six movable dams in operation; and the three remaining movable dams are under construction. The aggregate length of the eleven pools is 88½ miles. The fixed dams have 12 feet lift, the movable ones 7 to 9 feet. The locks below Charleston are 55 feet wide and 342 feet between the quoins. The passes are 248 feet wide, except one which is 250 feet; and the rest of the dam is thrown into a single weir, varying in width from 210 feet to 420 feet. The entire dam is operated from a service bridge,[1] Appendix II.

The choice between the two types of dams is controlled in part by the general conditions common to all streams and all countries, and in part by those which are local and peculiar. The primary advantages of the fixed dam are its less cost, and the greater lift which can be given it. The cost of maintenance and working was formerly reckoned an important point in favour of fixed dams; but experience has shown that, for a long term of years,

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[1] "Report of the Chief of Engineers," 1892, Atlas, plates 94–99.

this item is about the same for both. The cost of operating the lock is an important part of the whole, and is practically independent of the type of dam, being slightly in favour of the movable dam. The greater range of pool-level with fixed dams necessitates higher and heavier gates which, for very wide locks, are difficult to swing and manœuvre. The disadvantages of the fixed dams are the engorgement of the high-water section, the accumulation of river detritus in the pool, and, in mobile beds, the increased scour below the dam, and particularly the comparatively short period of navigation over it. The present and proposed slack-water improvements are mainly on streams which are the outlets of important coal-fields, and the coal traffic exerts a dominating influence upon their design. Coal is transported in barges of uniform size and rectangular in deck-plan, so that a number of them can be assembled in a compact mass, like so many blocks of wood. They are firmly lashed together with chains set up by screws, and form in reality a single vessel, of which the tow-boat, also rigidly lashed at the middle of the stern, is little more than a rudder. As it takes some hours to make up such a tow, the crews are naturally reluctant to undo and do over their work every time a lock is to be passed. It being impracticable to build locks large enough to take an entire tow, steam-boat men demand that lockage shall be a minimum, and open navigation a maximum. Early improvements on the Monongahela and elsewhere, with fixed dams, created such a prejudice against slack-water navigation that movable dams were at first opposed. The same impatience of delay is manifested by all classes of traffic. Where no open navigation exists, or can be secured by improvement, the presumption is in favour of fixed dams; but where such navigation is possible, the presumption in favour of movable dams is so strong that it can be overcome only by an unusual combination of conditions unfavourable to that type and favourable to the other. The Illinois River presents such an exception. The slope is small, the pools long, and the dams low. The traffic is not excessive, and is not of the character which suffers most from lock detentions. The Great Kanawha affords a very good illustration of the adaptation of the two types to the same stream. The two fixed upper dams cover a part of the river in which the fall is $3\frac{1}{2}$ feet to the mile, and in which secure open navigation is scarcely possible. By their higher lift, they secure as great a length of pools as three movable dams could do. Below them the fall is less, open navigation is possible for a part of the time, and movable dams are adopted. To facilitate navigation while slack-water projects are in course of execution, as well as to reduce the lockage period when they are completed, projects for open navigation are frequently carried on at the same time. On the whole, while slack-water navigation is increasingly popular, the lock is more than ever regarded as an emergency structure, to be used only when it cannot be avoided. The dam is expected to be on the spot when wanted, and out of the way at all other times.

River Improvements.

First Class of River Improvements.—The improvement of rivers falls naturally into three classes. The first includes operations directed to the removal of foreign and accidental obstructions—such as logs, stumps, trees, isolated boulders, and points of rock, which project beyond the normal section, so as to make the full natural capacity of the stream available for navigation—which occupy an important place in river improvement in the United States; but the problems they present are mostly mechanical and administrative. Snag-boats for the smaller streams are usually stout-hulled craft, of the greatest practicable length and beam, and the minimum draught. A pair of shears is mounted over the bow; and capstans are provided, which give a dead lift under the shears of 25 to 60 tons. The powerful boats in use on the large rivers are very broad, and have double bows, with a well extending back one-third of the length, dividing the hull into two parts for that distance. A broad horizontal "butting-beam," of heavy timbers sheathed with iron, is built across the well near the bows and at the load water-line. Operations are carried on as far as possible at low stages, when most snags project out of the water. Those which resist the lifting-tackle are loosened by running the boat at them at full speed, catching the projecting ends on the butting-beam, and delivering a blow of 13 to 15 million foot-pounds.[1] Stumps and water-logged trunks are dropped in deep water; buoyant trunks are sawn into short logs and dropped into the well, whence they dive under the hull and float down-stream. Where timber is found on caving banks, a swath is cleared along the margin; and, as the banks recede, the stumps sink to the bottom, and the trunks float away. Work of this character is required on nearly every stream.

Second Class of River Improvements.—The second class comprises

[1] A full description of one of these boats is given in the "Engineer Department, U.S. Army, at the International Exhibition, 1876," Washington, 1884.

projects for the amelioration of navigation, as far as is possible, by operating on limiting cross-sections, so few and so distributed that changes in their form have no appreciable effect upon the aggregate resistance to flow in their vicinity. Abnormal obstructions, which occur infrequently and greatly restrict the depths elsewhere available, may be removed in a large number of open navigations in the United States without creating new conditions reacting upon neighbouring portions of the bed. Many of the rivers, in their natural condition, are so nearly commensurate with the traffic seeking them, that the slight improvement obtainable by a dredge cut here, a dyke there, or a subsidiary channel closed by a dam in a third place, suffices.

The closure of subsidiary channels, or "chutes," is a method of section retrenchment easily effected and purely beneficial, affecting the remaining channel like an increased natural discharge, which does not disturb the form of the cross-section or the distribution of velocities within it. The closing-dam is generally placed near the head of the chute, which for tidal rivers has the advantage of having the lateral reservoir filled and emptied through its lower end. In non-tidal, alluvial streams, the head of the chute usually has a minimum cross-section and the least erosible material, and can be closed to the required height with least difficulty and cost. In chutes of considerable length, two or more dams may be required to distribute the fall and lessen the strain. The construction of the dam varies with local conditions; but it is, with rare exceptions, a combination of brush and stone. On the Mississippi above the Missouri, where a large amount of this kind of work has afforded ample opportunity to develop the best methods, the dams consist of alternate layers of brush and stone. The brush is formed into fascine mattresses of equal width, which are alternated with layers of riprap. Each mattress is set off slightly upstream from the preceding one, so as to give a downstream slope of about one to one, which can be covered with stone. The mattresses gradually take an inclined position corresponding to the upstream slope, which is usually two to one. The roots of the dam are guarded by a shore protection of brush mattresses ballasted with stone, which are laid a short distance above, and a longer distance below. When necessary to prevent the dam being flanked out, the shore protection on the island side is carried quite round the upper end. Similar protection is used generally when caving banks have to be protected. The mattresses are of continuous fascines laid parallel to the stream, with flexible binding poles athwart them. They are placed on a slope graded to about two horizontal to one vertical, and ballasted with stone. The upper part of the slope is pitched with stone on the natural soil. The proportion of materials in this class of work averages four volumes of stone to three of brush.

Wing-dams and training-dykes are used for local deepening in an erosible channel, the choice depending mainly upon the lay of the ground and their relative development and cost. If the shoal is very short and within the radius of effect of a single spur, that type is preferred. For a longer shoal, the number of spurs required is estimated, and their cost compared with that of a training-dyke. In a few streams with swift currents and highly erosible beds, oblique and longitudinal dykes induce a scour beyond the needs of navigation and tending to their own destruction. The same characteristic of longitudinal dykes renders them preferable for situations where the maximum result is desired from a feeble current. Dykes vary greatly in construction. Some, in exceptional situations, consist wholly of random stone; a few are timber cribs, juxtaposed and filled with stone; and a large majority have piles for a basis. A single row of piles, braced if necessary, and supporting the waling-pieces of a line of sheet-piling, is a frequent construction. A more common form is two parallel rows of piles, retaining a filling of the cheapest material which the locality affords, and which will retain its form when immersed in water. In lumber districts, the refuse of saw-mills is utilized; and gravel in bags or boxes, and oyster-shells have been used. The material most employed is brushwood. Sometimes the piles and filling are made a hearting simply, and are completely covered with riprap; but oftener the stone is used for ballast only, and the piles and exposed filling form the sides of the dyke. On the upper Mississippi, wing-dams and dykes are constructed precisely like the closing-dams already described. For purposes of silting, permeable dykes are constructed by substituting for the filling a thin curtain of brush, wattled on the piles, or even hung as a screen against them. It is usually necessary to protect dykes from scour by aprons of brush and stone laid along one or both sides. Permeable works find little application in the class of projects now considered.

When the material composing the shoal, though alluvial, is too compact to be moved by the concentrated current, a dredger must be used to open the channel. In material of comparatively light character, the dredger, though not necessary, is a most desirable adjunct. The true function of contracting and regulating works is to maintain, not to create a channel; and the original removal of the material can best be accomplished with the dredger. Material taken out with a dredger is moved laterally, and deposited in a place where it remains permanently; whereas, if moved by the scouring action of the current, it is transported longitudinally, and is again deposited in the track of vessels, whence it may again have to be removed. A dredged cut can be made with greater depth and lesser width than an eroded one, and when so made will be maintained by the regulating works in a form more favourable than they could have created it. The channel, moreover, can be dredged in a predetermined direction, co-ordinated with conditions above and below it, and will then be maintained by the contraction works in a position and direction different from those in which it would have developed under their creative influence, and more favourable to navigation. This is true of any scouring current, whether influenced by training-works or not. Cuts dredged through shifting sands in New York Harbour, and on the Mississippi, have been maintained far beyond all expectations. Finally, the work of the dredger is just so much strain spared the contraction works, increasing their security for a given strength, and permitting a less strength for a given security.

The dredgers in use are the clam-shell, the dipper, and the hydraulic dredger. A clam-shell dredger, in which the bucket is closed by steam-power, is a novelty, and promises success. Recent improvements in dipper dredgers have included the increase in size and strength of all the working parts, and a corresponding increase of engine-power, the introduction of hydraulic cylinders for operating friction-clutches, and arming the rim of the dipper with heavy teeth of steel for hard digging. With these improvements, all hard-pan and much soft or rotten rock may be removed without blasting. In hydraulic dredgers, the capacity of the pumps has been largely increased; but the most important improvement has been the application of efficient cutting or stirring devices, with ample power to drive them. Revolving cutters of various forms are now used, and a fair share of the available power is devoted to driving them. A regular supply of solid matter is thus assured, neither too little, nor enough to choke the pump. The use of these cutters, or auxiliary diggers, has greatly broadened the range of hydraulic dredging. Material is now handled which it would have been impossible to move with the earlier machines. Several large dredgers of this class have been built for the United States during the past year.

In rock, too hard to be broken by the dipper of a dredger, heavy chisels have been used with advantage. A machine, mounting four chisels of 8 tons each, has recently been constructed for use on the Hudson.[1]

Projects of the second class have been undertaken on many streams differing widely as to slope, sediment, volume, and character of bed, and have been uniformly successful. They comprise ameliorations in which the aggregate effect of the changes made in the cross-sections treated is not sufficient to be appreciable in the general regimen of the stream.

Third Class of River Improvements.—The third class is distinguished from the second by the reversal of the above conditions. The number of sections to be operated upon is so great, and the changes to be made in them so radical, that reactions are set up which cause disturbances at intermediate points; and the entire length of the stream must be placed under control. Such projects are required when the depth demanded is much in excess of that afforded by the stream in its natural condition. No definite delimitation of the two classes is possible. The second passes gradually into the third, through a zone which partakes of the character of each. In the third class it is convenient to separate the tidal and non-tidal rivers, as some of the leading methods involved in their regulation are dissimilar, although the principles upon which these methods rest are identical. Complete regulations are fewer in number, and of greater individual importance, than minor projects. The principal American tidal rivers have been regulated by nature, through a large part of their length, by the gradual narrowing of arms of the sea, often under conditions which the most elaborate scheme of regulation could scarcely improve. The Delaware, for example, in its unimproved condition, afforded 17 feet up to Philadelphia at mean low water; and to deepen it to 26 feet requires operations on five shoals only, situated in the first 30 miles below that port, one of the shoals being a ledge of rock. On the Hudson and the James, the ports to which navigation must be carried are relatively higher up; and in each case the upper reach requires regulation.

The head of the navigation on the Hudson is at the State dam near Troy, where the Erie Canal debouches. The original low-water depth was 4 feet for 20 miles to New Baltimore. In 1867, when the regulation was begun, the mean low-water depth had been increased to 7½ feet by desultory work. The mean tidal range at the State dam is 0·8 foot, at Albany 2·32 feet, and at New Baltimore 3·42 feet. The plan of improvement is directed

[1] "Reports of the Chief of Engineers," 1893, p. 1013, and 1894, p. 812.

to the development and maintenance of a channel 12 feet deep at mean low water, 300 feet wide from the dam to Troy, and 400 feet wide from that point to Coxsackie, 28 miles in all, Plate 6, Fig. 6. Tidal conditions are dominant, the fluvial contribution being relatively small. In the dry season little water passes over the dam at Troy, and the fresh prism consists mainly of the lockage out of the canal. The greatest freshet due to rainfall rose 19 feet at Albany, but higher levels due to ice-gorges have been observed. Gorges often cause extensive deposits in the channel. With a river discharge too small to affect its level in any considerable degree, the mean high-water plane is higher than at New York by 2·6 feet at New Baltimore, 2·7 feet at Albany, and 3·3 feet at Troy. Longitudinal dykes, aided by extensive dredging, are depended upon to effect the desired result. They are placed at a gradually increasing distance apart; and the side areas are converted into tidal reservoirs, connected with the channel at their lower ends, Fig. 6, Plate 6. The crests of the dykes are kept to the plane of tidal high-water, or sufficiently near it to avoid engorgement of freshets. Some recent dykes have been built to 3 feet above this plane. Dredging is used to open the channels, the material being deposited in a secure place.[1] At the present time the river is confined between two dykes, or between a dyke and an opposite shore, for 4½ miles of the 6 miles above Albany, and 10¼ miles of the 22 miles below. The distance between the dykes, or between the dyke and the shore, is 650 to 750 feet above Albany, and 800 to 1,200 feet below, the lesser width in each case being at the upper end. Some of the dykes were built previously, and have been incorporated into the present scheme at some sacrifice as to location. Natural features, both salient and re-entrant, have influenced locations, especially the latter when occupied as shipping points. Contraction work for the last few years has been principally the reconstruction of old dykes, and is in a condition to justify the rapid advancement of the dredging, which is now to be made the leading objective. At 12 feet depth much rock is encountered, which makes the dredging slow and costly. The oldest form of dyke, a mound of sand and gravel supported by piles front and rear and paved with stone, is still preferred as the best, and, permanence con-

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[1] "Report of the Chief of Engineers," 1894, p. 724. The Report of 1895, at p. 678, contains a historical résumé and sketches of the condition at that date. The scale of the sketch opposite p. 696 is wrong; hundreds of feet should read thousands.

sidered, the cheapest. To advance the work more rapidly with the funds available, cheaper forms made of piles and rubble have been extensively used.

The head of the navigation on the James is at Richmond, 100 miles above Hampton Roads, where a series of rapids end, having a fall of 83 feet in 4 miles. The average range of tides, in the absence of freshets, is 3·7 feet at Richmond, 2·5 feet at Hampton Roads, and 2 feet at an intermediate point 25 miles above the latter.[1] The fresh-water discharge varies from 1,300 cubic feet to 200,000 cubic feet per second. Extreme freshets, with a rise of 25 feet at Richmond, produce a rise of only 2 feet at a point 50 miles below; but such floods are rare. Moderate rises of 12 feet occur frequently. Flood velocities reach Richmond only during very low fresh-water discharges; at higher stages, the tide merely produces pulsations in the downward current. Fluvial conditions are dominant for 20 miles below Richmond, or over the entire length now in course of improvement. The lower river, for a distance of 70 miles, has only seven shoals, all of soft material, with present depths of 15 to 21 feet at low tide. The middle section, 23 miles long, has the usual characteristics of an alluvial river, namely, a winding bed, in which the thalweg follows first one bank and then the other, with a shoal at each crossing. This section has nine shoals, over which the mean low-water depth prior to improvement was not less than 12 feet. Evidently this section has been the locus of the fluvial deposits; and its adequate regulation to pass these deposits entirely through it to the larger bed below, is the most interesting problem presented by this improvement. The upper section, 7 miles long, is underlaid with rock; and in its original condition the mean low-water depth did not exceed 7½ feet. The longitudinal profile was controlled by outcropping ledges, the intervening hollows being filled with heavy alluvial detritus. At the depth of the proposed improvement, the rock is encountered over a considerable distance. The present project, adopted in 1892, has in view a navigable channel 22 feet deep at mean low-water, with widths of 200 feet in the upper, and 300 feet in the middle section, Figs. 7 and 8, Plate 6. Radical changes in the forms of the cross-sections are involved, and are to be secured by dredging and the construction of contracting and training dykes. For several reasons, spur dykes have been preferred in this regulation. Such a great reduction of width is better done tentatively, so as not to carry it beyond the point

[1] "Report of the Chief of Engineers," 1882, p. 879.

necessary to maintain the increased depth. Wing-dams are well adapted to secure proportional results with a partial expenditure, a condition always desirable, and often essential. The regulated channel will have a larger capacity for discharging freshets than the natural one; and as the tidal currents are now amply strong enough for all the work required of them, conservation of tidal volume is relatively unimportant, and therefore silting outside the channel is encouraged, and progresses regularly to low water or above. At a point 15 miles below Richmond, it has averaged 0·7 foot per annum for fourteen years, and should ultimately bury the dykes completely. Spurs are projected from both banks in a majority of cases, and include between their heads a channel 400 feet wide in the upper, and 600 to 750 feet in the middle section, or a little more than twice the width desired at 22 feet depth, Figs. 7 and 8, Plate 6. The ends of the spurs are to be connected by longitudinal dykes when results indicate that they are of sufficient length, and this is now in progress at some points. All dykes are built to the plane of high tide; and they are mostly formed of 3-inch sheet piling, supported by round piles 10 feet apart, and revetted with non-erosible dredged material. Some consist of two rows of piles with brush-filling, also revetted. A cut-off known as the "Dutch Gap" Canal, begun during the war for military purposes, has been enlarged and incorporated into the project. It is in hard material, and maintains an engorged section of high slope; and one of the worst obstructions to navigation between Richmond and the sea was in the bend which it avoids.[1] The new channel is being developed gradually, both in width and depth, each annual appropriation being applied to produce, if possible, an increment of depth available for through navigation. On the 30th June, 1895, a channel was available with a least width of 80 feet, and a mean low-water depth of 16½ feet for 2 miles below Richmond, and 17½ feet thence to the mouth. The present project just begun is estimated to require $3,000,000 and twenty years to complete. The preceding project, for 18 feet depth, was nearly oompleted when superseded by the present one.

The only non-tidal regulations sufficiently important to require notice are on the Mississippi, which presents, in three parts of its course, three dissimilar problems. From the mouth of the Ohio to the gulf, the flood-plain, 600 miles long, is 20 to 60 miles

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[1] Cut-offs have been made on the San Joaquin and Sacramento rivers in California, with beneficial results. These also are tidal streams, to which the utility of cut-offs is limited.

wide. The river's channel wanders down this valley with a length along the thalweg of 1,200 miles, or double that of the plain, and a width of 1 to 2 miles. The flood-volume exceeds 2 million cubic feet per second, and its surface rises 36 to 53 feet above low water. Extreme floods, which occur often enough to make their control a matter of necessity, rise from 2 to 20 feet above the natural banks. The entire plain is fine alluvium, destitute of rock or even of large gravel. The banks are eroded with such rapidity that recessions of hundreds of feet in a single year are not uncommon. In fact, this river affords a colossal example of a bed absolutely subservient to the water flowing in it. In its unimproved condition, occasional depths as low as $4\frac{1}{2}$ or 5 feet are found; those of 6 feet are more frequent; and bars with 7 and 8 feet of water over them are numerous. The depth proposed to be obtained at low water is only 10 feet; but, partly by reason of the number of obstructions, and still more on account of their instability of location, a complete regulation is demanded. The adopted plan is directed to two chief objects; the conservation of volume, and fixation of channel. Conservation of volume, the only part of the plan which is notably advanced, is accomplished by embankments of earth. The lines of levees are kept as near together as possible, but will average double the width at bank-full stage, since they must be retired from banks that are low or rapidly caving. At the close of the war, the levees above the Red River were divided by numerous breaks into isolated mounds, containing a vast quantity of earth, but useless to prevent the escape of water from the channel. The connection of these mounds, and the strengthening of the system were begun at once by the riparian interests, assisted since 1882 by the Federal Government. The lines are substantially complete to Memphis on the east, and Helena on the west side. Liberal openings are left at the mouths of tributaries, most of which, having steeper slopes than the main stream, are back-flooded for short distances only. In 1893, the back-water at the mouth of the Yazoo flooded about 100 square miles out of a total of 6,648 square miles in the Yazoo basin, all of which would have been overflowed without the levee.[1] The levees are built to confine all floods. Those of average size are formed with crowns of 8 feet and slopes of 3 to 1 on each side; and a ditch is dug under the river slope and filled with selected material, well compacted. Usually the entire base is thoroughly grubbed, and all perishable material

[1] "Report of the Chief of Engineers," 1894, Map opposite p. 2970.

removed. Earth is taken from a wide shallow borrow-pit on the river side, and not less than 30 feet from the outside toe. The grade is 1 foot to 3 feet above the highest expected water, which is 5 or 6 feet above the highest unrestrained flood on record, that of 1882. No great flood has hitherto been absolutely confined; but all floods since 1882 have been materially restricted, resulting in a distinct depression of the low-water plane at some points, with no sensible elevation at any point. The depression reaches a maximum of 6 feet at Vicksburg, at which point there has been no elevation of the flood-line. At Helena, where the depression of low water is about 2 feet, there has been an elevation of the flood-line of 1 foot. The conservation of the flood-volume appears to have enlarged the channel; and this enlargement will probably continue until the flood-line of a confined flood of equal volume will be no higher than that of the unconfined flood of 1882.

The fixation of the thalweg has been sought principally by works designed to prevent the recession of the shores. In the early years of the undertaking, attempts were made to effect retrenchment of width by silting works, but without substantial success. The supply of silt is uncertain, and its deposition slow and precarious. A long period of time is required to produce the desired results, during which the maintenance of the fragile and perishable structures is difficult and costly. The continuous mattress revetment is generally used for shore protection,[1] Fig. 14, Plate 6. Spur-dykes have been used in exceptional situations, but have not been adopted for the typical alluvial bank.[2] Continuous revetment is carried from the top of the bank, or near it, to and across the thalweg; but failures are nevertheless frequent; and the protection is maintained only by constant attention and repairs. The lateral resistance offered by the protected bank so increases the scour that mattresses are often undermined at the outer edge and lost. Another source of failure is the hydrostatic pressure of the ground water which, on a rapid fall of the river, stands higher behind the revetment than the river does in front of it. The impounded water breaks through a permeable stratum, carrying with it the material on which the mattress rests, and depriving the structure of support. For the part above low water, this difficulty has been met by grading the bank to a very flat

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[1] "Report of the Chief of Engineers," 1890, p. 3601, and 1890, plates 5–33, opposite p. 3210; and the Report of 1894, p. 2867, gives the latest experimental form.

[2] "Report of the Chief of Engineers," 1888, pp. 2280 and 2294.

slope. The slope is too steep below low water, and no method of flattening it has yet been developed. The enormous scale on which these operations are conducted has not permitted any refinements in the curves given to the protected shores. To hold them on the lines they chance to occupy is all that is hoped for, and somewhat more than has yet been accomplished. Above low water, the asperities of trace are softened a little; otherwise, every sinuosity of the original shore is followed by the revetment, and is made permanent when the work is successful.

Between the mouths of the Missouri and the Ohio, the Mississippi presents conditions differing in some important particulars from those described. This portion is less than half the size of the lower river. The controlling affluent is the Missouri, a very muddy stream which furnishes a large and regular supply of sediment. Silting operations are therefore much more rapid and certain than on the river below. Overflows are less frequent; and the flood-plain, limited by nearly parallel lines of bluffs, is sufficiently narrow to render further conservancy of flood-volume unnecessary. At intervals, the channel touches the rocky bluffs; hence the thalweg is comparatively free from disturbances due to bank-recession; but elsewhere the bed is easily eroded. The project aims at 8 feet depth at extreme low water below the important port of Saint Louis, involving a very complete regulation for 200 miles. To secure 8 feet in this part of the river requires a larger measure of improvement than 10 feet below the Ohio, when the relative volumes are considered. This regulation is well described and illustrated in the yearly reports since 1888. The channel works are permeable spur-dykes and shore protection. These dykes are designed to cause the deposit of silt over the entire area between them; and such dykes must be much closer together than non-silting or impermeable dykes. The rapid decay of the materials used, and the stresses due to the impact of heavy drift, make constant attention and frequent repairs necessary to the preservation of the structures, until their work is done. Accumulations of drift, often covering acres of surface and several feet thick, are especially troublesome; and attempts have been made to utilize them by anchoring them on the bottom. The most promising method is to lay a mattress of brush over the drift, and load it with stone until the whole mass sinks. It then becomes a silting structure, to take the place of one it has destroyed. In this part of the river, slopes at all stages have identical values of 7 inches to the mile. Observations made to detect any change, though not as yet sufficiently extended to be conclusive, indicate that the angle of inclination remains unchanged in the distance affected by the regulation, but that the surface profiles for all stages have been uniformly lowered.

The Mississippi above the Missouri is again a changed stream, of smaller size and different characteristics. It has somewhat less than one-half the volume at Saint Louis; is nearly free from suspended sediment, deriving its colour from vegetable infusions; is divided by numerous islands (533 of them in 700 miles) into an intricate network of subsidiary channels; has banks of comparative stability, though slowly eroded in places; and is obstructed by shifting shoals of sand. The flood-plain is narrow, and the freshets are rarely violent. It is a very tractable stream as compared with the other parts of the Mississippi. Rapids at Rock Island and Keokuk divide it into three parts; at the former a cut has been dredged through the obstructing ledges; at the latter a canal has been built.[1]

This improvement was begun in 1878, and has been directed to securing a depth of 4½ feet at low water, with ulterior possibilities of 6 feet, Figs. 9 to 12, Plate 6. For many years operations were confined to closing subsidiary channels, and local treatment of the worst shoals, the whole falling into the second category of the classification herein adopted. In pursuit of this plan, 100 miles of dams and 94 miles of shore protection had been built up to the end of the year 1894, Figs. 14 and 15, Plate 6; and the preliminary depth of 4½ feet was substantially continuous over the entire distance, at a cost only 25 per cent. greater than that of the Keokuk Canal, which gives 5 feet over 11 miles.

The improvement is now passing into a project of the third class, or regulation, designed to push the available depth at low water beyond 4½ feet, and as near 6 feet as possible, Fig 13, Plate 6. The river is now confined to a single channel over a great part of its length, within which it is proposed to control and direct its flow. Operations are still carried on in isolated localities, selected with reference to the immediate needs of navigation; but the work is extended at each locality over a length of river sufficient for a rational co-ordination of its various parts. The system of wing-dams is almost exclusively employed; and their length and location are made conformable to the rules laid down by Schlichting. They are oriented with respect to the

[1] "Notes on some of the chief Rivers and Canals of the United States and Canada," by G. T. Walch, p. 178.

tangents to the channel line at the points where they meet it, inclining upstream slightly, the angle between the tangent and the upper side of the dam ranging from 90°, the minimum for a convex shore, to 110°, the maximum for straight reaches. For concave shores, the angle is 100° to $102\frac{1}{2}$°, or practically constant. The distance between the dykes is made equal to the channel width in convex reaches, to five-sevenths of that width in straight, and one-half in concave reaches. The channel width in this case increases from 300 feet at Saint Paul, to 1,600 feet at the mouth of the Illinois, Figs. 9 and 13, Plate 6. The results thus far seem to show that the rules adopted are correct, except that the dyke intervals are less than is necessary for maximum efficiency when the length of dyke exceeds the width of the proposed channel. Some dykes with lengths nearly twice the channel width have been located with intervals equal to the length. In improving a reach, it has been found best to begin at the lower end.

With regulation of rivers may be classed the attempt to increase the low-water volume by impounding rainfall during the wet season. The lake region at the head waters of the Mississippi affords a favourable field; and four reservoirs have been made by damming outlets, a fifth reservoir is under construction, and a sixth is projected. The capacity of the four now in operation is 88 thousand million cubic feet; their aggregate flowage area is 469 square miles; and they have a drainage basin of 3,828 square miles, with an average yearly rainfall of $24\frac{3}{4}$ inches. Of the total precipitation, 16·83 per cent. passes over the dams into the channel. The scheme of release from the present reservoirs is, from the 15th November to the 15th April, 300 cubic feet per second; from the 15th April to the 1st August, 900 cubic feet per second; in August, September, and October, 2,700 cubic feet per second; and from the 1st November to the 15th November, 1,600 cubic feet per second. These quantities maintain the river 1 foot above normal low water at Saint Paul during the dry season, and they increase the navigable depth by that amount at least. The effect of the reservoir flow probably extends, diminishing in quantity, to Lake Pepin, 50 miles below Saint Paul.[1] It tends to equalise the capacity of the river above and below the lake, and thus benefits through navigation. Incidentally, the reservoirs have secured a reliable 5-foot navigation over 370 miles of the

[1] "Reports of the Chief of Engineers," 1883, p. 1455; 1887, p. 1681; and *Engineering Record*, 16th Feb., 1895.

Mississippi above the falls of Saint Anthony, and have increased the power available at the falls.

Lake Harbours.

The shores of the Great Lakes, within the United States, are conspicuously free from indentations. Those which exist are generally formed by the entrance of the small streams which drain the very narrow basin. The foreshore is flat and sandy, and the material of which it is composed travels along the coast in the direction of the prevailing storms. The phenomena of a littoral current are presented, but with less activity than on the sea-coast, and extending only to the depth of the disturbing action of waves. In their natural condition, the entrances to the harbours were obstructed by the extension of the foreshore across the inlet, forming bars over which depths of 2 feet to 7 feet only were found. Fluvial action, always feeble, was only felt during the freshets; and its results were soon nullified by the rebuilding of the bar. The plan adopted many years ago, and still pursued, is to form a sheltered channel between parallel piers, generally 150 to 300 feet apart, starting from the shore on each side of the river channel, and extending across the bar to a depth somewhat greater than that proposed to be maintained. At 1,000 feet from the shore the depth is 15 feet to 18 feet. At a depth of about 16 feet, the littoral action practically ceases; and deeper contours advance very slowly, if at all. Piers extended to this depth completely and permanently interrupt the drift, and do not require extension unless a deeper channel is desired. In the earlier works, projected for moderate depths, the fluvial action, unopposed by the littoral current, was able in some cases to open and maintain the channel. The demands of commerce, for several years past, have exceeded any depths so obtainable; and dredging is now depended upon for opening the channel, and usually for its maintenance. In most cases the rivers now contribute nothing to the enlargement of the channel, and the muddy ones assist in obstructing it.

The piers are timber cribs, filled with rubble, resting on the natural bottom, on piles, or on mounds of rubble. They are built in lengths of 50 feet to 100 feet, and placed end to end, rising to low water; and after a reasonable time for settlement, a continuous timber superstructure is built over them. Where additional shelter is required, breakwaters are built, on the same general plan, but with increased strength; and the timber superstructure is tightly decked to prevent the rubble from washing out of the pockets.[1] Concrete superstructures for breakwater piers are being constructed at Buffalo,[2] a very exposed situation, and at Marquette, Michigan. The base at Buffalo is made of concrete blocks, surmounted by concrete in mass. The Marquette superstructure consists of concrete monoliths 10 feet long, separated only by a thickness of tarred paper, and founded on a continuous layer of concrete 2 feet thick, extending from 1 foot below, to 1 foot above low water. The section consists of an 8-foot banquette 6 feet above low water, and a 6-foot crown 4 feet higher, with slopes of 1 to 1 on the lake side, and a vertical wall on the harbour side. Under the crown is a tunnel to be used by the keeper of the light on the outer end of the breakwater.

The storms of the lakes are sudden and violent; there is rarely sea-room to ride them out, and much of the shipping could not breast them if there were. At points of unusual exposure, or on long reaches of shore without commercial ports, harbours of refuge have been established in areas of good anchorage, sheltered by breakwaters of the type described. With the commercial ports, they form refuges so numerous and so distributed that a vessel overtaken by a storm can find shelter without delay, and without lengthening her voyage by turning back on her course. In the harbour of refuge at Sand Beach, Lake Huron, 20,375 vessels, aggregating 6½ million tons, took shelter from 1877 to 1893.

The action of the waves on exposed breakwaters is interesting. It has long been observed that the rear walls of cribs suffer more than the front ones; but the significance of the fact was not fully apprehended until the complete overturn, at Milwaukee, of a crib which, according to all theories of wave impact, should have been perfectly stable, led to a more thorough investigation. Dynamometers attached to the outer and inner walls, 6½ feet above the water, read 200 lbs. and 1,430 lbs. to the square foot, respectively, in one storm, and in another gale, placed 2½ feet above the water, they read 300 lbs. and 3,460 lbs. On a second exposure in the same position, they read 316 lbs. and 1,970 lbs.[3] These startling results show that if any vertical surfaces are exposed on the rear wall, as by the failure of the deck and washing out of the rubble, a tremendous overturning moment results. They account for the loss, from the banquette of the Buffalo breakwater, 12 feet wide

[1] "Report of the Chief of Engineers," 1894, pp. 2134, 2412, and 2424.
[2] *Ibid*, 1887, p. 2357; and Reports for the years 1888–9.
[3] *Ibid*, 1894, p. 2086.

and sheltered by a parapet 9 feet high, of 346 blocks of concrete weighing 7½ tons each, which were washed into the lake during the gale of the 9th and 10th January, 1889.

The principal lake-harbours have depths of 15 feet to 17 feet at normal low water. The recent low water is abnormal, and these depths have been impaired. As additional depth secured by pier-extension and dredging is increasingly expensive, the present emergency has given new impetus to the scheme for controlling the levels of the lakes by dams across their outlets. The completion of the St. Mary's lock, and of the 20-foot channel through the connecting rivers, will necessitate the same depth in several of the important harbours. The aggregate cost of creating these additional depths, and maintaining the present ones, will justify a large outlay on any plan which will accomplish both objects at once.

The Paper is illustrated by twenty-eight maps, prints, and tracings, some of which are reproduced in Plate 6.

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APPENDIXES.

APPENDIX I.

DIMENSIONS OF THE MORE IMPORTANT CANALS IN THE UNITED STATES.

Name of Canal.	Length.	Trunk. Surface Width.	Trunk. Depth.	Locks. —	Locks. Working Length.	Locks. Width.	Total Lockage.	Remarks.
	Miles	Feet.	Feet.	No.	Feet.	Feet.	Feet.	
1. Albemarle and Chesapeake	44	80	7½	1	220	40	2	
2. Cascades of Columbia River	1	140	8	1	462	90	24	
3. Champlain	81	58	6	32	110	18	180	
4. Chesapeake and Delaware	14	66	9	3	220	24	32	
5. Chesapeake and Ohio	185	50	6	75	100	16	609	
6. Delaware and Hudson	111	48	6	107	100	15	1,028	
7. Delaware and Raritan	66	60	6	14	220	24	150	
8. Dismal Swamp	29	40	5	7	100	16½	35	
9. Erie	381	70	7	72	110	18	656	30 miles slack-water.
10. Erie, Oswego branch	38	70	7	18	110	18	156	20 miles ditto.
11. Erie, Black River branch	76	42	4	109	90	15	1,080	4 miles ditto.
12. Harlem	6	150	12	..	..	..	..	Level canal.
13. Illinois and Michigan	97	60	6	15	110	18	141	
14. Keokuk	11	250	5	3	325	80	19	
15. Lehigh	108	44	6	90	{100 / 90}	{22 / 11}	540	
16. Louisville and Portland	2½	100	6	{2 / 2}	{285 / 335}	{50 / 80}	36	Parallel locks.
17. Miami	274	50	5½	93	{87 / 99}	15	907	
18. Morris	103	45	5	33	88	20	1,674	1,439 feet by inclined planes.
19. Muscle and Elk River Shoals	16	70	6	11	300	60	131	
20. Ohio, and branches	317	40	4	150	90	15	1,207	
21. Pennsylvania	193	{40 / 100}	{4½ / 6}	71	{85 / 180}	{14 / 17}	646	
22. Portage Lake	7	100	14	..	..	..	..	Level canal; includes Portage River.
23. Saint Mary's River	1	120	{17 / 21}	{1 / 1}	{515 / 800}	{80 / 100}	18	
24. Schuylkill Navigation Company's	108	60	6¼	71	110	18	619	20 miles slack-water.
25. Sturgeon Bay	2	100	14½	..	..	..	..	Level canal.
26. Susquehanna and Tide-water	45	50	5½	32	170	17	230	
27. Willamette	1	..	9	5	210	40	40	

Where widths and depths vary the minimums are given.

APPENDIX II.

Slack-Water Improvements in the United States.

Name of River.	Fall.	Total Length.	Locks.	Kind of Dams.	Completed. Length.	Completed. Locks.	Remarks.
	Feet.	Miles.	Number.		Miles.	Number.	
Allegheny	7	6	1	Movable	..	..	Lock now building.
Beaver	18	12	2	Fixed	12	2	
Big Sandy	9	13	1	Movable	13	1	Needle dam.
Black Warrior	45	15	5	Fixed	10	3	
Chippewa	..	..	1	"	..	..	
Coosa	323	147	31	"	10	3	
Cumberland	347	480	37	..	..	..	Several locks building.
Fox	200	160	27	Fixed	160	27	16 dams; 12 canals.
Great Kanawha	107	96	11	..	55	7	2 fixed, 9 movable dams.
Green and Barren	90	180	6	Fixed	175	5	
Illinois	28	225	4	"	225	4	
Kentucky	250	261	17	"	121	6	
Little Kanawha	50	42	5	"	42	5	
Mississippi above St. Paul	20	20	4	..	..	..	
Monongahela	100	112	10	Fixed	102	9	
Muskingum	75	75	11	"	75	11	
Ohio below Pittsburg	25	25	5	Movable	5	1	
Rock	..	27	4	Fixed	4	3	Part of Hennepin route.
Tombigbee	90	323	..	..	..	..	
Wabash	9	5	1	Fixed	5	1	

(Paper No. 2977.)

"Economic Railway Construction in Victoria."

By Maurice Edwin Kernot, M. Inst. C.E.

The State railway-system of Victoria has, during the years 1893–96, been extended from several points into the Mallee district, where lines suitable for conveying agricultural produce, chiefly wheat, towards the sea-board, at minimum rates, were strongly demanded, while, the population being light, ordinary goods and passenger traffic would not yield sufficient revenue. Under these circumstances only indispensable works were first executed, further works being deferred until the development of the district might require them. This system, combined with careful economy and the building of the lines under the butty-gang system, has reduced the cost greatly below that previously regarded as the lowest limit, and has supplied efficient railway accommodation to a large area, which could not have supported expensive lines, but which gives good returns on lines constructed for £2,000 per mile and less.

The Mallee district is an area of about 15,000 square miles, in the north-west of the colony, for the most part covered with a dense growth of the scrub "*eucalyptus dumosa.*" This area was long looked upon as almost valueless, as its grazing capabilities were slight and the cost of clearing off and grubbing the stumps of the scrub, to prepare the land for cultivation, was prohibitive. The introduction of the mallee roller, which, when dragged through the scrub breaks it down, as a standing crop is thrown down by a mowing-machine, and leaves it ready for burning off; and of the stump-jumping plough, which ploughs between the low stumps left after the mallee scrub is rolled and burnt, and trips over them without stopping in its course, has led to the cultivation of extensive areas. The soil is a light sandy loam, which, with an average of about 14 inches of rainfall per annum, yields wheat of high quality. The surface is generally level or slightly undulating, with occasional sand-hills and ridges. The sub-soil is of an absorbent nature, and the local rainfall soaks into it, while watercourses, fed in flood-time from the mountains to the south, meander through the country and are gradually lost.

Seven separate extensions, of a total length of 192 miles, have now been made. They are of the Victorian standard gauge of 5 feet 3 inches, and are laid with 60-lb. steel flange-rails, which will carry all the rolling-stock of the colony except some of the heavier engines. The saving effected by a lighter rail would have been reduced by the additional sleepers it would have required, and working expenses would have been increased, owing to lighter engines with less hauling-power having to be used. The sleepers are 9 feet long, 9 inches wide by 4½ inches deep, and of the varieties of eucalyptus timber known as grey box, iron-bark, and red gum; they had to be brought by rail from distances varying between 50 miles and 150 miles. Their life will be about twenty-five years, the timber being slow-grown, hard, tough, and dense, weighing 70 lbs. and more per cubic foot. Many sleepers of the same timber used on lines constructed thirty-five years ago now remain in the road, and some seem likely to last as long again. Gravel ballast was used, where obtainable at reasonable cost, but, on a total length of 80 miles, sand has been adopted, as extensive deposits occurred at intervals. This sand, having a tendency to set, has not blown badly in dry weather, and has stood satisfactorily when wet. The roads are cheaply maintained, and the running is less noisy and smoother than with any harder ballast, thus reducing some of the items of wear and tear, while the sand is free from most of the objections to loam ballast. A thickness of 4 inches was used for gravel ballast under the sleepers, which were boxed up 2½ inches with extra quantity where the formation was weak, and for sand 9 inches, about half being under the sleepers. Very little maintenance-ballast has been required, though the earlier lines have stood through three winters. The average amount of excavation for earthworks per mile varied on the different lines between 3,400 cubic yards and 6,200 cubic yards. A formation width of 13 feet 6 inches was tried, in accordance with a recommendation of a Parliamentary committee, but so much strengthening of banks was necessary before the lines were opened that 15 feet was adopted, allowance also being made for shrinkage.

The bridges are of timber, with openings of 11 feet and 15 feet, and are undecked except on curves sharper than 20 chains radius. The culverts are of the box type, built of sleepers, which are nearly as durable as country-made bricks. Fencing was not erected at first, but it was soon found advisable to proceed with it, and most of the lines are now enclosed by a fence of split-timber posts, 10 feet apart, and five plain wires with a barbed wire on the top. In some cases the landowners have erected the fence, the Government supplying materials which represent three-fourths of the cost. At public-road crossings cattle-pits are used, consisting either of an open pit with chamfered beams across to carry the rails, or a shallower pit with similar beams with timber grids made with feather-edged battens over the hole. The latter are more easily drained.

Road-side stations occur at 6-mile intervals, and one or two sidings 1,100 feet long, are provided at first, but space is left for more. The passenger-platforms were raised only 6 inches above the rail-level, corridor-carriages with steps at the ends being used. When stations occurred in cuttings the platforms were kept nearly up to the floor-level of the carriages, and much trouble is thus saved in handling van-goods. The cost of raising all the platforms would have been less than £100 per station.

The engines generally used are of an English type, with six wheels coupled, 4 feet 6 inches in diameter, with a load of 12 tons on the driving-axle, the tenders weighing 24 tons, including 2,200 gallons of water. Loads up to 900 tons are hauled.

The cost of the various items of work on the several lines are shown in the Appendix. Rolling stock was available, and consequently no expense has to be recorded for that item. The land was provided by local authorities at their own cost, but this was not great, as most of the area was held under conditions providing for free resumption for railway purposes. The last of these Mallee lines, between Wycheproof and Sea Lake, a distance of 48 miles, was constructed, and, as opened for traffic cost only £1,338 per mile. The works were started in April, 1894, the navvies starting close behind the surveyors who marked the permanent route. The clearing was pushed through quickly, and a telephone line was erected and proved of great convenience to the staff. As it was desired to provide work for the unemployed of the large towns, the earthworks were executed with the pick and shovel, and wheelbarrows or horses and carts. A saving might have been made by the use of ploughs and earth-scoops or grading-machines. As the shallow embankments, of which the formation principally consisted, were formed they were rolled with a 6-ton water-ballast roller dragged backwards and forwards several times by a team of bullocks. Before the rails were laid, the formation was trimmed and again well rolled, with the result that the earth was so well consolidated that, where the permanent way was laid, prior to the ballasting, material trains were run regularly without pressing the sleepers into it, though a considerable amount of rain fell. The sleepers and 60-lb. steel rails were supplied from a depot at the commencement of the line, the former being machine-adzed and bored. The rails were laid at the rate of 50 chains per day, and a higher rate could have been attained at a small increase of cost, but was not necessary. Water was provided by excavating an artificial tank, of 3,000,000 gallons capacity, at the middle point of the line, round which the spoil was placed in the form of a bank, with only one break for the inlet. When a flood came down the adjoining watercourse it filled the tank to 3 feet above the natural surface, and, the inlet being closed, a large quantity of water was stored for summer use. An evaporation of 60 inches per annum was allowed for, and measurements show the actual loss to closely approximate that depth. At the end of the line a natural lagoon yielded a good supply. Sand-ballast was obtainable at intervals on the second half of the line; but the first half had to be ballasted from a pit 25 miles out. One mile of the line and some roads were made with broken granite, and the station yards were metalled with limestone. The ruling gradient is 1 in 100, and the greatest length of it is 50 chains, so that trains of sixty trucks carrying 10 tons of paying load each are run easily, and a large wheat traffic is conducted at minimum working expense.

The butty-gang system was adopted generally on these lines, no large contracts being let, the work being divided and allotted to "butty-gangs," consisting of a convenient number of men, in practice ranging between two and sixty, and paid for at rates to allow efficient industrious men to earn the standard wages in eight hours, which was the recognized day's work. Weak and inferior men were thus enabled to take the easier portions of the work and make earnings in proportion to their abilities. In forming the gangs men of equal efficiency were placed together. The men appointed their own gangers, but the earnings were shared equally. Portions of the work were also given to picked men in petty contracts, and they were allowed to employ others, who were paid by the engineer at the standard rate of wages, the contractors receiving the balance due on the work after deduction of the wages so paid. Day-work men were only employed for such of the work for which fixed prices could not be fairly determined beforehand, or where piece-workers would require an excessive amount of supervision, and the day-gangs were put back on piecework as soon as convenient, as it was found that their efficiency usually diminished as the period of their employment lengthened. Sleepers and other timbers were cut in the forest and delivered at the nearest railway station at fixed rates by men working individually or in small gangs, an officer being sent periodically to inspect and pay for them. On these lines the works are measured, and the men are paid, fortnightly. Tools, tents, and explosives are supplied at cost-price. The system has shown a saving of time, as the works can be commenced very shortly after the permanent survey is started, while under the system of large contracts many months were required to make the survey, to prepare plans and specifications, and to obtain and settle tenders. A saving of cost is also effected. The workmen have performed their work as cheaply as if employed by a contractor, the resident staff has cost no more than if large contracts had been let, and consequently the cost of the contractor's staff and the whole of his profits have been saved. This has represented fully 15 per cent. on the cost other than for rails and fastenings, which were obtained by contract, the rails having to be imported from England. Alterations in the works, to meet unforeseen contingencies, have been freely made without considerable expense, and the difficulties in settling heavy claims for extras and detention, which so frequently occur with large contractors in such cases, are altogether avoided, the accounts being settled directly the line is opened, and the staff being available for fresh duties a few weeks after the opening. Generally, the freedom to adapt the details of the works to the varying circumstances which arise during construction without being hampered by a rigid contract has been of great advantage.

The standard rate of wages for labourers was 6*s.* per day of eight hours, being for a time reduced to 5*s.* Tradesmen were paid at corresponding rates.

The whole of the lines referred to, with the exception of that between Warracknabeal and Beulah, have been constructed under the control of the Author as District Engineer, acting under the Engineer-in-Chief of the Victorian Railways.

APPENDIX.—ANALYSIS OF COST PER MILE OF LINES CONSTRUCTED UNDER THE "BUTTY-GANG" SYSTEM.

Description of Works.	Warracknabeal to Beulah.	Donald to Birchip.	Beulah to Hopetoun.	Dimboola to Jeparit.	Natimuk to Goroke.	Boort to Quambatook.	Wycheproof to Sea Lake.	Average, 191¼ miles.
Length . . . . miles	22	32½	16	23	28½	22	48	
Date of Opening . . .	5/1/93.	28/3/93.	6/3/94.	19/6/94.	31/7/94.	7/8/94.	8/3/95.	
	£	£	£	£	£	£	£	
Clearing and grubbing	20	5	10	10	23	6	7	11
Fencing	80	87	48[1]	8[2]	51[3]	14[2]	..[2]	37
Cattle-pits at crossings	28	39	30	6	13	5	..	15
Earthworks (including stations and approaches) . .	165	214	192	146	240	150	126	173
Bridges	62	49	32	11	66	23	..	33
Culverts	34	42	40	25	25	17	6	24
Gravelling roads and approaches . . .	25	36	12	5	18	19	8	17
Ballast (main line and sidings) . .	305[4]	238[4]	128[5]	109[6]	174[4]	250[4]	85[5]	175
Sleepers (red-gum, ironbark, or box—main line and sidings) . . .	459	369	439	381	424	320	321	376
Rails and fastenings, 60-lb. steel (main line and sidings, including freight and laying)	679	699	681	650	642	687	615	659
Temporary station buildings (including platforms) . .	40	41	32	10	12	12	8	20
Water-supply (temporary)	..	10	9	..	6	..	20	8
Signals	2	3	..	5	2	..	..	3
Telegraph . . .	10	14	11	11	13	16	10	13
Engineering and surveying	216	168	191	128	262	168	95	167
Miscellaneous items .	9	3	8	5	3	..	7	4
Interest on capital during construction	27	35	29	34	45	35	30	33
Total cost per mile to date of handing over	2,161	2,052	1,892	1,544	2,019	1,722	1,338	1,768
Approximate expenditure since opening	173	168	40	33	157	72	19	92
Total cost per mile (to 30/6/95) . . .	2,334	2,220	1,932	1,577	2,176	1,794	1,357	1,860

[1] Two wires only. [2] Unfenced. [3] Incomplete.
[4] Gravel. [5] Sand. [6] Sand and gravel.

(*Paper No. 2696.*)

"The St. Rollox Locomotive and Carriage Works of the Caledonian Railway."

By Peter Livingston Dunn, Assoc. M. Inst. C.E.

The rapid development of traffic on the Caledonian Railway has rendered necessary large additions to the rolling stock, and in 1882 the Directors decided to erect large workshops in which locomotives, carriages and wagons could be built and repaired. The site for the new buildings was chosen on land adjoining the then existing repairing shops and stores at St. Rollox, in the north-eastern district of Glasgow, about 1 mile from the terminus at Buchanan Street Station. This site was selected because it was the centre of the railway system, where there was abundance of skilled labour; it was also well adapted for the foundations of heavy buildings, as there are no underground workings of mines so common in the surrounding districts. Another advantage of this situation was the facility with which the works and yards could be satisfactorily drained.

The main range of buildings, Fig. 1, Plate 7, are bounded on the west side by Springburn Road, in which is situated the principal entrance; on the north by the Caledonian Garnkirk Extension to Buchanan Street; on the east by the extensive depot of St. Rollox East; and on the south by the Old Garnkirk Railway. The new shops cover an area of 15 acres.

The Locomotive Workshops and the depot in front of them cover an area of ground bounded by the Springburn Road, the Garnkirk Extension and Old Garnkirk Railways. The shops were laid out in such a way that the proper sequence of operations could be followed so as to minimize labour and thus lessen the cost of the construction and repair of the rolling stock. Under one series of roofs are included the iron- and brass-foundries, the boiler- and smith-shops, the forge, the erecting, tin-smith, wheel- and machine-shops, the carriage- and wagon-shops, and the saw-mill and the joiners' shop. Detached from the main building are the timber-drying store, and the paint-shop. To provide more space the old edifices belonging to the Stores department were taken down, and new structures in their stead were erected on Charles Street, where an extensive yard was laid out. These give greater facilities both for receiving stores from the city and forwarding them direct to different points along the railway. The fact that the repair of rolling stock had to be continued without intermission caused much extra trouble and anxiety during the clearing and levelling of the ground for the removal of the old and the erection of the new shops over and around the same site. The walls of the work-shops, resting on concrete foundations, are built of red brick, relieved with white brick at corners, windows, doors and cornices; and they are surmounted by parapet walls with dressed-sandstone copings. The roofs of the carriage- and wagon-shops, the machine-shop, the smith-shop, the forge, and the saw-mill, run at right angles to those of the foundries, the erecting-shop, the wheel- and the tin-smiths' shops; but they together form one building covering an area of over 11 acres. The roofs are supported on girders and cast-iron columns. The wrought-iron principals, except where glass is used, are covered with $1\frac{3}{8}$-inch boarding and 20-inch by 10-inch Welsh slates. The purlins consist of angle-bars, with a wooden runner, to which the boarding is nailed, bolted to them. The shops are lighted by windows which extend along both sides of each roof. The glass, $\frac{1}{4}$-inch rough cast British plate, is fixed by small iron pins and putty, to the malleable-iron astragals. Sheet lead (weighing 6 lbs. per square foot) is placed along the bottom and sides of the windows.

As the stones for heavy door hinges are frequently destroyed in such workshops, hollow cast-iron blocks of $\frac{3}{4}$-inch metal were designed for these buildings. These blocks are filled with concrete and are built into the walls. Each is fitted with a $1\frac{1}{4}$-inch malleable-iron pin to keep the hinge in position.

Rain-water from the roofs is led along cast-iron valley gutters and down inside the columns into fireclay pipes leading into an egg-shaped brick sewer connected with the Glasgow Corporation sewer in Springburn Road. In cold weather the shops are heated by pipes with the exhaust steam from the stationary engines. The service of good water for drinking and cleansing purposes, for boiler use, and for the prevention and extinction of fire is assured by two supplies—from the Corporation of Glasgow and from the Company's waterworks a few miles from the city. Special precautions are taken for the prevention and extinction of fire throughout the shops. Hydrants are laid at convenient places inside and outside the buildings. There is also kept in readiness a fire-engine on a four-wheeled carriage, which can be utilized when required by members of the staff drilled for that purpose. Buckets filled with water, for use only in case of fire breaking out, are placed in every shop. Gas is supplied from the mains of the Glasgow Corporation to lamps hanging from the roofs, and to brackets fixed on the columns and side walls.

For the small low-wheeled trucks used for easily transporting heavy materials, a railway of 1-foot $8\frac{1}{2}$-inch gauge, traverses every part where required of the main building. The rails are flat, $1\frac{1}{2}$ inch by $\frac{7}{8}$-inch iron-bars fixed to the flooring by countersunk screws set 18 inches apart. The floors of the erecting-, machine-, wheel-, carriage-, and wagon-shops consist of oak frames from wagons that had been broken up. The flooring is spiked to timber runners, and rests on a thick bed of engine ashes. Within the walls of the main building there are laid $3\frac{1}{4}$ miles of railway, of 4-foot $8\frac{1}{2}$-inch gauge, connected with the many miles of sidings in the yard. The buildings were designed and fitted with machinery and tools of the most recent approved types of British and American manufacture, so as to save labour and to ensure uniformity and accuracy of workmanship. These locomotive workshops provide constant employment for about 3,000 men, whose comfort and efficiency were promoted by the change from the old into the new shops. Outside the workshops from the eastern doors there is a slight gradient, falling towards the junction of the yard sidings with the main line of railway.

Besides these workshops in connection with the locomotive department there are a number of running-sheds situated at convenient points on the line of railway wherever locomotives require to be sheltered and small repairs attended to while they are in active service. These sheds are provided with small stores for holding the materials necessary; and with water-tanks and coal stages, turntables, and furnaces for drying sand.

The Iron Foundry, Fig. 2, 159 feet long by 80 feet wide and 22 feet high, is built in two spans, and is placed in a wing to the south-west of the main building. The excavations for foundations were taken out to 5 feet below the level of the present floor; Arden lime concrete was then laid to the depth of 2 feet. On this the walls were built of red brick, 2 feet thick, to the top of the base, then the wall is divided into panels 18 inches thick, with a thickness of 2 feet at the pilasters and cornices. Above the level where the roof principals rest there are 9-inch parapet walls, $2\frac{1}{2}$ feet high, with sandstone copings. On the inside of the south wall, at 20-foot $4\frac{1}{2}$-inch centres, there are brick piers, 2 feet wide by 14 inches deep and 17 feet high, on which are supported one line of the rolled beams and rails for the travelling crane used in the shop. The north side of the shop is composed of a wooden partition, which can easily be removed when an extension of the foundry is deemed necessary. The cast-iron columns supporting the roof in the middle of the shop are bolted to hard sandstone blocks, 3 feet by 3 feet by 1 foot 3 inches, which rest on the brick and concrete foundations. The stones are perforated to contain the cast-iron pipes, which lead the rain-water from the columns to 6-inch fire-clay pipe drains. The floor level is 5 feet above the bottom of the concrete foundation. The concrete is 2 feet thick. The cast-iron columns, 20 feet $4\frac{1}{2}$ inches apart, which support the roof, are each 22 feet long, circular in section, except the 3 feet at top, which, to suit the connections with the girders, are 9 inches square, and of 1-inch metal. The diameters of the circular parts of columns are 15 inches at the bottom, tapering to 12 inches below the seats of the girders; the metal is $1\frac{1}{2}$ inch thick. On these columns, at 17 feet from floor level, there are brackets to carry the beams and rails on which the travelling crane runs. The sole-plates, of 2-inch metal, are 2 feet 6 inches square, with four holes for $1\frac{1}{4}$-inch bolts attached by lead to the foundation stones. The malleable-iron lattice roof-girders are 3 feet deep and 40 feet long. They are built up with 9-inch by $\frac{1}{2}$-inch flat bars, and 4-inch by 4-inch by $\frac{1}{2}$-inch angle-bars on the top and bottom flanges, with 6-inch by 3-inch by $\frac{1}{2}$-inch T-stiffeners, 5 feet $1\frac{1}{8}$ inch apart, and $2\frac{1}{2}$-inch by $\frac{3}{8}$-inch lattice bars. The rivets are $\frac{3}{4}$ inch diameter, at 4 inches pitch. Each girder is fastened by four 1-inch bolts to the square upper part of the column. The roof trusses are entirely of malleable iron, the span being 38 feet 6 inches, and the height 13 feet. They are spaced at 10 feet $2\frac{1}{4}$ inches centres. The rafters are $3\frac{1}{2}$ inches by $4\frac{1}{2}$ inches by $\frac{1}{2}$ inch T-bars, joined at the apex by two $\frac{1}{2}$-inch plates. The tie-rods are $1\frac{3}{8}$ inch and $1\frac{1}{4}$ inch in diameter, with forged eyes, and are pinned to the rafters and shoes by means of $1\frac{1}{4}$-inch bolts. The middle vertical rods are $1\frac{1}{8}$ inch, and the side rods $\frac{5}{8}$ inch in diameter, and have screwed ends, nuts and washers. The trusses rest on malleable-iron shoes, made up of two pieces of 6-inch by 6-inch by $\frac{1}{2}$-inch angles, and a $\frac{1}{2}$-inch plate riveted to them. The shoes are each fixed by

1-inch bolts, 6 inches long, to the bearing stones on the wall, or to the girders over one of the stiffeners. There are on each roof rafter five malleable angle-iron purlins, 3 inches by 3 inches by ½ inch, with 2½ square inch wood runners, to which the slate boarding is nailed. The shop is lighted by windows (5 feet wide), extending along each side of each roof the length of the building. The astragals for the glass are malleable iron of an inverted cross section. 2 inches deep by 1¼ inch broad by ¼ inch thick, and placed 15 inches apart. The glass used is ¼-inch rough cast British plate, in panes 5 feet 6 inches long, and glazed with putty. Along the ridge of each roof there is a ventilator constructed with 3½-inch by 3½-inch by ½-inch T-bars stayed by 3½-inch by 3½-inch by ½-inch angle-bars to the top of each principal, and with 2½-inch by 2½-inch by ½-inch angle-iron diagonal bracing supporting the 3-inch by 3-inch by ⅜-inch T-iron apex of the ventilator. Upon this T-bar the astragals are fixed at the top, and they rest on 3-inch by 3-inch red pine purlins, supported on 3-inch by 3-inch by ½-inch angle-irons riveted to the standards. The ventilators are glazed in the same way as the roof windows, but have cast-iron semi-circular 4½-inch gutters, with conductors to prevent the rain from being blown into the shop. The ridges of ventilators are protected by 6-lb. sheet lead, fixed by copper tacks to a wooden runner fitted on the top of the T-bars. The roofs, where not glazed, are covered with 1⅜-inch tongued and grooved slate boarding, on which are nailed the 20 inches by 10 inches Welsh slates. The gutters, cast to fit the pitch of the roofs, are 30 inches by 6 inches at the valleys, and 14 inches by 5 inches at the parapet walls. They were jointed with red lead and screw-bolts. The rain-water is conducted down the cast-iron columns, and at the walls down 3½-inch heavy cast-iron conductors, into the underground fire-clay pipe-drains. Over the roof gutters are placed snow-boards.

In the south span, the whole length of the iron foundry, an overhead crane travels on rails secured to rolled beam girders, which are supported on the column brackets, and on the brick wall-piers. Outside the south wall, the cupola is supplied with materials by means of a hydraulic lift. The blast is obtained from a fan in the engine-house attached to the foundry. There are two core ovens.

The Store for Patterns, Fig. 2, is 96 feet long by 39 feet wide, and 22 feet high. It occupies a bay to the north of the iron foundry, to which it may be, if required, added by removing the timber partition between the two departments. The details of construction, with the exception of the columns, are similar to those of the foundry. As the cast-iron columns are only for the purpose of supporting the roof, they have no brackets, and are of smaller cross section, viz., 12 inches in diameter at the bottom, and 9 inches at the top, the metal being 1 inch thick.

The Brass Foundry, Fig. 2, is 78 feet 6 inches long by 38 feet wide, and 22 feet high, and is enclosed by 14-inch thick brick partition walls. The crucibles are arranged alongside the north wall of the shop. The furnace is below the floor-level, and the chimney is led up one of the gables of the boiler-shop. The crucibles can easily be lifted out of the furnace and conveyed to the moulds. At the west end of the shop a moulding-machine is worked by the pressure of air supplied by a Westinghouse pump; the sides of the casting-box are pressed together, and, by means of a flexible pipe, the air may be directed on the loose particles of sand, and instantly blows them away.

The Pattern-makers' Shop is 78 feet 6 inches long by 38 feet wide. Besides the door leading into the brass foundry, it has one to the boiler-shop and another to the store for patterns.

The Boiler Shop, Figs. 2 and 4, covers an area of 29,538 square feet. The outside walls are 22 feet high, and 18 inches thick, and 2 feet thick at the pilasters. There are a number of brick piers built against the walls to support beams and rails for travelling cranes. The west portion of the boiler-shop (108 feet by 86 feet) is in two spans of 54 feet each. The south-east portion, 141 feet long by 75 feet span, and the north-east portion, 129 feet by 75 feet, have three spans of 43 feet each, so as to allow the overhead cranes in the erecting-shop to travel into the boiler-shop. The 54-foot roof principals, placed 10 feet $2\frac{1}{4}$ inches apart, are composed of 4-inch by 5-inch by $\frac{1}{2}$-inch T-bar rafters, the $1\frac{1}{2}$-inch pin-holes for tie-rods being at 54 feet centres, and the height of the principals being 18 feet. The horizontal tie-rod varies between $1\frac{3}{4}$ inch and $1\frac{1}{2}$ inch in diameter; it is in two parts, joined at the middle by two $\frac{3}{4}$-inch plates, and two $1\frac{3}{8}$-inch bolts The middle vertical tie-rod is $1\frac{3}{8}$ inch diameter, and bolted at top to the two $\frac{1}{2}$-inch plates joining the rafters, and at the bottom to the tie fish-plates. The other two vertical tie-rods at each side of the middle one are of $\frac{3}{4}$ inch and $\frac{5}{8}$ inch diameters respectively. The junction points of the middle vertical rod with the horizontal rod in each principal are connected by a tie-rod running longitudinally from end to end of the building. The struts are made of 3-inch by 3-inch by $\frac{1}{2}$-inch T-bars, fished at the top to the iron rafters, and bolted at the bottom to the tie-rod. There are six purlins (3-inch by 3-inch by $\frac{1}{2}$-inch angle-bars) on each slope of the roof, which, as well as the ventilators, are of the same construction as those of the foundry, except that there are four, instead of two, lines of 5-foot sky-light windows in each roof. The girders for supporting the roof are also of the same style as those in the iron foundry, but they vary slightly in length. The columns (15 inches to 12 inches in diameter and of $1\frac{1}{2}$ inch metal) have two brackets each, excepting the one at the end which has three, to suit the girders of a crane that may be used to run at right angles to the present travellers. In the north wall is a door leading to the forge; in the west wall a door to the passage where the tubes for locomotive boilers are cleaned; and in the south wall, a door to the pattern shop. In the corner of the west portion of the shop there is a saw for cutting tubes. The south-east portion of the boiler-shop is covered with one 75-foot span by a roof running at right angles to that just described. The principals, having a rise of 18 feet 6 inches, are placed at 9 feet centres, and rest on malleable-iron shoes bolted to stones on the wall-head. The roof rafters are 5-inch by 6-inch by $\frac{5}{8}$-inch T-bars. The horizontal tie-rod, divided in two parts, varies between $2\frac{3}{8}$ inches at ends and 2 inches at middle, where it has a rise of 2 feet 6 inches. There is a longitudinal tie-rod with screw couplings for adjustment. The middle vertical tie-rod is 2 inches in diameter, and those on each side are $1\frac{3}{4}$ inch, $1\frac{1}{8}$ inch, and $\frac{7}{8}$ inch respectively. The T-bar struts are 4 inches by 4 inches by $\frac{1}{2}$ inch, $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{1}{2}$ inch, 3 inches by 3 inches by $\frac{1}{2}$ inch, and 3 inches by 3 inches by $\frac{1}{2}$ inch respectively. There are eight purlins on each rafter, otherwise the roofs are the same as those on the foundry. There are six lines of windows on the roof, giving a total width of 30 feet for the whole length of this portion of this shop. There are, in the east wall, two large arched doors leading to the outside yard. The north-east portion of the boiler-shop is an extension of the erecting-shop, so as to permit the overhead travelling cranes to enter, in order to lift and transfer the locomotive boilers to the frames on which they are to be erected. There is, in the west wall, an arched doorway to the forge, but there are no partitions on the north side between the boiler-shop and the smiths' shop, or on the east side between the boiler-shop and the erecting-shop. This scarcity of partitions is one of the striking features of the workshops.

Among the machinery in this shop for constructing boilers are a horizontal rolling-machine to bend the plates; drilling-, punching-, and shearing-machines, a hydraulic riveter, a saw for cutting tubes, angle-bars and boiler-plates, and outside a tube-cleaner, which derives its motion from a belt from the shafting placed along the west wall of the shop. The steel plates for boilers, the brass tubes, and the copper for the fire-boxes are bought by the Company, but the edges of the plates are planed, the rivet-holes drilled and punched, the riveting done by hydraulic power, and the boilers completed in the workshops.

The Smiths' Shop, Figs. 3, is 390 feet long by 75 feet wide in one span. The walls on which the roof-trusses rest are 22 feet high and 18 inches thick, with five arched doorways in the west wall to the forge, and five in the east wall to the carriage- and wagon-shops. The north end of the smiths' shop is enclosed by a brick gable, with a chimney-stalk in the middle of it to conduct above the roof the smoke from the various fires. The roof and longitudinal ventilator are of the same description as those of the 75-foot span roof in the boiler-shop. The smiths' shop is well lighted and ventilated. There are seventy hearths, arranged in four rows—one along each side-wall, and two, back to back, in the middle of the shop. They have cast-iron hoods, from which the smoke and fumes are conducted to the chimney through sheet-iron pipes hung from the roof in the middle, and one at each side. The blast is produced by a large Root blower, and is conducted to the hearths by cast-iron pipes laid under the floor of the shop. Ten small steam-hammers are distributed conveniently throughout this shop. At the north end of the building is the spring shop where the steel plates are bent, tempered and secured together by wrought-iron buckles shrunk on to them. The spring furnace is 9 feet by 6 feet. At the south end of the smiths' shop are machines for making bolts, rivets, ferrules, &c., and also the grinding shop for sharpening tools, finishing surfaces of iron and steelwork, &c.

The Forge, Figs. 3, 546 feet 9 inches long by 40 feet 9 inches wide, occupies the extreme west portion of the main building—next the smiths' shop and the boiler-shop. The roof is made up of parts of those removed from the old buildings, and it is supported at the front on wrought-iron lattice girders and cast-iron columns, and all that side is left open. A ventilator extends along the whole length of the ridge of the roof. The columns, spaced 36 feet apart rest on stone, brick and concrete foundations, 19 feet 6 inches high, 12 inches diameter at the bottom and 9 inches at the top, the metal being 1 inch thick. The columns also serve as rain-water conductors. The girders are 2 feet 6 inches deep, and similar to those in the wagon-shop. A line of railway is constructed along the front of the forge to the north end of the boiler-shop, so that materials, such as coals and boiler-plates, can be delivered from the wagons directly on the spot where they are required. Among the appliances in the forge are five steam-hammers of 60 cwt., 30 cwt., 20 cwt., 15 cwt. and 5 cwt. respectively; a scrap-shearing machine capable of cutting pieces of iron and steel up to 6 inches square; veeing presses and a machine for forming the triangular spokes for the wheels of wagons; fires for wheels; hydraulic press for wheels; five furnaces with locomotive boilers to supply steam; suitable hearths; and cranes at the sides of furnaces for lifting forgings to and from the steam-hammers. The foundation of the 60-cwt. steam-hammer was constructed of concrete, 16 feet square, and 6 feet 9 inches deep, and on the top of this, six layers of pitch-pine logs 14 inches square, each layer at right-angles to the one below, the top layer being 10 feet square. The furnaces are built with fire-clay bricks and jointed with fire-clay, and strengthened in the usual way by iron tie-rods outside. In a separate house in the south-east corner of the forge is placed the engine for pumping the water to supply the hydraulic power for use in the workshops.

The Erecting Shop, Figs. 3, extends east of the boiler-shop in three bays, each 43 feet span—two lengths of 578 feet each, and one of 546 feet. In each bay there are three lines of railway—a running- and two standing-roads; the latter are provided with engine-pits between the rails to enable the workmen easily to get beneath the locomotives. The engine-pits are 2 feet 6 inches deep, 3 feet 10 inches wide, and extend the full length of the shop. They are built of red-brick walls 18 inches thick, resting on concrete foundations. The bottom of the pit is composed of brick on edge, and is of a convex form, having a falling gradient to bell-traps placed at short distances apart. On the top of the walls there are bolted, 16 feet by 8 inches pitch-pine longitudinal sleepers, to which the cast-iron chairs for the steel rails are spiked.

The only part of the old works that was allowed to remain, and it was heightened and altered to suit the present buildings, was the north boundary wall of this erecting-shop. The south wall, into which the I-columns are embedded, are 18 inches thick at panels and 2 feet at the pilasters, base and cornice. It serves as a partition between the erecting-shop and the department for dressing castings, the tinsmiths' shop and the store for fitters' materials, and the remainder of it is an outside wall. The three gables facing the yard to the east are also of 18 inches red-brick work, increased at the base, pilasters and cornice, and all relieved in appearance by white bricks at the corners. The walls are surmounted by a dressed sandstone, 14 inches by 6 inches coping.

The roofs are supported on the walls on cast-iron columns placed at 15 feet 6½ inches centres on foundations of stone, brick, and concrete, and on cast-iron beams; the last also serve as gutters to carry off rain-water, which is carried down every alternate column to the fire-clay pipe-drains. The round cast-iron columns are 32 feet long, with diameters tapering from 15 inches at the bottom to 12 inches at the top, with metal between 1½ inch and 1 inch thick. The 17-inch by 14-inch I cast-iron columns, built into the wall, are 32 feet long with metal 1½ inch thick. All the columns have brackets, 22 feet from the floor, on which rest the rail girders for the overhead travelling cranes. The wrought-iron roof trusses, 12 feet 9 inches rise, are set 7 feet 9¼ inches apart, and are connected to ears on the cast-iron beams or girders. They are supported alternately over a column and over the middle of the span of the girder. Stretching along each slope of the roof are two lines of windows. The glass is ¼ inch rough cast British plate, in panes 5 feet 6 inches long, glazed with putty on malleable iron astragals placed 1 foot 3 inches apart. At the bottom of windows there is 6-lb. sheet lead.

In each of the three spans of the erecting-shop there are two 30-ton overhead travelling cranes, driven by ropes running at a high speed, the manipulation of their various motions being attended to by a man on each crane. The girders for supporting the crane-rails are composed of 12 inches by 6 inches I rolled-iron beams, weighing 168 lbs. per lineal yard, with a steel rail on the top weighing 78 lbs. per lineal yard. The cost of these girders and rails was 45*s.* per lineal yard. Between the columns that support the roofs, and also against the walls, are placed ranges of fitters' benches supplied with vices, &c.

The erecting-shop has accommodation for ninety locomotives and eighteen tenders. Here they are built up with the parts brought from the various other shops in which they have been finished; from the foundries, the forge, the smiths', boiler-, wheel-, and machine-shops. The locomotive engine frame-plates are taken to a vacant berth on one of the side roads of the erecting-shop, and there fixed in position over the engine-pit. The cylinders are then fixed, and the boiler, by the aid of the travelling cranes, is lifted into its place on the frames, and the wheels with axles and axle-boxes placed under. Then the eccentric and connecting-rods are fixed, the valves set and all the fittings completed. The locomotive is now lifted upon the running road in the middle of the floor and dragged by the travelling cranes to, and lifted on, the weigh-bridge at the eastern end of the shop where the weight on each wheel is adjusted. It is then tested by water- and steam-pressure, and, with its tender, which is constructed in another part of the erecting-shop, it is taken to the paint-shop at Charles Street.

The Company owns six hundred and ninety-six locomotives and five hundred and ninety-one tenders; of these during the six months ending 31st July 1892, eighteen engines and eighteen tenders were constructed. Repairs and renewals in the locomotive department for the same six months cost £56,952, of which £25,166 was paid in wages and £31,785 for materials. The running expenses of the locomotives for the same period amounted to £170,324. The total cost of locomotive power is at the rate of 8·07*d.* per train-mile.

The Coppersmiths' and Tinsmiths' Shop is 201 feet long by 40 feet 3 inches wide and 18 feet high. It is placed outside the south wall of the erecting-shop, to which communication is kept up by means of doors in the wall. The outside wall of this shop is built of 14-inch brickwork, with pilasters 18 inches thick and 3 feet wide placed at 15-foot 6½-inch centres; these pilasters, with base and cornice, dividing the wall into panels and adding to the appearance of the buildings. The brick wall with scarcements rests on a concrete foundation 2 feet thick. The shop is lighted from the roof in the same manner as the other buildings. The roof-work here is of the same kind as that of the iron-foundry.

Fitters' Store.—To the east and adjoining the tinsmiths' shop is the store, 93 feet by 40 feet 3 inches, for materials used by the workmen, especially the fitters, in the erecting-shop, to whom they are given out through a window in the division wall on presentation of written orders signed by the foremen. This store is fitted with shelves, &c., for keeping systematically in stock the materials required. The construction of the building is similar to the coppersmiths' shop, of which it is a continuation.

Castings Department.—Conveniently placed adjoining the erecting-shop and boiler-shop, and west of the coppersmiths' shop, is the building, 109 feet by 40 feet 3 inches, in which the castings from the iron-foundry are dressed. In the panels in the front wall open archways, 14 feet high and 11 feet wide, are formed; otherwise the structure is the same as the coppersmiths' shop. There is also an archway leading into the erecting-shop.

The Wheel Shop, 247 feet long by 80 feet wide, to the north of and separated from the erecting-shop by the old wall, is composed of two spans, each 40 feet wide. The height and style of the building are the same as those of the erecting-shop. The roofs are supported on the old repaired wall, on a line of columns in the middle of the shop and on columns built into the north, 18 inches and 24 inches thick, brick wall. The columns are of cast-iron, 32 feet high, 17 inches by 12 inches I section, with metal 1½ inch thick, and have brackets cast on them 22 feet above floor-level for the rail girders of the travelling cranes. The roof-work is the same as that on the erecting-shop, with the exception that the spans of principals are slightly less and the rain-water is conducted to the drains by 3½-inch cast-iron pipes fixed to the columns. As the wheel-shop is higher than the adjoining machine-shop, the extra height at the ends of the two spans are filled by gables composed of wood lining secured to malleable iron framing.

In each span of the wheel-shop there is one 10-ton overhead travelling crane; and to the side walls and columns there are attached numerous cranes with horizontal jibs, for moving carriages from which the loads are suspended, to be worked in or out as well as swung around. There are in this shop three lines of shafting, 5 inches in diameter, attached at 17 feet 3 inches from the floor-level to the side walls and to the centre line of columns. The shafts are driven from a wall-engine in the machine-shop. In the wheel-shop there are four rows, extending along the building, of turning lathes and other tools. Wheel-tires 8 feet in diameter and under can be turned. At the west end of this shop are placed the large planing-machines. In the middle of the floor in each span there is laid a standard line of railway which is convenient for transporting the wheels; the narrow-gauge rails are also fixed to the floor inside the 4-foot 8½-inch way.

The Machine Shop, 576 feet 8 inches long by 80 feet wide, is surrounded by the wheel-shop, the erecting-shop, the boiler-shop and the wagon-shop. The roofs, 22 feet above floor-level, are a continuation of the wagon-shop roofs, running at right-angles to those of the erecting-shop, and having the old walls of the latter as a gable. The cast-iron columns are of I section, 17 inches by 12 inches with metal 1½ inch thick. They are of this shape for convenience of attaching the shafting to them. They are 22 feet high, 2 feet 6 inches at the top, of square section, 9 inches by 9 inches and 1 foot thick, to which the malleable-iron girders are bolted. The sole-plates are 3 feet by 2 feet 4 inches by 2 inches thick. The columns in the lines of the roof-supporting girders are placed 40 feet apart, and at right-angles to those lines at 41 feet 3 inches from centre to centre. The wrought-iron lattice girders for supporting the roofs between columns are 39 feet 3 inches long, and those between the columns to the gable wall 40 feet long. The girders are 2 feet 6 inches deep. To resist the vibration of the machinery and to suit the shafting for the pulleys actuating the leather belting, there are additional wrought-iron girders fitted between the columns at right-angles to the roof-supporting girders. The iron roof-trusses are placed at 10 feet centres with their shoes bolted to the girders; the span between the centres of pin-holes in the rafters is 40 feet 3 inches, and the height of truss 12 feet. There are four rows of windows in each roof. Slates nailed to $1\frac{3}{8}$-inch sarking cover the remainder of the roof. The ridge is of 8 inches by 8 inches cast-iron. The rain-water is taken from the 30 inches by 6 inches cast-iron gutters in $3\frac{1}{2}$ inches cast-iron conductors, which are secured by malleable-iron glands to the I columns.

The machine-shop is provided with a great number of turning lathes, planing-, shaping-, milling-, slotting-, drilling-, screwing- and tapping-machines, each suited to its own particular work. These tools are arranged in rows along the shop. There are three lines of 5-inch shafting, one fixed on the wall and one on each row of columns. The engine from which they derive their motion is secured to the wall at the east end of the shop where the pulleys on the shafts for the rope gearing are 7 feet $1\frac{15}{16}$ inch in diameter. The machines stand upon solid brick and concrete beds. In the middle of the floor of both bays in the machine-shop there is laid the narrow-gauge railway for use in transporting the materials required to be moved between the various shops.

The Carriage and Wagon Shops, Fig. 3, are together 576 feet 8 inches long and 372 feet wide. This department is bounded on the south by the wheel- and machine-shops; on the west by the smiths' shop; on the north by a store and the saw-mill and joiners' shop; and on the east by the depot. The outside walls are 18 inches thick and 2 feet thick at the pilasters, base and cornice, with a 9-inch thick parapet wall with a copestone on the top. The walls are carried down 3 feet below floor-level and rest on 2 feet of concrete. The doors measure 16 feet by 11 feet, and are two-leaved, with semicircular tops and they all have wickets. The roofs—fourteen spans, each 41 feet 3 inches—are transverse to the lines of rails. The wrought-iron roof-trusses are carried on lattice girders supported by cast-iron columns. The latter, 22 feet high with diameters 12 inches at the bottom tapering to 9 inches at the top and of 1 inch metal, also serve as rain-water conductors; under the roof-supporting girders, they are placed 36 feet apart in the wagon-shop and 40 feet apart in the carriage-shop. A length of 2 feet 6 inches at the top of each cast-iron column is in the form of a 9-inch square to which the girders are bolted. The girders, 35 feet 3 inches and 2 feet 6 inches deep, in the wagon-shop are made up of 9 inches by $\frac{1}{2}$ inch plates, 4 inches by 4 inches by $\frac{1}{2}$ inch angles; 6 inches by 3 inches by $\frac{1}{2}$ inch T-bar stiffeners, and $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch lattice bars set at an angle of about 45°. In the carriage-shop the girders are 39 feet 3 inches long, the angle-bars are 4 inches by 4 inches by $\frac{5}{8}$ inch, otherwise the section is the same as in the girders of the wagon-shop. The roof-trusses are 40 feet 3 inches span. The purlins, glazing, sarking and slating are the same as in the machine-shop. In the carriage- and wagon-shops there are twenty-two lines of the standard gauge of railway laid on cross sleepers in the usual manner, the whole length of the shops from the eastern doors. The floor of these shops is composed of oak as described. At the north side there is a store, 80 feet by 34 feet, containing the materials required in the carriage and wagon building. Above the store is an office, from the windows of which a good view of the shops is obtained. Parallel to and between every pair of standard-gauge roads there is a narrow-gauge line, and there are also transverse lines at the middle and end of the shops.

In the carriage-shop various kinds of vehicles are erected—saloons with lavatory accommodation; first, second, third class and composite carriages, many of them with lavatories. The bodies of the carriages are constructed principally of oak, teak, and mahogany timber and the partitions of pine. The woodwork panels in the inside of first-class compartments are usually composed of sycamore with maple mouldings. The wheel-tires and axles are of steel and the bodies of the wheels are made up of teak. The axle-boxes are fitted with brass bearings and with oil-boxes. All the carriages are fitted with the Westinghouse continuous automatic brake, and with the apparatus for being lighted by Pintsch compressed oil-gas system.

The carriage-shop has accommodation at one time for ninety carriages under construction and repair. The working stock of the coaching department comprises two hundred and twenty-eight first-class carriages; eight hundred and twenty second- and third-class carriages; two hundred and sixty-nine composite carriage and saloons; three post-office vans; one hundred and sixteen horse-boxes; forty-one carriage trucks; ninety-one fish and milk trucks; three store vans; one hundred and eighty-six luggage vans; and one prison van; making a total of one thousand seven hundred and fifty-eight.

The wagon-shop accommodates four hundred and twenty wagons under construction and repair. The timber used is generally oak and pitch pine, with the angles and edges strengthened and protected by wrought-iron straps and bars; the wheel-tires and axles are of steel and the axle-boxes of cast-iron. The wagons are generally fitted with wrought-iron couplings, spring draw-bars and spring buffers, so as to withstand the rough usage they undergo. Many of the wagons are also fitted with the Westinghouse brake.

The working stock of the merchandise and mineral departments of the Caledonian Railway Company include 10,414 goods wagons, 1,315 covered goods wagons, 875 cattle and sheep trucks, 431 brake vans, 1,053 swivel-wagons, 38,044 mineral wagons, five gun-powder vans, four tank wagons, nine crane wagons, 254 ballast wagons; making a total of 52,404 vehicles.

The Saw-mill and Joiners' Shop, Figs. 3, are placed to the north of the carriage-shop. The building is 332 feet long by 72 feet wide, with a basement floor covering the same area, and an annex, 52 feet by 40 feet, with a basement used as a boiler-house. The construction above floor-level is the same as in the wagon-shop. There are four windows in each of the nine gables to the north, one 13 feet 6 inches by 7 feet, with smaller windows, 10 feet 6 inches by 5 feet, on each side, and a circular one, 7 feet diameter, in the upper part of the wall. The floor is 3 inches thick, resting on 12 inches by 3 inches joists, set at 18 inches centre. The columns are spaced about 10 feet 4 inches apart, and are arranged longitudinally in three rows, one under the middle of the saw-mill, and one under the middle of each bay. The columns stand on stone, brick, and concrete foundations. The floor of the annex to the saw-mill is 5 feet higher than the floors of the shops, to give plenty of head room to the large steam-boilers placed there in the basement. Here the cast-iron columns are 13 feet 3 inches long, but the other details are the same as those already described. The basement is lighted by windows, 7 feet by 3 feet 6 inches, facing an area 10 feet wide and 10 feet deep, along the north side of the saw-mill. The retaining-wall is built of red brickwork 3 feet thick at the top, with scarcements of 2½ inches every 2 feet 6 inches of depth at the back, and a batter of 1 in 8 at the front. The wall stands on a concrete foundation, and on the top of wall there is a dressed sandstone coping 2 feet by 9 inches. The saw-mill and joiners' shop contain wood-working machines of many kinds—circular, vertical-frame and endless-band saws, turning-lathes, mortising-, tenoning-, moulding-, boring- and planing-machines. The machines receive their motion from shafting placed along the north gables, and also, in order not to hinder the manipulation of the timber and not to obstruct the entrance of light from the roofs, the shafting pulleys and belting for machines not at the wall are fixed in the basement. The engine-house, 67 feet by 10 feet, is built in the area. The large steam-boilers are in the basement, west of the saw-mill, and are conveniently placed near to a railway siding, from which the coals required are discharged from wagons into the area.

The General Offices for the locomotive department are placed at the entrance to the workshops on Springburn Road, close to St. Rollox railway station. The building is 135 feet long by 36 feet wide, and two storeys in height. On the ground floor are situated a general clerks' office, 62 feet long by 32 feet wide; a works-managers' room, 19 feet by 13 feet; a telephone and telegraph room, 13 feet by 8 feet; a small apartment in the hall for the office attendant; a lavatory, 18 feet 6 inches by 11 feet; a pay-office, 15 feet 6 inches by 10 feet; and a weigh-office, 15 feet 6 inches by 10 feet. The safes are contained in a fire-proof room built under the stairs and opening off the head clerk's room. On the upper floor are the locomotive superintendent's room, 32 feet by 25 feet, with lavatory 13 feet by 6 feet; private clerk's room, 17 feet 9 inches by 13 feet; waiting-room, 17 feet 9 inches by 13 feet; lavatory, 13 feet by 9 feet; assistant locomotive superintendent's room, 13 feet 3 inches by 13 feet; and drawing-office, 62 feet by 32 feet. In the attics are the photographic and book rooms. Dining-rooms are provided in a building opposite to the forge.

The Timber Drying Store, Figs. 5, 397 feet long by 62 feet wide and 22 feet 6 inches high, is a short distance to the north-east of the main building of the workshops, and is so placed that one of the spans may be easily extended if required. The back wall of brick bounds the south side of the road leading to the loading banks; the timber roof, in two spans, is supported on the back wall and by two lines of girders on cast-iron columns. In front the shed is open, and railway sidings are laid alongside so that timber can be unloaded directly into the store. The materials used, with the exception of the bricks, were some of those removed from the old workshop buildings. In the panels of the walls there are a number of perforations in order to promote a free circulation of air. The cast-iron columns, set 18 feet apart for supporting the roofs, are 22 feet long, 9 inches to 7 inches in diameter and of $\frac{3}{4}$-inch metal. They are also used as rain-water conductors, and are bolted to stones 3 feet square by 1 foot 3 inches deep, which rest on concrete foundations 4 feet square and 2 feet deep. The roofs, with overhanging eaves, are constructed of timber. The roof principals, 12 feet apart, are supported on girders made up of two 12-inch by 5-inch timber beams with a $\frac{3}{4}$-inch wrought-iron plate between them, and all bolted together and resting on the cast-iron columns. The doors in the gables are 10 feet 6 inches high, 11 feet wide, in two leaves, and with louvre boarding filling the semicircular space above. Each door has a small wicket (6 feet by 2 feet) for the convenience of the men passing in and out. The malleable-iron hinges are fixed by a $1\frac{1}{4}$-inch diameter wrought-iron pin to the cast-iron hinge blocks built into the walls. These blocks are 2 feet long by $11\frac{1}{2}$ inches high, $14\frac{1}{4}$ inches wide, and the metal is $\frac{3}{4}$ inch thick. The blocks are the same as in the other buildings, but not so wide, so as to fit the walls in this structure. The timber-yard is covered with engine ashes, and there is a crane which travels overhead and under which wagons may pass freely. The crane works on a fixed timber staging and is useful for transporting the timber to the saw-mill to be cut up. In the store the timber is symmetrically stacked and protected from the sun and in a free circulation of air till it is properly seasoned and required for use.

The Paint Shop, on the south side of the Old Garnkirk Railway, is 507 feet long, 116 feet broad, and 18 feet 4 inches high to the tie-beam. It is situated near Charles Street, a few hundred yards from the main buildings of the workshops, and so is quite free from the effects of smoke and dust. The outside walls are built of red bricks relieved with white bricks in the same style as the other erections. The pilasters are built at 18 feet centres, and in the panel between them there is a window. The timber roofs, in three spans, are some of those which were removed from the old buildings. The cast-iron columns for supporting the roofs are spaced at 36 feet apart, and the lattice girders are the same style as those in the wagon-shop. At the west end of the paint shop there is a paint-grinding shop, 40 feet by 52 feet, an upholsterer's shop, 74 feet by 52 feet, a hair-teasing room, 35 feet by 23 feet, and an engine-room, 23 feet by 16 feet. An Otto gas-engine of 4 HP. gives motion to the machinery for grinding the paint and teasing the hair, which it does satisfactorily both as regards economy and convenience. There is accommodation for twenty locomotives and tenders and sixty carriages. The floor is paved with granolithic, and the shop is heated from a boiler in the engine-room by warm water circulating in cast-iron pipes laid in the middle of each track of railway. The furnace of the boiler is below the level of the floor, and coal is supplied to it through a shoot from the outside. There is a good supply of water from hydrants for cleansing purposes and for use in case of fire both inside and outside the building.

The Stores Buildings in Charles Street were erected for the General Stores Department to supply the place of those formerly standing at Springburn Road. They are constructed on the site of the permanent-way workshops, which were removed to Motherwell. The roof-work is of the usual style of timber construction. There are three separate erections. The first range consists of a two-storey building, 178 feet long by 46 feet wide; on the ground floor are the stationary-store, an oil-, paint- and varnish-store, a pay-office, a weigh-office. On the upper floor, with an entrance by a staircase from Charles Street, is the public office, a clothing- and cap-store, a sample room, 48 feet by 43 feet, and a chemical laboratory. This building is heated by hot water and open fire-places. In the laboratory the Company's chemist tests, analyzes and reports on the various kinds of materials required in the railway service. The brickwork in this building is of the same kind as in the locomotive workshops. The second range of stores buildings is separated from the first by the entrance to the yard. It is one storey in height (15 feet from the floor to the tie-beam) and 562 feet long by 46 feet 3 inches wide. It consists of a boiler-house 21 feet by 13 feet used for supplying the warm water for heating the two ranges of buildings; and a store for various kinds of materials. For security against fire these departments are divided by 14-inch brick gables carried above the roofs. Along the whole length and 30 feet in front of this range of stores building there is a railway siding constructed at a level 3 feet 8 inches below the surrounding ground. The 30-foot wide road is covered with concrete and granolithic paving. The platform walls at the siding were composed of posts placed 6 feet apart with sleepers in a vertical position between them, and a 12-inch by 6-inch timber coping, and bottom runner of the same size fixed together by iron tie-rods every 6 feet.

Wagon-Cover Shop.—The third range, about 20 yards east of the grease factory, on the building line of Charles Street, is the shop for making and repairing covers, or sheets for railway wagons. It is 242 feet long by 52 feet wide, with a boiler-house 27 feet by 16 feet, and is divided by brick walls into five compartments for safety in case of fire.

The stores-yard is easily accessible for carts and other vehicles from Charles Street, and the railway wagons and vans can be loaded, unloaded, and marshalled without impeding the traffic on the main lines. In the yard there is a timber-shed in which to store the oak keys used to hold the steel rails tightly in the cast-iron chairs. There are also several jib-cranes for manipulating the various materials.

Sleeper fencing.—The fencing around the yards consists of old sleepers, with a larch rail 3 inches by $1\frac{1}{4}$ inch spiked to them 1 foot from the top. The lower ends of the sleepers are sunk 3 feet into the ground. The upper ends are square and bevelled. There are three sleepers to the lineal yard of fencing.

Roads.—The roads, where not paved, were bottomed with a layer of slag or hard stones 9 inches deep, and covered with a 6-inch layer of whinstone, broken to pass through a 2-inch ring, and all properly blinded with a thick layer of clean ashes, well watered and rolled.

Concrete and Mortar.—The concrete used for the foundations of the buildings was composed of four parts of broken bricks, one part of sand, and two parts of Arden lime. It was laid in layers of 6 inches, and well pounded. The granolithic paving was laid on the top of 6 inches of concrete, made up of six parts of slag, three of sand, and two of Arden lime. The granolithic—2 inches thick—was laid in two coats; the under one of one part by volume of Portland cement to three parts of crushed granite, and the upper coat of one part of Portland cement to one part of very fine crushed granite.

The mortar used on the works consisted of the best ground Arden lime mixed with two parts, by measure, of clean sharp sand perfectly free from soil of any kind.

Arden lime is a natural slow-setting hydraulic cement found in the carboniferous limestone formation near Glasgow. Its tensile strength varies between 80 lbs. per square inch at 7 days, after being made and 350 lbs. at 6 months, and thereafter it still continues slowly to increase in strength for 2 or 3 years. In the Author's opinion it is equal in efficiency to Portland cement for the class of work in which it was employed in the buildings now being described. The cost of Arden lime, mortar and concrete was much less than Portland cement, mortar and concrete would have been. After the buildings were erected some holes required to be made for pipes, and it was then found that the mortar was as hard to cut through as the bricks; and, although some of the walls were founded on recently-made ground, not a crack has occurred from subsidence in any part of the workshops.

The Portland cement was required to weigh not less than 112 lbs. per striked bushel, which contains 1·28 cubic foot, levelled at the top with a straight edge. The cement was ground sufficiently fine to pass through a sieve of 2,500 meshes per square inch, leaving a residue not exceeding 20 per cent. When mixed with a proper amount of water in a brass mound, the cement, after being immersed 7 days in water, was capable of resisting without breaking a tensile strain of 350 lbs. per square inch. All cement was kept under cover till it was required for use.

Bricks.—All the bricks were machine made of the best quality of composition bricks, with a close texture, clean skin and uniform in size and colour. The white bricks were made of the best fire-clay and of various kinds of shapes to suit the work required. The arch bricks over the doors and windows were radiated to the proper centres. Round-ended bricks were placed at all corners where sharp edges would be liable to damage. The fire-grates were built in with fire-bricks with fire-clay joints. A very large quantity of red bricks taken from the old buildings were made use of in erecting the new works. The perfect bricks were cleaned and built into the walls, and the damaged bricks were broken up for use in making the concrete.

Stone.—The stones on which the cast-iron columns stand are ashlar blocks of special hard sandstone from Hermand quarries, and they have holes cut through the centres of such of them as were required to admit the pipes leading to the drains. The coping of the walls is composed of dressed ashlar blocks and which projects 1½ inch from the face of the walls. The window-sills are also of ashlar sloped on the top to run off the water. The masonry of the retaining walls consisted of large square, jointed, well-bonded, and flat-bedded stones, laid on their natural beds and well built with mortar. All stones were of hard durable quality, and not one of them greater in height than two-thirds of its breadth. The masonry retaining walls were built with a batter on the face of 1 in 12.

Iron Work.—All the cast-iron work was made of the best mixture of Scotch grey iron to ensure strength; and the castings are sound and clean, with a fine skin, and free from flaws and blemishes. The patterns were examined by the assistant-engineer before the castings were made; and the castings were not painted till they were inspected, after which they were thoroughly cleaned, scraped and painted.

The lattice girders, roof-trusses, and other wrought-iron work were made of the best quality of Glasgow plates, angle- and

T-bars. Each plate or bar should withstand a tensile stress of 22 tons to the square inch of original section, or an extension less than 7 per cent. of its length. The iron was tested at the contractor's expense before leaving the manufacturer's works, and before the girders and roof trusses left the contractor's workshops they were inspected by the assistant-engineer. An inspector in the Company's service devoted all his time overlooking the iron work being done in the contractor's shops. The angle-bar purlins, in long lengths, were joined only where resting on a rafter, and the joints are fished with plates 16 inches long of the full depth of the angle-bars and ½ inch thick. The rivets are of the best quality of rivet iron, not to break with a less tensile strain than 24 tons to the square inch of original section. The rivet-holes were drilled except where punching was allowed by special permission of the engineer. Before being exposed to the weather all iron-work received one coat of anti-corrosive oil paint, and after erection three coats of silicate paint.

The principals were designed and made with a greater pitch than is usual for iron roofs. This was done so that when snow fell it would easily slide into the gutters, and thus not obscure the light entering through the sky windows. Simplicity and economy were aimed at by using angle- and T-bars of an easily obtained section, and by not having a needless variety of sizes. The style of roof-truss adopted in the foundries, boiler-shop and smiths'-shop is different from that in the erecting-, carriage- and wagon-shops. The former is more convenient for making hip connections, and also, perhaps, for the joining of the horizontal ties when in two portions; but in the small spans in some of these shops there was no economical reason why either of the styles should not alone have been used. Lattice girders were chosen for supporting the roofs, because their appearance is better and they do not obstruct so much light as web-plate girders. The exact angles of the lattice-bars were determined by the positions on the girders of the roof-trusses.

The roof-trusses, girders and columns were hoisted into position, some of them by means of jib-cranes mounted on railway trucks suited to the standard gauge of the line, and the remainder of them were lifted by tackle fixed on long single derrick poles stayed with guy ropes. The roof-trusses were temporarily braced with light timber lashed to the iron-work to resist the irregular strains they had to bear while being hoisted into their places. The chain-sling was attached at one point on each rafter, and the truss was easily raised, by means of the winch, to the top of the girders. The men kept them steady and guided them into their positions by ropes suspended from both ends of each truss. The temporary timber bracing was also useful for supporting scaffold-planks until after the angle-bar purlins were lifted by tackle attached to the principal and fixed permanently to the roof-rafters.

The cast-iron columns were adjusted by the aid of a plumb-line and small wedges placed between the sole of the column and the stone foundation. After exact adjustment the space between the sole-plate and the stone was filled with liquid Portland cement, which quickly set and became as hard as the stone, and thus made a perfect seat for the column. The sole-plate was also attached to the foundation by four Lewis-bolts fixed by lead poured and caulked into the dove-tail shaped holes in the stone.

Carpenter and Joiner work.—The timber used in the construction of the workshops was all of the best quality, thoroughly seasoned, free from sapwood, large or loose knots, or other imperfections, and dressed with the plane where exposed. The wood purlins bolted to the angle-bars are in long lengths, and the joinings are placed over the T-bar rafters. Snow-boards, which also act as foot-boards are laid over all the valley-gutters on the roofs. They are composed of $1\frac{3}{8}$-inch red pine spars, 3 inches broad and $\frac{1}{2}$ inch space between them, with bearers at 24-inch centres.

Slates.—The roofs are covered with 20-inch by 10-inch Welsh slates and Scotch Highland slates. They were machine-bored $1\frac{1}{2}$ inch from the top of the slates. They were laid with 3 inches of cover at the eaves, gradually diminished to 2 inches at the ridge, and were fixed with galvanized-iron nails, weighing 12 lbs. per thousand. The Welsh slates are double nailed every course, the Highland slates every third course, and all were properly bonded. The Welsh slates are of uniform thickness and have smooth surfaces, and, perhaps, make a better appearance on the roof. The Highland slates are stronger than the Welsh, and are usually thicker in the middle than at the edges. The Highland slates taken off the old buildings, although containing a large quantity of iron pyrites crystals, showed no signs of deterioration after many years of exposure to a smoky atmosphere.

The Paper is accompanied by eleven photographs, and eleven tracings, from which Plate 7 has been prepared.

[APPENDIX.

APPENDIX.

Stationary Engines in Workshops.

Foundry cupola blowing-engine, 10-inch cylinder by 24-inch stroke; speed, 60 revolutions per minute.

Foundry crane-engine, 6-inch cylinder by 8-inch stroke; speed, 160 revolutions per minute.

Boiler-shop wall-engine, 16-inch cylinder by 20-inch stroke; speed, 100 revolutions per minute.

Grinding-shop horizontal engine, 14-inch cylinder by 20-inch stroke; speed, 100 revolutions per minute.

Forge horizontal engine, 10-inch cylinder by 18-inch stroke; speed, 80 revolutions per minute.

Erecting-shop wall-engine (coupled) for travelling-cranes, 12½-inch cylinder by 22-inch stroke; speed, 100 revolutions per minute.

Machine-shop wall-engine (coupled), 17-inch cylinder by 24-inch stroke; speed, 100 revolutions per minute.

Saw-mill horizontal engine, 20-inch cylinder by 36-inch stroke; speed, 100 revolutions per minute.

Saw-mill horizontal engine, 18-inch cylinder by 22-inch stroke; speed, 100 revolutions per minute.

Paint-shop, Otto gas-engine, 4 HP.

(*Paper No. 3009.*)

"The Horwich Locomotive Works of the Lancashire and Yorkshire Railway."

By John Audley Frederick Aspinall, M. Inst. C.E.

The Lancashire and Yorkshire Railway Company had for many years locomotive works at both Miles Platting and Bury, but they became inadequate for dealing with the repairs of the locomotives and for building such additional engines as were required, and it was determined to build new works at Horwich. The site was selected upon the advice of Mr. John Ramsbottom, a Director of the Company, who advised that the works should be built on the broad lines which have been since observed. It became the duty of the Author to superintend the erection of the works and the arrangement of the machinery, and to start them as a working establishment.

There are three entrances to the works, the "main entrance" leading to the offices and workshops generally; the "central entrance," in close proximity to the men's dining-room and cottage hospital; and the "foundry entrance," which is conveniently situated for access to the property built at that end of the works. The works were commenced in 1886, some of the shops were ready and brought into use in 1887, and by the year 1892 they were practically completed. The lighting and ventilation have been carefully studied; the buildings generally are lofty, and operations are exclusively conducted on the ground floor. Gas made at the gas-works is now in use to a great extent both for lighting and manufacturing purposes, but electric light is used in all the large shops where it is more advantageous. A complete telephonic system connects the offices and shops throughout the works. Besides the ordinary 4-foot 8½-inch gauge railway connecting the various parts of the works, there is a narrow-gauge railway (18 inches) traversing every part of the works, its total length being about 6½ miles. It is worked by small locomotives, which draw trains of strong trollies conveying materials and finished work between the several parts of the establishment.

On the left of the plan, Fig. 1, Plate 8, are shown the chief mechanical engineer's offices, which cover an area 323 feet long by 58 feet wide. The offices for assistants, the drawing office, and the office for accounts, etc., are placed at each side of a wide and well-lighted corridor running the whole length and terminating at the gallery of the stores. On the ground floor is a well-equipped physical laboratory, and on the top floor, immediately under the water-tank which commands the whole works, is a chemical laboratory. One portion of the ground floor is used for a test-room, containing a 100-ton testing-machine, spring-testing machine, etc., the other portion being used for the works manager's and clerks' and timekeeper's offices. The rail-level at the stores is the common rail-level throughout the works, being 395 feet above Ordnance datum.

The General Stores consist of a two-storey building, 198 feet long by 111 feet wide, formed in four bays, a gallery being built round the four sides, leaving a well for light and air in the centre. The heavy goods are stored on the ground floor, and the light goods on the gallery; access to which for tramway trucks, etc., is afforded by means of a small hydraulic lift, other large stores being hauled up by a hydraulic crane direct from the wagons as they arrive. A small space is set apart for the workmen who require any article from the stores, where they present their respective foreman's ticket.

The Boiler Shop, Fig. 2, is 439 feet long by 111 feet wide, formed in three bays, the first being used for building and repairing boilers, the middle bay being used for miscellaneous work including tenders and tanks, whilst the third bay is used exclusively for tools, such as drilling-, punching-, shearing-machines. Over each bay, and running the whole length of the shop, is an overhead travelling crane with a longitudinal traverse of 150 feet per minute, driven by a rope. The small rivet-furnaces in this shop are fired by liquid fuel injected by compressed air. At the end of the shop the roof is carried some 16 feet higher for two spans and the full width of the shop, to form a riveting-tower. In this space is provided a pair of hydraulic pumps and accumulator, and two fixed hydraulic riveters for boiler work, each having a hydraulic crane for lifting the boilers when riveting. The longest boiler can be riveted in a vertical position. Liquid-fuel furnaces are fixed in close proximity to the cranes and riveting machines. Portable hydraulic riveting-machines are used in every case where it is possible.

The Boiler-Shop Smithy, which is an adjunct to the boiler shop, measuring 120 feet long by 111 feet wide, formed in two bays, is fitted with several smiths' hearths, dome fire, etc. The hydraulic flanging presses are also fixed in this shop for flanging fire-box backs, tube-plates, etc., gas furnaces being built near them for reheating the plates.

The Forge, Fig. 3, 452 feet long by 111 feet wide, formed in two bays, contains the necessary heavy tools for the work required on the railway, the forgings being heated in the gas-furnaces. At the back of the forge are the gas-producers, and, the natural formation of the ground at this point being 14 feet higher, the producers are charged direct from the top, whilst the ashes are drawn out at the bottom through a water-seal into tram-wagons on the lower level, no hoisting being required. The scrap is cut up on the high level, and is conveyed through a conveyor into the forge, where it is made up in piles for the furnaces.

The Steel Foundry, Fig. 4, measuring 150 feet long by 135 feet wide, formed in four bays, contains one 20-ton and two 10-ton Siemens-Martin regenerative melting furnaces, heated by gas from their own series of gas-producers. The advantage of the higher ground at the back also proves most economical, as the metal can be run directly into the charge-holes without crane-power. A high-level tramway has been fixed to carry the steel-ladle on small cast-iron columns and also one at right-angles to it. The middle bay is provided with an overhead rope-driven travelling crane, which travels also the full length of the iron foundry. The core-stoves are fixed in the bay nearest to the high level. In the bay where the moulding is performed small hydraulic cranes have been fixed against the columns to deal with the moulding-boxes.

The Iron Foundry, Fig. 5, 212 feet long by 111 feet wide, is also formed in three bays. This shop is used for general castings, not only for locomotive work but for those used in connection with the permanent way, the signalling, and the carriage and wagon departments. There are two cupolas at the back of the foundry, the natural formation of the ground at the back proving most advantageous, as it permits the coke and iron to be unloaded and wheeled direct to the charge-holes of the cupolas.

The Chair Foundry, Fig. 6, which is an adjunct to the iron foundry, is 62 feet long by 111 feet wide, in three bays. It is exclusively used for the manufacture of chairs for the permanent-way department, and has two cupolas fixed at the back similar to those of the iron foundry. A feature of this shop is the fettling-bench available for working at each side. After the chairs are cleaned, they are placed on the endless chain running in the centre of the bench, and are conveyed direct to the wagons, which are on a lower level than the common rail-level of the works.

The Fettling-Shop, Fig. 7, 90 feet long by 47 feet wide, in one bay, is used for cleaning castings after leaving the foundries, and is also provided with two double annealing-furnaces heated by gas.

The Wheel Shop, 165 feet long by 47 feet wide, in one bay, is next to the fettling-shop, being separated from it by a partition wall. After the wheels have been fettled, they are taken to the lathes to be bored and turned, and are then loaded direct into the wagons which are run into the shop; the hauling being performed by an overhead rope-driven travelling crane running the whole length of the wheel shop, smaller swing-cranes being used for the different lathes fixed to the walls. The carriage wheels are also put together in this shop, and a special hydraulic press is provided for forcing the wood blocks between the wheel centre and the tyre, as well as another press for forcing the wheels on the axles. Close to the foundry, connected by the 18-inch tramway, a space is allotted, fenced in with wrought-iron fencing, for the storage of spare and stock castings.

The Bolt Shop, 60 feet long by 111 feet wide, formed in two bays, contains modern bolt-and-nut-making machines, rivet- and nail-making machines, and drop stamps for light smithy work.

The Smithy, Fig. 8, is a continuation of the bolt shop, measures 212 feet long by 111 feet wide, and is likewise in two bays. It is a spacious and well-lighted building, containing thirty-three single hearths along the outside walls and eleven double hearths along the middle. Between the hearths are placed at intervals small steam-hammers. The blast for the fires is produced by a Root blower, fixed at one corner of the shop.

The Spring Smithy, Fig. 9, 153 feet long by 47 feet wide, in one bay, is fitted with two gas-heated spring furnaces, hydraulic press, buckle stripping-machine, small steam-hammer, etc. Single smiths' hearths are fixed along each side of the walls.

The Signal Shop is 128 feet long by 111 feet wide, and is formed in three bays. One bay is used exclusively for the construction of signal cabins and posts, a rack saw being provided. The signal cabins are so made and marked that they can be taken to their destinations in pieces and easily erected. The other two bays are occupied for fitting up locking-frames and for general signal work. Outside the signal shop are stored the various small castings, etc., appertaining to the signalling apparatus, and beyond this a long timber steam gantry has been erected, under which the wagons can be run and the long timber-logs unloaded for signal posts, etc.

The Points-and-Crossings Shop, an adjunct to the signal shop, measures 72 feet long by 111 feet wide. It is in three bays, and is provided with special machinery for the manufacture of points and crossings, including an angular planing-machine, a duplex slotting-machine, and a special machine for milling and drilling locking-frame standards at one setting. A walking crane, driven by a rope, is provided in the outer bay.

The Fitting-Shop, Fig. 10, 508 feet long by 111 feet wide, is formed in three bays. Along each, traversing the full length of the shop, is a walking crane driven by a rope for the haulage of heavy materials from one machine to another. There are four lines of shafting running down the shop, driven by two large wall-engines at one end. A space is allotted to the cylinders which are brought from the foundry to be bored, drilled, studded, and finished before being sent on to the erecting-shops. A number of milling-tools, both horizontal and vertical, are provided, almost all the engine motions being completed by this class of machine; while the usual machine tools, such as drilling- and slotting-machines and various kinds of lathes, are arranged in their different classes. One portion of the fitting-shop is allotted to the brass-finishers, and close to the brass-finishers' side is the tool-room which supplies and repairs all the milling cutters, twist drills, taps, and other tools required for the various machines in the fitting-shop. At the lower end the setting-out benches are fixed and all the fitters' benches where the small amount of necessary hand-work is done. The shop is heated in winter by pipes carried in trenches along the middle of each bay, covered with chequered grating which serves also for tram-lines, grooves being cast in it for this purpose. The shop is lofty and well lighted. The artificial light is afforded by inverted arc-lamps of 50 candle-power fixed under large white painted wood disks suspended from the principals, which help to throw the light upon the machines without sensible shadow.

The Boiler-Houses, in two nests of five boilers each, are on each side of the large chimney, the space below being occupied by two sets of Green economizers, the whole covering an area 156 feet long by 47 feet wide, in one bay.

The Brass Foundry, Fig. 11, 105 feet long by 47 feet wide in one span, is provided with a gas furnace for heavy work, and a gas crucible-furnace for the lighter work, the moulding of the lighter articles being carried out on a bench at one side of the shop.

The Tinsmiths' Shop, 150 feet long by 47 feet wide in one span, is provided with all the newest tools for tin-plate working. All the tin-ware required for the railway is made here, and all repairs and renewals of lamps, etc., are also carried out.

The Coppersmiths' Shop, 90 feet long by 47 feet wide in one span, is fitted with the necessary coppersmiths' hearths and furnaces for brazing tube-ends, etc.

The Tube-Cleaning and Case-Hardening Shops, are combined, measuring 75 feet long by 47 feet wide in one span, and contain a case-hardening gas furnace, two tube-cleaning machines, two annealing gas furnaces for small articles, and a special furnace for taking the tyres off old wheels.

The Telegraph Shop, Fig. 12, 153 feet long by 47 feet wide in one span, is provided with special tools, lathes, etc., for making and repairing telegraph and block instruments, and other electrical work. A small room is set apart for experimental work and for testing instruments.

The Electric-Power House contains an engine and dynamos for the supply of light to the north-west end of the works, and also to all the offices.

The Erecting Shops, Fig. 13, 1,520 feet long by 118 feet wide, is divided into two large bays and one smaller bay in the middle of the shop. The outside bays are used for the repairs and renewals of locomotives, the small middle bay being used for the fitters' benches and for small tools such as drills, placed in suitable positions along the shops, and for the storage of materials. The erecting shops are divided into Nos. 1, 2, 3, 4 and 5 respectively. No. 1 shop is used for the erecting of new tenders and repairing of existing stock. Of No. 2 shop about one quarter is taken up for boiler mounting, the boilers being received from the boiler shop are here fitted with tubes and the brass mountings; they are also tested both with water and steam before being sent to the erectors; the other three-fourths of the shop are taken up with general locomotive repairs. Nos. 3 and 4 shops are exclusively used for locomotive repairs. No. 5 shop is mainly used for locomotive repairs, but a small portion is set apart for new work. Each outside bay of each erecting shop is provided with two 30-ton overhead travelling cranes, making twenty in all. Wheel-lathes are provided at various parts of the erecting shops for dealing with the wheels taken from locomotives under repair. A number of portable hydraulic riveters is also provided. Access for locomotives to the centre portion of the shops is provided by two traversers.

The Pattern-Makers' and Joiners' Shop, Fig. 14, 164 feet long by 111 feet wide, is divided into three bays, one being exclusively used by the pattern-makers with the drawing stores at one end. The middle bay is fitted with the most modern wood-working machinery, such as circular saws, general-joiner, planing- and moulding-machines, etc., and the third bay is divided into two portions, one half being used by the joiners, and the other half by the saddlers for repairing and renewing the belting etc. of both the in-door and out-door departments. Along each side bay and across the ends a gallery has been formed for the storage of patterns and other work. A sprinkler arrangement has been fixed in this shop, both on the ground and gallery floors, as a precaution against fire.

The Millwrights' Shop, Fig. 15, 146 feet long by 111 feet wide, is also divided into three bays, each bay having an overhead rope-driven crane travelling the full length of the shop. All general and hydraulic and engineering work for out-stations is carried out in this shop, in regard to the repair and maintenance of cranes, turntables, water-columns, etc. The shop is fitted with the usual mechanics' tools.

The Paint Shop, Figs. 16, measuring 234 feet long by 111 feet wide, differs from all the other shops in construction by having a weaving-shed type of roof which has been found most suitable for its purpose. The same principle is adopted for the Company's engine-sheds. It is a well lighted and ventilated shop, and a heating arrangement has been provided in order to dry the paint quickly. The necessary grinding- and mixing-machines are also provided.

The Chain-Testing Shop, Fig. 17, 111 feet long by 28 feet wide, is an adjunct to the chain-smithy, and each chain when completed is brought here to be tested by the hydraulic chain-testing machine capable of testing up to 100 tons. Each chain, after being tested, is stamped, and all particulars are entered in a book before the chain is sent out.

The Engine-Shed is provided for stabling the locomotives used about the works.

The land adjoining the works, but on the opposite side of the Chorley Road, has been laid out for building purposes, and has been disposed of from time to time to builders of workmen's cottages, the Company still reserving some plots. One of these reserved plots, containing about 11 acres, situated in front of the main entrance, has been laid out as recreation grounds, comprising a cricket ground, football ground, two full-sized bowling greens, and boys' and girls' playgrounds. Pavilions have been built both for the cricket and bowling greens. A large dining-room, previously referred to, has been provided in very close proximity to the middle entrance of the works, and is well patronized by the workpeople, an average of one thousand men using it daily.

A system of evening classes has been instituted, and a fine pile of buildings for this use has been erected on Chorley New Road by the generosity of the Directors and of Mrs. Fielden, the widow of a former Director. The classes, which are numerous and embrace many subjects, are conducted by experienced and efficient tutors. It is called the Horwich Mechanics' Institute, and is governed by a committee of officials of the Company and an equal number of the workpeople's representatives, the latter being elected by ballot each year. The buildings comprise class rooms, art room, library, reading-room, smoke-room, magazine-room, etc., the basement being used for the metallurgical classes, and also for the electric-lighting plant for the building, which is driven by a gas-engine. Above the reading-rooms is a large hall used for public meetings and other purposes. It is fitted with dressing-rooms and complete stage appurtenances. This hall is capable of accommodating 1,000 persons. In connection with the Institute there is also a laboratory, directed by a qualified analytical chemist, and in addition, accommodation for the photographic society.

The physical development of the youths employed in the works and the members of the Institute has not been neglected, as, by the further generosity of Mrs. Fielden a splendid gymnasium has been erected, and was opened in 1895. It is situated at the rear of the Institute, and has direct access from it. It is fitted with the best appliances of a modern gymnasium, and is well patronized every evening during the week. It is under the control of an efficient instructor, and is governed by the Institute Committee.

Mr. Henry Yates Thompson, a Director of the Company, has generously given a cottage hospital for the treatment of accidents that may happen in the works. It is built in close proximity to the middle entrance, and is under the supervision of the Company's surgeon and of a qualified nurse.

The communication is accompanied by three sheets of drawings from which Plate 8 has been prepared.

(*Paper No. 3031.*)

"Junee Water-Supply Works, N.S.W."

By Harold Arthur Blomfield, M. Inst. C.E.

The town of Junee, N.S.W., is situated at the junction of the Great Southern and South Western Railways, and is 287 miles distant from Sydney. It is the centre of a large pastoral and agricultural district, and contains a population of about 2,000 inhabitants, who for the most part are employed upon the railway, or in the cleaning and repairing shops. The matter of water-supply, both for the townspeople and also that necessary for the railway, has long occupied the attention of the municipal authorities, and various pumping schemes have been considered. In 1892 Mr. E. B. Price, M. Inst. C.E., was entrusted with the work of examining the country, and he discovered a natural basin in the Bethungra Range, 20 miles from Junee, where a concrete dam could be built across a valley to form a reservoir capable of impounding 140 million gallons of water, with its top water-level 470 feet above Junee, and having a catchment-area of 5½ square miles. After exhaustive surveys, his scheme was found to be in every way suited for supplying the town with what might be regarded as a never-failing supply. It involved the building of a concrete weir across the Ulandrie Creek, 528 feet long and 40 feet high at the deepest part; an 8-inch wrought-iron pipe, about 18 miles long, to the service reservoir, which was designed to hold 400,000 gallons; 2½ miles of wrought-iron pipe to the town; and about 6 miles of 6-inch, 4-inch, and 3-inch distribution pipes. The cost of the scheme was estimated at £45,000.

The Engineer-in-Chief for harbours and rivers, Mr. C. W. Darley, M. Inst. C.E., in whose department the scheme was originated, approved of the works, and when the necessary bond from the Borough Council of Junee, agreeing to the work being executed, was signed and the requisite bills passed by Parliament, the contract plans were prepared, and tenders were invited for the work in the following sections:—Dam for the storage-reservoir, main wrought-iron pipes and pipe-laying, service-reservoir, cast-iron pipes and pipe-laying for distribution.

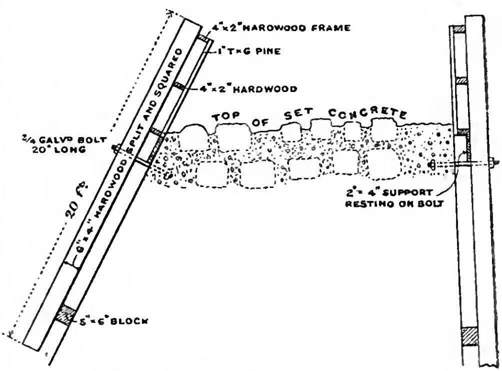
Dam for the Storage-Reservoir.—The dam is straight in plan, and measures 528 feet from end to end. Its greatest depth from the overflow is 40 feet 9 inches. It is only 3 feet 6 inches wide at the overflow, and 11 feet wide 17 feet lower. From this point to its base it has a batter of 1 in 20 on the up-stream side, and on the down-stream side 1 in 1½. The overflow is 300 feet long; the remaining 228 feet being carried up vertically on both sides 2 feet 6 inches higher, to act as a parapet on which the caretaker can walk to reach the winch, which is placed over the supply-pipe. The foundation of the dam is on granite rock, which was found not far from the surface; the outcrop of the bar of granite in the bed of the creek having led to the selection of the site. The outlet works, through the wall, consist of a scour pipe 24 inches in diameter, 1¼ inch thick, made of cast iron, with flange-joints, and having a 24-inch stop-valve; and of a supply-pipe 15 inches in diameter, 1¼ inch thick, with a 15-inch stop-valve. A pipe having two 8-inch branches was next bolted on to the 15-inch valve; as only one is at present required, the other is provided for future extensions. A concrete gangway gives access to the valves. Two right-angled bends are bolted to the supply-pipe at the inner side of the dam, one end being fitted with a knuckle joint-machined and bushed with gun-metal to allow the pipe to be raised to any position in the water or out of it, in order to clean the screen. The swinging-pipe, 15 inches in diameter, is of galvanized wrought-iron plate ¼ inch thick, with butt-riveted joints, in four sections, connected by flange joints, and fixed to the knuckle-joint by a cast-iron pipe ¾ inch thick. A screen of galvanized woven wire, of ⅛ inch mesh, was wound round a circular cage at the top of the pipe, made of wrought-iron bars, with the screen tied on with galvanized wire so as to be easily removed for cleaning. The swinging-pipe is supported by two floats, the larger one submerged and bolted to the pipe, and the smaller attached to the pipe by a short chain, and so designed that only 3 inches of its height appears above the top of the water. For the purpose of drawing the pipe from its floating position in the water up to the wall, so that the screen may be periodically cleaned, a winch was securely bolted on two wrought-iron plates on to the top of the dam.

The wall was specified to be built on a rock foundation and to be composed of two kinds of concrete, and granite blocks of not less than 1 cubic foot in size. The concrete was composed as follows:—(I) 1 part of cement, 3 parts of sand, and 5 parts of crushed granite varying in size between ⅛ inch and 1½ inch. (II) 1 part of cement, 2½ parts of sand and 3½ parts of crushed granite varying in size between $\frac{1}{8}$ inch and $\frac{1}{2}$ inch. The granite dust from the crusher was mixed with the sand, and it was found particularly beneficial, as the sand was somewhat coarse.

The concrete was mixed by hand on a timber platform 30 feet by 16 feet. The sand and cement were thoroughly incorporated before being placed on the broken stone; then all were turned over three times dry, after which water was added through a rose while three more turnings were given. All concrete in place for more than 24 hours was washed with a jet of water, and grout was poured on before the new layer was deposited.

The foundation was well cleaned with a jet of water at a pressure of 43 lbs. per square inch, and all crevices and fissures in the rock were filled with cement grout; a layer of 3 to 1 cement mortar $\frac{1}{2}$ inch thick was spread over the rock foundation before the concrete was deposited in place. The inner face of the dam from the rock foundation to the overflow level was composed of the No. 2, or richer concrete, 18 inches thick; and the rest of the work of No. 1 concrete and granite blocks. A depth of 18 inches of concrete was spread over the foundation before any blocks were set. They were placed with their longest dimension at right angles to the axis of the dam, spaced not less than 18 inches from the inner, and 6 inches from the outer face of the dam. A clear space of 6 inches was left between the blocks in every direction. The work was built in courses, about 2 feet 6 inches in depth, between framed moulding-boards of 4-inch by 2-inch hardwood, on which were nailed 4-inch by 1-inch tongued and grooved pine flooring-boards. The first three courses of moulding-boards were held in position by struts from the surface. Above this height, the method of holding the boards in position was novel and proved very simple and effective, *Fig. 1.* Twin-screw $\frac{3}{4}$-inch galvanized bolts, 20 inches long, with square nuts, were set in the concrete, about 1 foot from

Fig. 1.



Scale, $\frac{3}{16}$ inch = 1 foot.

METHOD OF BUILDING THE DAM.

the top of the course, at both ends of the moulding-boards. These were held in position by the moulding-boards while the concrete was setting for 4 days. A scantling of hardwood, 10 feet long by 6 inches by 4 inches, was bored to receive the bolt at a point 4 feet from the upper end. This was run on to the bolt, leaving 5 inches for the thickness of the moulding-board. A block of wood 6 inches by 5 inches was placed near the bottom of the 6-inch by 4-inch profile to act as a heel, and then the moulding-board was placed in position and the outer nut screwed up till the inner face of the profile was in a straight line parallel to the face of the work and 5 inches from it, allowing the moulding-board to stand in its correct position. The old work, with the length of 6 feet between the bolt and heel, easily bore the strain of the weight of 2 feet 6 inches of green concrete in the next course. Curved moulding-boards were used for the upper 17 feet of the dam. After 4 days the outer nuts were taken off, the moulding-boards were removed and the profile shifted. The bolt was then unscrewed, leaving the inner nut embedded in the concrete, and the hole was plugged up with neat cement. In about 5 days the concrete had set hard enough for the profiles and moulding-boards to be placed in position and bolted up. The concrete was well punned and worked with spades between the stone blocks and against the moulding-boards, so as to avoid all chance of hollows in the work, or rough faces when the boards were removed. The top of the wall, however, was rendered with a layer of cement mortar $\frac{3}{4}$ inch thick, to ensure a level by-wash.

The dam was built by contract, the contractors being Messrs. Love, McCormick and Dwyer, who began work on the 1st August, 1894. The excavation was taken out in 2 months, and the contractors finally decided to use a wire ropeway for lifting the stone blocks and depositing them in position. Owing, however, to the wheels being made too small, the ropes did not last long; the drum gear and its connections with the engine were rough and clumsy, causing continual breakdowns, and the carrying capacity of the ropeway was reduced to 2 tons. The contractors made no attempt to square the stones, consequently, as they could not be placed closer to one another than 6 inches, a large amount of space had to be filled with concrete—the more costly part of the material. These circumstances made the cost of the work unduly high, and after having deposited 2,666 cubic yards of concrete and stone blocks in place, the contractors abandoned the work in July 1895, and the Author was instructed to carry on and finish it by day labour. The ropeway was dispensed with. The height of the wall being 22 feet below overflow level, where it was barely 14 feet wide, it was not worth while to erect either a costly traveller, or to make a reliable ropeway. The stone blocks were accordingly cut down to a size weighing about 2 cwt. each, which a man could wheel in a barrow, and they were squared in the quarry before being carted down to the hoist, by which they were lifted to the landing-stage, and then wheeled to their place as required. By using the smaller but squared stones, the proportion of the cement to the aggregate was reduced.

The contractors were paid the low rate of 23*s.* 3*d.* per cubic yard for all concrete, including stone blocks, and they deposited in place 2,666 cubic yards, the value of which at 23*s.* 3*d.* was £3,099 4*s.* 6*d.* The cost was about £4,005, so that they lost about £900 on the concrete. That part of the work carried out by the contractors, being the lower portion where the width of the wall is greatest, was the simplest and most economical. The cost per cubic yard was 30*s.*, and, considering the large blocks of stone which might have been used at this width, the cost should have been considerably less. When the Author began with day labour, the wall was built to the level of 1,438 feet above datum, and its width was only 14 feet. The cost per cubic yard of the remainder would be therefore greater than previously. All concrete having to be lifted and wheeled much farther, the narrower width between the boards and the much greater percentage of space occupied by the No. 2 concrete, tended to make the work of a more costly nature. The day labour work cost £1 12*s.* 3*d.* per cubic yard for all concrete and blocks. The wages paid for eight hours' work was: carpenters and blacksmiths 8*s.*, labourers, quarrymen, 7*s.*, 6*s.* 6*d.*, and 6*s.*, engine-drivers 7*s.*, horse-drivers and carts 10*s.* per day. Portland cement cost 18*s.* 9*d.* a cask ($4\frac{1}{3}$ cubic feet) delivered on the ground, the freight on the railway, 268 miles, being 7*s.* a cask. The concreting was finished on the 6th December 1895, and the rendering and cleaning up was completed by the end of the year.

The cost of the dam was:—

	£
Contractors' portion	3,974
Day-labour ,, ...	3,600
Total . . .	7,574

Exclusive of cost of land, office expenditure, etc.

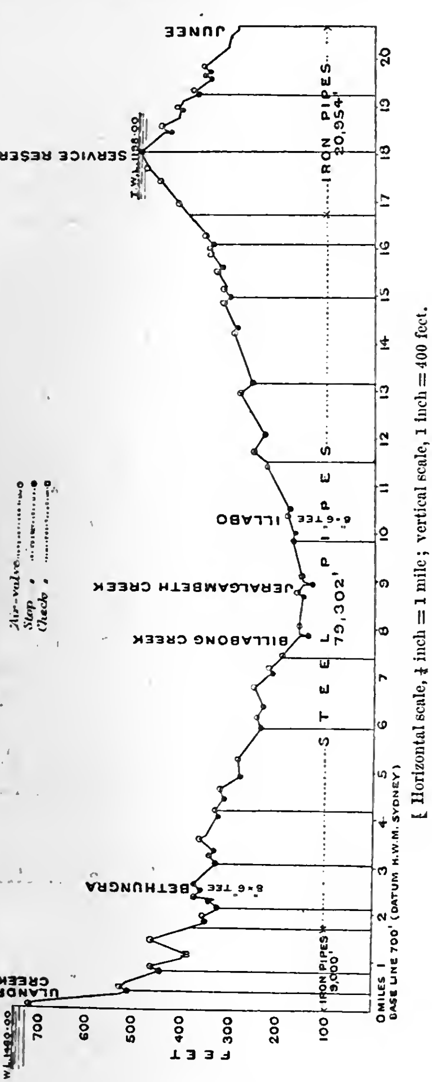
Pipes.—The pipes were of mild steel and wrought iron; the former being imported from England and the latter made in New South Wales. The steel plates were capable of withstanding a tensile stress of 30 tons per square inch of original section and the iron plates a stress of 20 tons. The bore of the pipes was 8 inches, and each standard pipe was 23 feet 7 inches long. They were constructed of plates not less than 4 feet wide and of such lengths as to be equal to the circumference of pipe with the necessary lap. The plates were rolled to their correct curve, the longitudinal lap-joints being double-riveted zigzag, and the transverse joints single-riveted. The laps, pitches, etc., are as follows:—

Thickness of Plate.	Breadth of Lap.		Diameter of Rivets.	Pitch of Rivets in Line—Longitudinal Joints.	Distance apart of Pitch Lines—Longitudinal Joints.	Pitch of Rivets—Transverse Joints.
	Longitudinal Joints.	Transverse Joints.				
$\frac{1}{8}$ inch	$1\frac{1}{16}$ inch	1 inch	$\frac{5}{16}$ inch	$1\frac{1}{4}$ inch	$\frac{23}{32}$ inch	$\frac{7}{8}$ inch.

The pipes were fitted at one end with a welded and rolled socket, shrunk on, riveted and caulked. The spigot end was formed by carefully welding it so as to be seamless, and of an equal thickness with the body of the pipe, and a welded ring, $4\frac{1}{2}$ inches in width and $\frac{1}{8}$ inch thick, was shrunk on and secured with countersunk rivets. The necessary bends were made in two plates and riveted similarly to the standard pipes. The plates were punched with multiple machines, and hydraulic riveters were employed. The seams were also caulked by machinery. For air-valves and scour-valves a 3-inch hole was cut in one of the plates and a cast-iron flanged connection riveted on. Relief-valves were attached to all the scour-valves, the springs of which could be adjusted for heads varying between 50 feet and 650 feet of water. The steel pipes were tested to a hydrostatic pressure of 400 lbs. and the wrought-iron pipes to 250 lbs. per square inch before being coated. The coating was made of bitumen and coal tar distilled until free from naphtha, in about equal parts. The pipes were twice dipped, and immediately before the second dipping had dried they were placed in a frame, in a horizontal position, and made to revolve while sand was allowed to fall on the coating. This helped, when the coating cooled, to prevent it running, and preserved the pipes against injury in transit. There were 168 tons of iron and 448 tons of steel pipes used; the former costing £26 7*s.* per ton, the latter at £24 19*s.* per ton, delivered at Sydney railway station.

The first 2,000 feet of pipe-laying down the cliff from the storage-reservoir was performed by day labour, and was the only difficult portion to deal with. The remaining 20 miles, with the exception of the first two, ran alongside the railway fence and was an exceptionally easy line for laying pipes, *Fig. 2.* The country was gently undulating, and very little rock was met with; evidence of the evenness of the ground is given by the fact that only 166 cubic yards of extra excavation, in addition to the stipulated quantity for an 18-inch cover over the pipes, was found to be required. The joints of the pipes were made in the usual way, with spun-yarn gasket and pig-lead, melted and run in at one running and lightly caulked. The laying was commenced in January, and completed in August, 1895. The contractors' prices for excavating the trenches and filling, 2 feet 2 inches deep, were $3\frac{1}{2}d.$ per lineal yard, and for laying and jointing pipes $4d.$ per lineal yard. Much of the

Fig. 2.



Horizontal scale, ¼ inch = 1 mile; vertical scale, 1 inch = 400 feet.

LONGITUDINAL SECTION OF THE PIPE-LINE.

excavation was carried out for 3*s.* 6*d.* per chain; the yarning and running joints for 1½*d.* per joint, and caulking for 2*d.* per joint. The amount paid to the contractor was £1,210, and the total cost of the pipe-line was:—

	£
Pipes, castings, valves, &c.	16,026
Railway freight and placing pipes along line	2,730
Laying pipes—contractor	1,210
,, ,, day labour	173
Total	20,139

or about £1,000 per mile.

Owing to the scattered position of the houses, the length of mains for the distribution was somewhat great. Six miles of 6-inch, 4-inch and 3-inch cast-iron pipes were laid with the usual socket and spigot joints, ball-hydrants being fixed about 80 yards apart, and the necessary stop-valves at intersections of streets. The pipes were laid at a depth giving 18 inches cover over them. The prices paid for excavating and filling trenches, laying and jointing pipes, providing lead, gasket, labour, etc., was, for 6-inch pipes, 9½*d.*, for 4-inch pipes, 8*d.*, and 3-inch pipes, 7*d.* per lineal yard. The total amount paid to the contractor for laying pipes, fixing hydrants, providing concrete blocks round surface boxes, etc., was £430 4*s.* 6*d.* The pipes were delivered at Sydney railway station (having been made in Sydney) for £7 10*s.* per ton. The cost for pipes, valves, etc., was £1,169; railway freight, Sydney to Junee, £723. The total cost of distribution was £2,322, or £387 per mile.

The Author's thanks are due to the Engineer-in-chief for Public Works, Mr. C. W. Darley, M. Inst. C.E., for his assistance in the preparation of the Paper.

The Paper is accompanied by five drawings, from a selection of which the *Figs.* in the text have been prepared.

(*Paper No. 3034.*)

"The Action of Sea-Water upon Hydraulic Cements."

By Dr. WILHELM MICHAËLIS.

Translated and Abstracted by WALTER FRANCIS REID.

WHEN a saturated solution of lime acts upon the combined hydrates of silica, compounds of ferric oxide and alumina are formed, containing respectively, 3, 4 and 5 molecules of lime to 2 of the oxides, and these compounds are united with water in such proportion, that at least 1 equivalent of water is combined with 1 equivalent of lime. Hydraulic cements rich in lime must, therefore, during the hardening process, segregate the lime as hydrate. In Portland cement the hardened mass is completely permeated with crystals of calcic hydrate. The hydrate of the combined aluminate and sulphate of lime ($Al_2O_3, 3CaO + 3CaOSO_3 + 30H_2O$) has been observed when the compound was dried over sulphuric acid, and the following calculations are based upon this proportion of water although in practice it must be far greater. Each molecule of alumina present in hydraulic mortar as the hydro-aluminate of lime can form about 12 parts of this double salt and the hydro-ferrate of lime acts in the same way. The true Roman cements, containing 1 part by weight of silicate to 1·1 to 1·2 parts by weight of lime, are, from the chemical point of view, the best hydraulic mortars, because, during the hardening process, they form the most stable compounds, without unsaturated residues. Such cements are, however, burnt at so low a temperature that they are deficient in density, so that mortars made with them shrink considerably when exposed to the air through the evaporation of the water which they have absorbed. All water exceeding in quantity that required for the formation of calcic hydrate must be considered as water of expansion and is very loosely combined. Hydraulic limes, such as that of Teil, bear a close resemblance to Roman cements; but are even looser in texture. Of the 68·6 per cent. of lime in Teil lime, 36·48 per cent. only would combine with the other constituents during the setting process, leaving 32·12 per cent. of lime in an uncombined state.

Portland cement, having been burnt at a higher temperature, is denser than Roman cement in the ratio of 5 to 3; but from the chemical point of view this cement is also defective, because, even supposing the richest calcareous compounds are produced during the setting process, there still remains an excess of uncombined lime. A Portland cement containing 61·04 per cent. of lime would leave 13·79 per cent. of lime unsaturated, while one containing 68·379 per cent. would leave a similar residue of 29·1 per cent. In the case of a Portland cement of average composition, with 1 part of silicate to 2 parts of lime, 25 per cent. of lime or 33 per cent. of calcic hydrate would be segregated.

A body containing a substance of such strong chemical affinity as free lime cannot be regarded as stable. The free lime will continue to re-act until it forms a saturated compound. When the mortar hardens in the air or in water containing carbonic acid the lime is converted into carbonate; but in sea-water it is chiefly the sulphates which act upon the lime. In the first instance it is the free lime that is converted into carbonate or sulphate, then the very unstable compound with ferric oxide, then the aluminate, and finally the silicate. The formation of the sulphate with 2 equivalents of water causes a considerable increase of volume, and may destroy the cohesion of the mass. With this formation of gypsum the production of lime aluminate-sulphate goes hand in hand, and this causes an enormous increase of volume, and a total destruction of the cohesion, for this double compound crystallises with at least 30, probably with 60 equivalents of water, and in doing so converts the strongest mortar into a mud, the only parts of which retaining any cohesion being those protected by the formation of carbonate. Good Roman cements resist the action of sea-water well because they only contain enough sulphate of lime to form 16 parts of the double salt which finds sufficient space for expansion in the pores of the mortar. In such hydraulic limes as that of Teil there is little alumina, and consequently the chief increase of volume is due to the formation of calcic sulphate and not to the double salt. One of the reasons why Teil hydraulic lime has proved more successful for marine work than Portland cement is that the blocks made with it are allowed to harden in the air for a long time before immersion, while Portland cement is generally exposed to the action of the sea-water at once. Even if Portland-cement concrete blocks be exposed to the air until a protective skin of carbonate of lime is formed, such a skin cannot attain any considerable thickness, and the chemical reactions to which the destruction of the cohesion must be attributed will eventually take place. In order to ascertain the action of carbonic acid and sea-water upon the strength of Portland cement, a series of experiments were carried out. Two sets of briquettes were made according to the German standard rules, one composed of 1 part by weight of Portland cement to 3 parts by weight of standard sand, and the other of 1 part cement to 5 parts of standard sand. These briquettes were allowed to harden for 24 hours in the air; but protected from carbonic acid, and were then placed in boiled distilled water for 56 days, the vessel in which they were kept being hermetically closed. Half of the briquettes were then treated with moist carbonic acid for 5 weeks, and were finally returned to the closed vessels in which they remained 4 weeks longer. When tested, the briquettes were therefore 120 days old. The 1 : 3 mortar protected from carbonic acid gave a tensile strength of 26·9 kilos. per square centimetre, while the briquettes treated with that gas gave 28·5 kilograms per square centimetre (405·3 lbs. per square inch). The crushing strength was 309 kilograms per square centimetre in the first case, and 338 kilograms per square centimetre (4,806·3 lbs. per square inch) in the second. The 1 : 5 mortar protected from carbonic acid broke at a tensile strain of 14 kilograms per square centimetre (199 lbs. per square inch), and, treated with carbonic acid, the strength increased to 16·8 kilograms per square centimetre (238·9 lbs. per square inch). The crushing tests gave 112 and 138 kilograms per square centimetre (1,592·6 and 1,962·0 lbs. per square inch) respectively.

In the 1 : 3 briquettes only 13·3 per cent. of the total lime, and in the 1 : 5 only 24·8 per cent. was converted into carbonate. These briquettes being very small, and the conditions for the absorption of carbonic acid favourable, it is evident that even a long exposure of concrete blocks to the air would only cause a very thin film of carbonate to be formed. The whole of the lime was not converted into carbonate until the mortar had been coarsely powdered and exposed to the action of carbonic acid for some time. Immersed in sea-water, or in a 2 per cent. solution of magnesium sulphate, the briquettes which had been protected from carbonic acid soon disintegrated, and even those which had been carbonated were strongly attacked in seven months, especially the 1 : 5 mortar, although this had absorbed more carbonic acid.

In fresh water the conditions are more favourable, for only the free lime can be dissolved or converted into carbonate. The more lime is dissolved out, the more insoluble are the residual silicates and aluminates. The whole of the lime can never pass into solution, although this may be effected on a small scale when carbonic acid is excluded. A well mixed and burnt Portland cement may contain 70 per cent. of lime and yet resist the action of fresh water.

The magnesia which is deposited during the action of sea-water upon hydraulic mortar, is a preservative agent which tends to close the pores of the mass. It would be more correct to speak of the injurious action of the sulphates in sea-water, than to attribute such action to the magnesia salts, although it is true that magnesium sulphate is the special salt which acts in sea-water. The sulphates of lime or of the alkalis, in fact, any soluble sulphate, have the same destructive action; but do not act with the same degree of energy.

The Author finds, as the result of his investigations, that those cements which are richest in lime are those which offer the least resistance to sea-water. The addition of lime or of more calcareous cements to Portland cement mortar is therefore unsuitable, and modern Portland cements of high strength, but rich in lime, are less suitable for marine work than the older cements containing less lime. A mortar containing free caustic lime is as unstable from a physical as from a chemical point of view. By the reactions already explained, great internal strains are produced, and expansion and cracking continue, sometimes for many years. All these defects may be avoided by offering to the lime, which remains or becomes free during the hardening process, hydraulic silica or alumina with which it can form more stable compounds. The disadvantage of the efflorescence of caustic alkali cannot be avoided; but as the quantity is small, and it is easily soluble, this caustic alkali cannot endanger the stability of the mortar. In water the alkali is simply washed out; in the air it is only a temporary efflorescence which can be washed off.

The addition of milk of lime to Portland-cement mortars must be injurious, and hastens their destruction. Even in fresh water the advantages of such an addition are only apparent; the excess of lime is easily washed out and the mortar soon becomes porous. Even in two to three years a diminution in the strength of such cement-lime mortars takes place. The action of carbonic acid may come to the rescue, but the chief use of this addition is to make poor mortars more plastic.

In carrying out experiments on the action of sea-water upon cements, it is of importance that the test-pieces should be as porous as possible, otherwise the results would only be delayed. In carrying out a series of experiments with various mortars the

Author used artificial sea-water, and solutions of calcium sulphate, magnesium sulphate and sodium sulphate. The mortars were moulded in the form of prisms 10 centimetres long with a rectangular section of 5 cubic centimetres. For 24 hours the briquettes were allowed to harden in moist air, from which carbonic acid was excluded; they were then placed in the test solutions. The solutions were renewed daily for 14 days, weekly for 3 months, and then monthly. One of the mixtures which withstood the action of calcium sulphate best was Teil lime mixed with 5 parts of standard sand; but all mixtures containing hydraulic silica either as hydrate, or in the form of trass or burnt kaolin, were but slightly acted upon, and remained intact after the lapse of 2 years.

In a 1 per cent. magnesium sulphate solution similar results were obtained. Neat Portland-cement mixtures, without the addition of hydraulic substances, soon disintegrated, especially in the case of those cements rich in alumina. A Bavarian Roman cement containing 47·2 per cent. of lime stood well, while a Bosnian Roman cement with 49 per cent. of that substance began to show signs of deterioration. Long before there are visible signs of disintegration through the action of sea-water the tensile strength indicates whether an injurious action is taking place. As porous briquettes are more rapidly acted upon than impervious ones, it is advisable to use a mortar containing 1 part of cement to 5 parts of sand, rather than one composed of the 1 : 3 mixture. A number of experiments were carried out by the Author, in which the briquettes were composed of 1 part of cement mixed with 5 parts by weight of Berlin standard sand.

The cements used were :—A, a Stettin Portland cement; B, a Portland cement made by the dry process; C, Teil lime; D, a Bavarian Roman cement.

—	A.	B.	C.	D.
Silica	21·712	21·331	23·88	23·881
Alumina	5·805	8·918	2·57	9·709
Ferric oxide	2·949	2·695	0·88	4·052
Lime	64·851	63·776	69·15	44·263
Magnesia	1·030	0·805	1·60	3·992
Potash	0·748	0·777	0·14	..
Soda	0·160	0·101	0·07	..
Calcium sulphate	2·468	1·631	1·09	7·203
Residue	0·357	0·123	..	6·381
	100·080	100·157	99·38	99·481

Artificial sea-water was used, 1 litre of which contained 30 grams of sodium chloride, 12 grams of magnesium sulphate with 7 molecules of water, 3 grams of magnesium chloride, and 1 gram of calcium sulphate with 2 molecules of water (gypsum). The majority of the briquettes were kept for the first day in a closed space saturated with moisture; but in some cases, marked Ma, they were exposed to the air for 8 weeks in order to absorb carbonic acid, during which time they were sprinkled daily. Those marked M were kept in sea-water, those marked S in fresh water. The age of the briquettes is reckoned, not from the date of making, but from 1 day before immersion. The results are given in the following Table in kilograms per square centimetre :—

Age.	AS.	AM.	AMa.	BS.	BM.	BMa.
7 days . .	7·23	6·00	15·93	10·50	7·86	17·05
28 ,, . .	10·09	7·54	15·25	12·68	6·91	17·75
90 ,, . .	11·60	10·40	15·28	15·00	9·10	15·89
1 year . .	16·00	16·00	6·5 to 18·00	16·70	11·20	·2 to 15·00

Age.	CS.	CM.	CMa.	DS.	DM.	DM.
7 days . .	3·81	4·96	7·75	2·86	6·27	13·12
28 ,, . .	5·17	6·50	6·97	5·11	9·22	13·50
90 ,, . .	8·38	10·86	9·89	9·68	11·43	14·66
1 year . .	13·25	15·20	12·50	14·43	14·12	15·44

The cement A was then mixed with Plaidt trass, which left 41 per cent. residue upon a sieve with 2,500 meshes per square

Composition of Cement A.

	Per cent.
Hygroscopic water	4·141
Water chemically combined	6·899
Loss at 900° C.	0·202
Silica	53·583
Alumina	19·008
Manganic oxide	0·115
Ferric oxide	4·193
Lime	1·736
Magnesia	1·652
Potash	4·147
Soda	4·242
Sulphuric acid	0·107
	100·025

centimetre. Heated for 10 hours upon a waterbath with 10 per cent. caustic soda solution, it yielded 15·543 per cent. hydraulic silica, and 4·810 per cent. hydraulic alumina. Heated for 24 hours under the same conditions the figures were 16·708 per cent. hydraulic silica, and 6·043 per cent. hydraulic alumina. Its composition is shown on p. 330.

Two mixtures were made ; the first, E, was composed of 1 part by weight of cement A, 1 part of Plaidt trass, and 4 parts of standard sand; the second mortar, F, contained 1 part by weight of cement A, 0·5 part of Plaidt trass, and 4·5 parts of standard sand. In the following Table the letter S denotes immersion in fresh water and M in sea-water. The results are given in kilograms per square centimetre, each being the average of ten tests.

Age.	ES.	EM.	FS.	FM.
7 days . . .	9·80	11·80	11·05	10·10
28 ,, . . .	19·15	28·00	16·90	19·55
90 ,, . . .	26·70	35·70	21·80	23·65
1 year . . .	30·95	39·50	27·55	24·59

From a Portland cement with an average amount of lime about 33 parts by weight of calcium hydrate would be liberated. It is therefore probably advisable to add 125 or more parts by weight of trass to 100 parts of Portland cement. Of course, the higher the proportion of lime, the more trass should be added. In FM an injurious action of the sea-water becomes evident in one year; in this mixture 10 parts by weight of lime would remain free to react with the sulphates of the sea-water.

A further series of experiments was carried out with mixtures of Portland cement on Teil lime with trass and standard sand. The composition of the various mortars was as follows :—

G, Portland cement containing 9 per cent. of alumina—1 : 5 Berlin standard sand;

H, 1 part by weight of the same cement with 1 part by weight of trass and 6 parts by weight of Berlin standard sand;

I, 1 part by weight of the same cement with 1 part by weight of trass and 6·75 parts by weight of Berlin standard sand;

K, Teil lime, 1 : 5 Berlin standard sand;

L, 1 part by weight of the same lime, with 1 part by weight of trass and 5 parts by weight of Berlin standard sand;

M, 1 part by weight of the same lime, with 1 part by weight of trass and 6 parts by weight of Berlin standard sand.

K, L, and M were allowed to harden exposed to the air for 7 days in an enclosed moist space.

The experiments E to M are to be extended over a period of 3 years. After the lapse of 1 year the broken briquettes are placed partly in a 2 per cent. and partly in a 3 per cent. solution of magnesium sulphate, and are therefore exposed to a much more energetic attack than in the strongest sea-water.

The following are the results obtained so far in kilograms per square centimetre, each figure being the average of ten tests. Δ gives the density of 1 cubic centimetre immediately previous to testing.

Time of Immersion.	GS.	GM.	HS.	HM.	IS.	IM.	KM.	LM.	MM.
28 days. .	8·80	6·35	10·40	21·65	10·10	20·45	2·97	11·75	10·30
Δ . .	..	..	..	..	..	..	2·162	2·195	2·227
90 days. .	10·25	7·55	16·85	24·55	16·55	24·60	2·39[1]	21·57	20·10
Δ . .	2·137	2·172	2·26	2·28	2·274	2·292	2·252	2·250	2·259

An examination of the above figures shows at once that the action of sea-water, in the case of all the mortars in which lime is liberated, is antagonistic to an increase in strength. Two processes, the hydraulic hardening process and that of crystallization, struggle for supremacy, and, as a rule, the latter is victorious and destroys the cohesion already attained.

One of the briquettes, B M, showed, in 90 days, signs of destruction; it was so disintegrated and cracked, that it broke while being placed in the clips of the testing-machine. The fracture showed a deposit of magnesia hydrate to a depth of several millimetres. In one year this deposit of magnesia was found to have penetrated as far as 5 millimetres; the same was observed with the BMa briquettes. It was remarkable that those briquettes which had been exposed to the action of carbonic acid were even more rapidly destroyed; the carbonated crust split off and curled up. All the D briquettes were perfectly sound and did not show the slightest deposit of magnesia on the fractured surface.

The addition of trass or of an efficient pozzuolana to hydraulic cement containing an excess of lime, such as Portland cements, can increase the strength of mortars twice or three times, and

[1] The 90-day tests of Teil lime without addition showed signs of swelling of the external crust in addition to the diminution in strength.

render them stable in sea-water. This is not surprising, because the best pozzuolanas contain at least as much active hydraulic material as the best Portland cement.

Hydraulic cements which contain more lime than is required to form stable hydrosilicates and hydroaluminates should not be used for marine work unless improved by the addition of substances such as those named The proportion of pozzuolana or trass to be mixed with the cement can easily be calculated in each case. It would be preferable for the manufacturer of the cement, rather than the consumer, to add the necessary quantity of material, as the proportion would vary with the composition of the cement, which is best known to the manufacturer.

The Author suggests that the resistance of mortars to the action of sea-water should be tested by means of porous briquettes (1 : 5), whether for tensile, crushing, or elastic strength; the briquettes to be immersed in artificial or natural sea-water which should be renewed daily for the first twenty-eight days, and afterwards weekly. In order to maintain a uniform percentage of sulphuric acid in the water-rods of gypsum tied up in linen, they should be suspended in the artificial sea-water. A 2 per cent. solution of crystallized magnesium sulphate will give quicker results.

(*Paper No. 3026.*)

"A New Indentation Test for Determining the Hardness of Metals."

By WILLIAM CAWTHORNE UNWIN, B.Sc., F.R.S., M. Inst. C.E.

THE physical properties of ductile metals are considerably altered by differences of mechanical treatment. Cold rolling, cold hammering, wire-drawing or stretching, convert a comparatively soft and tough material into a harder and more brittle one. In the case of steel, the physical properties may be altered by differences of thermal treatment in a similar way, but to a still greater extent. The differences of mechanical properties thus induced are of the highest practical importance. In some cases the hardening of the material by treatment is useful, as in the tempering of steel; in other cases a trustworthy material in its normal state may, by hardening, be rendered untrustworthy or useless. It is to get rid of artificially-induced hardness that processes of annealing are applied after certain mechanical operations.

Ordinary processes of testing, in which the tenacity and elongation are measured, indicate indirectly the condition of the material; but they cannot always be conveniently applied, and their indications are open to misinterpretation. An ordinary tension test of a rail or axle, for instance, does not clearly discriminate whether the material is properly annealed or not, and, in such cases, a more direct and sensitive test of hardness is required. For many other purposes, as in deciding on the relative values of different alloys, a direct measure of hardness would be useful.

Hardness is a property as to the definition of which physicists are not agreed, nor is any one method of measuring it generally adopted. Excluding quite brittle materials, which crush to powder under pressure, and with reference specially to the metals used in construction, hardness may be defined as resistance to permanent or plastic deformation. That definition accords with the ordinary meaning of the word hardness to engineers. Resistance to indentation by a very hard tool has been, by several experimenters, taken as the measure of hardness, and it occurred to the Author to contrive a simple method of producing a measurable amount of indentation capable of use as an ordinary workshop test of hardness, and to examine how far such a test was sensitive enough to be practically useful.

Methods of determining Hardness previously used.—A mechanic tests hardness by using a file, and the earliest scientific scale of hardness is that proposed by Moh. He selected ten substances and arranged them so that each would be scratched by the substance next above it in order, and would scratch that next below. This simple scratch test has been very useful in the case of brittle bodies; but it is less useful for ductile bodies. Recently Mr. Thomas Turner[1] has attempted to introduce a more definite and exact scratch test of hardness. A diamond point is balanced at the end of a lever and loaded till it will just definitely produce a scratch. The weight required is taken as the measure of hardness. Mr. Turner has obtained interesting results, but the method requires considerable skill, and it does not seem sensitive enough to discriminate the quality of ductile metals, such as iron and mild steel. For instance, the following are some values of relative hardness given by Mr. Turner:—

Mild steel, usually	21
Tire steel	20 to 24
Good soft cast iron	21 ,, 24
South Staffordshire bar iron	24

Some experimenters have used an abrasion test in determining hardness; but this again is difficult and laborious, and appears best adapted for brittle substances, such as stone. The only remaining method which has been used is an indentation test. Messrs. Calvert and Johnson[2] used, as a measure of the hardness of alloys, the weight which caused a small truncated cone to indent the alloy to a depth of $3\frac{1}{2}$ millimetres in half an hour. In some tests in the United States, the volume of indentation produced by a pyramidal point loaded with a weight of 10,000 lbs. was taken as a measure of hardness. An indentation of $\frac{1}{3}$ cubic inch was taken as unit hardness; half that indentation was called hardness 2·0.[3] This is a much more definite and scientific method of determining hardness in materials which are ductile or plastic.

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[1] Proceedings of the Birmingham Philosophical Society, 1886, vol. v. part ii.

[2] Philosophical Magazine, 4th series, vol. xvii. p. 114.

[3] Reports on Metals for Cannon, 1856, Ordnance Department, U.S.A.

The following are some values of relative hardness determined by this method :—

Bronze	1·36
No. 1 pig iron	2·55
Wrought iron	3·32
No. 2 pig iron	4·15

Middleberg[1] used a knife-edge as an indenting tool in determining the hardness of tires. The knife-edge was about $\frac{3}{4}$ inch long, ground to an angle of 30°, and having an edge curved to 1 inch radius. The knife-edge placed on the tire was loaded with 6,000 lbs., and the reciprocal of the length of indentation was taken as the measure of hardness. Martel[2] has described an indentation test in use at the foundry of Ruelle. The indenting tool is a pyramidal point very accurately ground to an exact pattern. Indentation is produced by a falling weight. The volume of indentation is easily calculated from one measurement of the length of the indentation. It appears that the volume of indentation for any one metal is nearly proportional to the work of the falling weight.

Let l be the measured length of an indentation produced by a given weight falling a distance h. The proportionality of work and volume of indentation leads to the equation $l = K \sqrt[3]{h}$, where K is a constant. For a weight P, falling a given height, $l = M \sqrt[3]{P}$, where M is a constant. Both these equations were verified experimentally with different weights P falling different heights h. It appeared also that, for the same weight and height of fall, the volume of indentation in any metal was nearly the same with indenting tools of somewhat different form. Hence, generally, if V is the volume of indentation produced by a weight P, falling a distance h, $V = \frac{P h}{D}$, where D is the work required to produce unit volume of indentation by the given tool in the given metal. D is taken as the measure of the hardness of the metal. Martel's method is simple; it gives definite results, and the only objections to it seem to be that it is not always convenient to use a heavy falling weight to produce the indentation, and, in principle, it does not seem right to use, in producing a plastic deformation, an action which is almost instantaneous, as plastic yielding requires

[1] *Engineering*, 1886, vol. ii. p. 481.

[2] Commission des Méthodes d'Essai des Matériaux de Construction, tome ii. p. 261.

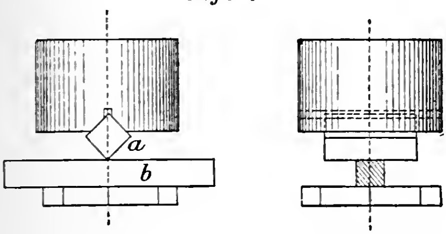
time. The following are some values of relative hardness obtained by this method :—

HARDNESS.

	Values of D.
Tool steel, tempered at cherry red in oil	420
,, ,, not tempered	415
Steel gun tubes tempered in oil . . .	455 to 300
Cast iron for guns	300 ,, 208
Rolled wrought iron	226
Bronze	154
Copper	156
Cast lead	9

The Author's method of Measuring Hardness.—The indenting tool is a straight knife-edge; the test specimen indented is a short bar of square section; and indentation is produced by a steady load.

Figs. 1.

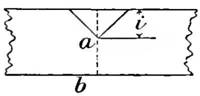


End elevation. Side elevation.

INDENTING TOOL.

A series of observations of indentation and load are taken, from which a constant is deduced, which is the measure of hardness. The indenting tool is a simple short bar of square tool steel, *a*, *Figs. 1*, ground accurately, so that the angles are right angles and as hard as possible. Any one of the edges can be used as an indenting edge, and the tool is easily reground. The test-piece, *b*, is a square bar of the metal to be tested, about $2\frac{1}{2}$ inches long, and, in the Author's tests, usually $\frac{3}{8}$ inch square. The tool is carried in an apparatus which ensures parallel movement, and which has a scale and vernier for measuring the indentation. The apparatus is placed in an ordinary testing-machine, loads are applied, and the indentation corresponding to each is noted. Each load rests on the specimen a few minutes, till the indentation ceases to increase. If the load is increased sufficiently, the test specimen shears through or tears at the section *a b*, *Fig. 2*, below the knife-edge. The test must not be carried so far. With metals which have a low yield point, such as some of the brass alloys, the load may produce a stress on *a b* which causes very sensible stretching. If that occurs, the indentations increase more rapidly. The point at which this stretching begins is well marked, if the indentations are plotted. The loads at which the indentations are measured should be less than the load at which this yielding of the specimen below the knife-edge begins. The depth of indentation, *i*, for each load is the quantity noted in the tests.

Fig. 2.

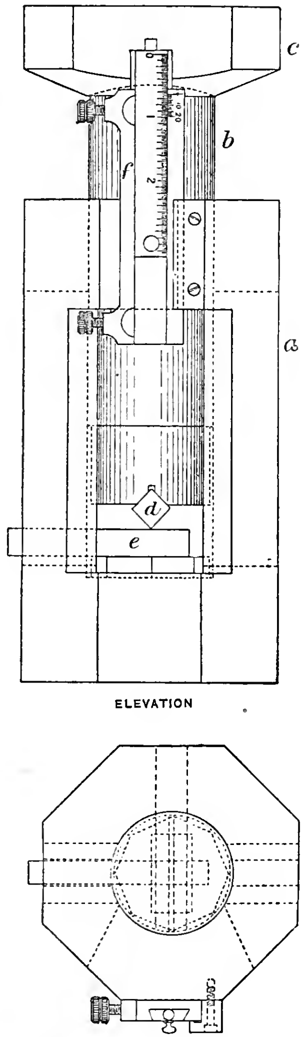


The following Table gives some tests in which the stretch of the specimen below the knife-edge was noted. It will be seen that, for the brass, stretching became sensible with a load of 5,000 lbs., and increased fairly rapidly. With the mild-steel specimen no stretch could be observed with a less load than 7,500 lbs., and the stretch increased much more slowly. In further tests the loads were kept below the limits thus indicated.

Load on Knife-edge in Lbs.	Load on Knife-edge in Tons per Inch width.	Indentation in Inches.	Amount of Longitudinal Stretching.
	Brass, No. 1. Width = 0·57 inch.		
0	0		
1,000	1·207	0·006	
2,500	3·016	0·012	
5,000	6·033	0·037	Just sensible stretching.
7,500	9·049	0·082	Stretching = 0·04 inch.
10,000	12·066	0·133	„ = 0·07 „
	Mild Steel (normal). Width = 0·375 inch.		
0	0	0	
1,000	1·190	0·008	
2,500	2·975	0·022	
5,000	5·952	0·051	
7,500	8·927	0·090	Perceptible stretch.
8,000	9·522	..	Stretch = 0·02 inch.
9,000	10·712	..	„ = 0·03 „
10,000	11·902	0·134	„ = 0·04 „

Description of the Apparatus.—Figs. 3 show the apparatus used in the tests. A cast-iron guide-block, *a*, has a loosely-fitted plunger, *b*, to which pressure is applied in the testing-machine through a block, *c*, which forms, with the plunger, a spherical joint; *d* is the indenting tool, and *e* the test-piece resting on a plate of hardened steel; *f* is a guide carrying a scale and vernier by which indentations could be measured to $\frac{1}{1000}$th inch.

Figs. 3.



Scale, 4 inches = 1 foot.

APPARATUS FOR INDENTATION TESTS.

Correction for Compression of Apparatus.—As the indentations are measured between the lower guide-block and the Table of the testing-machine, the compression of parts of the apparatus is included in the measurement of indentation. This compression was measured independently and is given in the following Table:—

COMPRESSION OF APPARATUS.

Load in Lbs.	Compression in Inches.
0	0·000
250	0·001
500	0·002
1,000	0·003
1,500	0·004
2,000	0·005
5,000	0·007
10,000	0·009
15,000	0·011
20,000	0·012

These compressions are deducted from the observed indentations in finding the real indentations. It will be seen that the correction is a small one compared with the indentations except in the case of excessively hard materials.

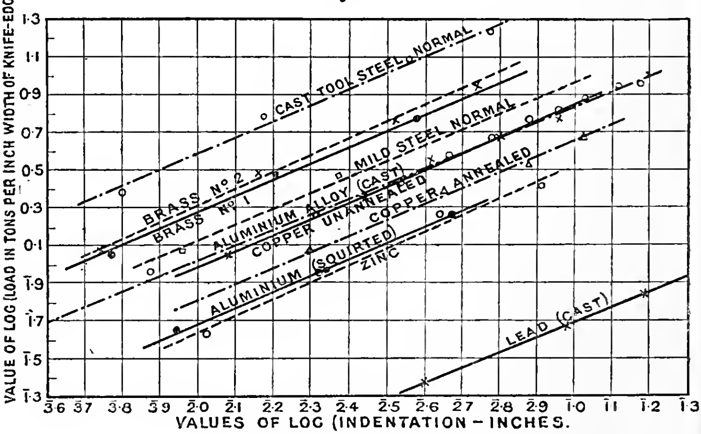
Relation of Load and Indentation.—To find a relation between the load and indentation the results of a series of tests on $\frac{3}{8}$-inch square bars of different metals were plotted in this way. The logarithms of the loads per inch width of bar were plotted as ordinates, and the logarithms of the depths of indentation as abscissas, *Fig. 4.* It will be seen that for each test-bar the plotted points lie approximately along a straight line. Also that for very different metals the slope of the lines is nearly the same. The agreement in these respects is so close that the relation $C\ i = p^n$ may at once be assumed, where p is the pressure per inch width of knife-edge in tons, and i the depth of indentation in inches; n is simply the slope of the line obtained by plotting the logarithms of p and i, and C is a constant for the metal tested.

The following are the values of n obtained by measuring the plotted lines :—

Material.	Values of n.
Cast tool steel, normal	1·17
Brass, No. 2	1·15
Brass, No. 1	1·16
Mild steel, normal	1·20
Copper, unannealed	1·20
,, annealed	1·18
Aluminium alloy	1·23
,, pure	1·19
Zinc	1·14
Lead, cast	1·23

It will be seen that these values vary little, and no one differs

Fig. 4.



much from 1·20. Considering the great variation of hardness of the metals tested, this coincidence is striking, and it has been further confirmed by later tests.

Hence the equation $C\ i = p^{1\cdot 2}$ may be taken as the relation between load and indentation, provided the loads do not exceed that at which sensible stretching begins below the knife-edge. Also since C is the only constant which varies with the hardness

RESULTS OF TESTS.

Load on Knife-edge in Lbs.	Load on Knife-edge in Tons per Inch Width.	Indentations in Inches.			Mean Indentation. Observed.	Mean Indentation. Calculated.
		CAST STEEL (NORMAL). Width = 0·37 inch.				
0	0					
2,000	2·413	0·007	0·006	0·006	0·0063	0·0052
5,000	6·033	0·016	0·014	0·015	0·0150	0·0155
10,000	12·066	0·036	0·037	0·035	0·0360	0·0360
15,000	18·098	0·061	0·061	0·059	0·0603	0·0585
		MILD STEEL (NORMAL). Width = 0·38 inch.				
0	0					
1,000	1·175	0·010	0·008	0·010	0·009	0·0085
2,500	2·937	0·023	0·023	0·027	0·024	0·025
5,000	5·874	0·056	0·059	0·060	0·058	0·058
7,500	8·811	0·094	0·095	0·096	0·095	0·095
		COPPER (ANNEALED). Width = 0·375 inch.				
0	0					
1,000	1·190	0·020	0·018	0·022	0·020	0·020
2,000	2·380	0·044	0·044	0·046	0·045	0·046
3,000	3·571	0·075	0·075	0·074	0·075	0·074
4,000	4·761	0·106	0·103	0·105	0·105	0·105
		COPPER (UNANNEALED). Width = 0·375 inch.				
0	0					
1,000	1·190	0·010	0·012	0·014	0·012	0·012
2,000	2·380	0·022	0·025	0·027	0·025	0·027
3,000	3·571	0·039	0·042	0·043	0·041	0·044
4,000	4·761	0·061	0·062	0·066	0·063	0·062
5,000	5·951	0·091	0·089	0·091	0·090	0·081
		BRASS, No. 1. Width = 0·375 inch.				
0	0					
1,000	1·190	0·006	0·004	0·008	0·006	0·0055
2,500	2·975	0·017	0·012	0·020	0·016	0·016
5,000	5·952	0·039	0·034	0·042	0·038	0·038
7,500	8·927	0·080	0·073	0·084	0·079 [1]	0·062
10,000	11·902	0·128	0·124	0·132	0·128 [1]	0·088

[1] Specimen stretching below knife-edge.

RESULTS OF TESTS.

Load on Knife-edge in Lbs.	Load on Knife-edge in Tons per Inch Width.	Indentations in Inches.			Mean Indentation. Observed.	Mean Indentation. Calculated.
		BRASS, NO. 2. Width = 0·500 inch.				
0	0					
1,333	1·190	0·005	0·007	0·005	0·0057	0·0050
3,333	2·975	0·0145	0·0155	0·0135	0·0145	0·0150
6,666	5·952	0·034	0·034	0·032	0·0333	0·0344
10,000	8·927	0·0535	0·0545	0·0535	0·0538	0·0562
13,333	11·902	0·0845	0·0865	0·0835	0·0848	0·0794
		ALUMINIUM (SQUIRTED). Width = 0·500 inch.				
0	0					
500	0·446	0·010	0·007	0·010	0·009	0·009
1,000	0·893	0·022	0·020	0·022	0·021	0·021
2,000	1·786	0·049	0·046	0·050	0·048	0·048
3,000	2·679	0·092	0·092	0·096	0·093	0·078
		ALUMINIUM ALLOY (CAST). Width = 0·96 inch.				
0	0					
1,000	0·465	0·004	0·004	..	0·004	0·004
2,000	0·930	0·007	0·008	..	0·0075	0·0088
4,000	1·860	0·019	0·022	..	0·0205	0·0205
6,000	2·790	0·032	0·036	..	0·034	0·033
8,000	3·720	0·045	0·049	..	0·047	0·047
10,000	4·650	0·058	0·063	..	0·0605	0·061
12,000	5·580	0·074	0·078	..	0·076	0·076
14,000	6·510	0·091	0·093	..	0·092	0·0915
16,000	7·440	0·108	0·110	..	0·109	0·1075
18,000	8·370	0·127	0·130	..	0·1285	0·124
20,000	9·301	0·147	0·150	..	0·1485	0·140
		CAST LEAD. Width = 0·48 inch.				
0	0					
250	0·233	0·037	0·043	0·039	0·040	0·040
500	0·465	0·093	0·100	0·095	0·095	0·095
750	0·698	0·151	0·162	0·155	0·156	0·1545
1,000	0·931	0·216	0·228	0·222	0·222	0·2185
		ZINC (CAST). Width = 0·50 inch.				
0	0					
500	0·446	0·010	0·011	..	0·0105	0·0095
1,000	0·893	0·022	0·019	..	0·0205	0·0215
2,000	1·786	0·046	0·045	..	0·0455	0·049
3,000	2·678	0·078	0·083	..	0·0805	0·080

of different materials, being larger with hard materials, and smaller with softer materials, C may be taken as the measure of hardness. Obviously C can be determined by a single observation of load and indentation. But it is better to measure the indentation corresponding to three or four loads, and thence to deduce a mean value of C.

Tests of Square Bars of different Metals.—In the tests, results of which are given on pp. 341 and 342, the test-bars were in most cases $\frac{3}{8}$ inch square and $2\frac{1}{2}$ to 3 inches long. Generally three indentations were made in each bar, and the mean of the three series of readings is taken in reducing the results. The first reading of the micrometer was always taken with some load on the bar to ensure that all parts of the apparatus were in contact. The second reading was taken with double the first load. The indentation observed was doubled and taken as the whole indentation for the second load. Thus for normal cast steel the first load was 1,000 lbs. The indentation between 1,000 lbs. and 2,000 lbs. was observed to be 0·0035 inch. Then 0·007 inch was taken as the indentation due to 2,000 lbs.

Using the formula already given, and putting p for the load on the knife-edge in tons per inch width, and i for the depth of indentation in inches, the following are the values of C obtained from the foregoing tests:—

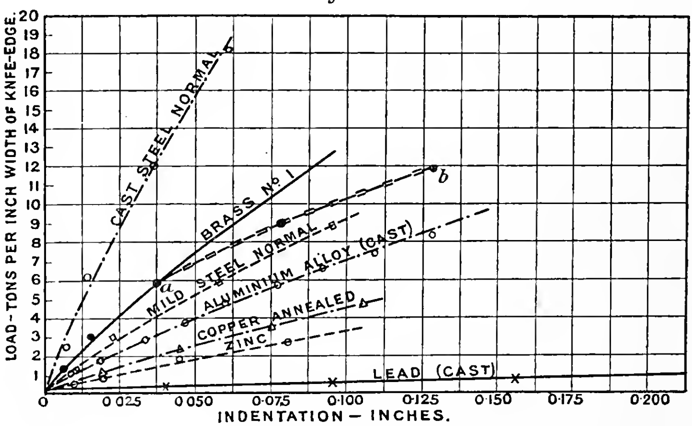
HARDNESS.

	Values of C.
Cast steel, normal	554·0
Mild steel ,,	143·5
Copper, annealed	62·0
,, unannealed	105·2
Brass, No. 1	221·0
,, No. 2	246·0
Aluminium, squirted	41·8
,, alloy, cast	103·5
Lead, cast	4·2
Zinc, cast	40·8

If these numbers are compared with those given by Martel, it will be seen that for the same metals they are not widely dissimilar. Apparently, the differences of hardness by the Author's method are somewhat greater. From the values of C given above, the indentations for each test-bar have been calculated and placed beside the observed values in the foregoing Tables. It will be seen that the agreement of the calculated and observed values is very close. *Fig. 5* shows the principal tests plotted in curves. The curves are drawn with the calculated values and the observed values are shown by dots. In the case of brass, No. 1, the dotted line *a b* corresponds to loads beyond the limit at which sensible stretching of the specimen begins. It will be seen how marked the increase of indentation is in that case. The constant C is of course obtained for loads less than that corresponding to the point *a*.

Influence of Width of Test-bar on the Load per inch width to produce a given Indentation.—The test-pieces used were all square bars, and it was found that for equal loads per inch width the indentations were nearly the same in bars of different width; they are, how-

Fig. 5.



ever, not exactly so. The following tests were made on three copper bars 0·75 inch, 0·50 inch and 0·25 inch wide with the same loads reckoned per inch width of bar :—

INFLUENCE OF WIDTH OF SPECIMEN.

Copper (unannealed).

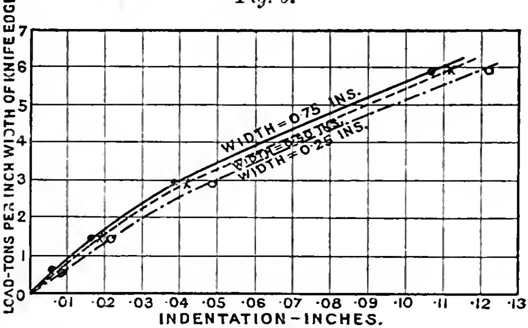
Width = 0·75 inch.			Width = 0·50 inch.			Width = 0·25 inch.		
Load on Knife-edge.	Load on Knife-edge per Inch width.	Mean Indentation.	Load on Knife-edge.	Load on Knife-edge per Inch width.	Mean Indentation.	Load on Knife-edge.	Load on Knife-edge per Inch width.	Mean Indentation.
Lbs.	Tons.	Inch.	Lbs.	Tons.	Inch.	Lbs.	Tons.	Inch.
0	0	..	0	0	..	0	0	..
1,000	0·595	0·006	666	0·595	0·008	333	0·595	0·008
2,500	1·488	0·017	1,666	1·488	0·019	833	1·488	0·021
5,000	2·976	0·039	3,333	2·976	0 042	1,666	2·976	0·049
7,500	4·464	0·071	5,000	4·464	0·073	2,500	4·464	0·082
10,000	5·952	0·108	6,666	5·952	0·112	3,333	5·952	0·121

The above specimens were cut from the same copper plate—an old tension specimen. *Fig. 6* gives the plotting of these results. The following are the values of C:—

	Width.	Hardness. Values of C.
Copper	0·75	86
„	0·50	82
„	0·25	75

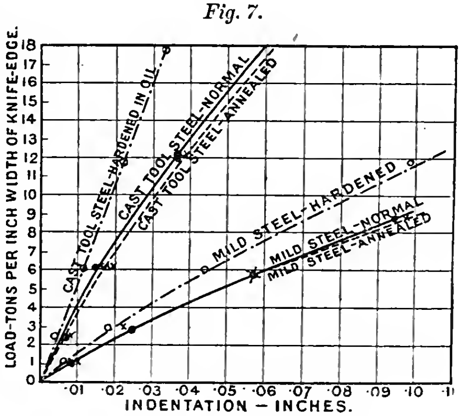
These values vary roughly as the cube root of the width of test-bar. Hence it is clear that to obtain strictly comparable results a uniform standard size of test-piece should be adopted.

Fig. 6.



Tests of Steel in different conditions.—By far the most useful application of a hardness test for the engineer would be to discriminate different qualities of steel and differences of treatment as to annealing and tempering. The following tests were made to determine how far the hardness test was sensitive enough to discriminate such differences. The word "normal" is used for the steel as received. *Fig. 7* gives the plotting of these results. The pieces of cast steel were all cut from one bar, and those of mild steel also were all cut from one bar.

Fig. 7.



CAST STEEL (HARDENED IN OIL). Width of specimen = 0·375 inch.

Load on Knife-edge.	Load on Knife edge in Tons per Inch width.	Mean Indentation.
Lbs.		Inch.
0	0	..
2,000	2·381	0·0047
5,000	5·952	0·0112
10,000	11·905	0·0222
15,000	17·857	0·0332

The specimen was heated to a dark red and plunged into oil. A piece of the same steel hardened in water was so hard that it blunted the knife-edge. Hence the results on this test-bar have been rejected.

CAST STEEL (NORMAL). Width of specimen = 0·37 inch.

Load on Knife-edge.	Load on Knife-edge in Tons per Inch width.	Mean Indentation.
Lbs.		Inch.
0	0	
2,000	2·413	0·0063
5,000	6·033	0·0150
10,000	12·066	0·0360
15,000	18·098	0·0603

CAST STEEL (ANNEALED).—THREE TEST-BARS. Width of each specimen = 0·37 inch.

Load on Knife-edge.	Load on Knife-edge in Tons per Inch width.	Mean Indentation.		
		A.	B.	C.
Lbs.		Inch.	Inch.	Inch.
0	0			
2,000	2·413	0·0053	0·0067	0·0060
5,000	6·033	0·0153	0·0177	0·0160
10,000	12·066	0·0373	0·0383	0·0375
15,000	18·098	0·0623	0·0640	0·0630

A was heated to a light red in a gas-furnace, and allowed to cool slowly.

B was heated in a fire to a dull red, and allowed to cool slowly.

C was heated to a dull red and allowed to cool in air till the colour just disappeared, when it was dipped into soap and water.

Load on Knife-edge in Lbs.	Load on Knife-edge in Tons per Inch width.	Indentations in Inches.			Mean Indentation.
		MILD STEEL (NORMAL). Width = 0·38 inch.			
0	0				
1,000	1·175	0·010	0·008	0·010	0·009
2,500	2·937	0·023	0·023	0·027	0·024
5,000	5·874	0·055	0·059	0·060	0·058
7,500	8·811	0·094	0·095	0·096	0·095
		MILD STEEL (HARDENED IN WATER). Width = 0·38 inch.			
0	0				
1,000	1·175	0·004	0·010	0·008	0·007
2,500	2·937	0·014	0·021	0·022	0·019
5,000	5·874	0·038	0·047	0·048	0·044
7,500	8·811	0·069	0·076	0·077	0·074
10,000	11·750	0·094	0·100	0·103	0·099
		MILD STEEL (ANNEALED). Width = 0·38 inch.			
0	0				
1,000	1·175	0·008	0·012	0·009	0·0097
2,500	2·937	0·022	0·026	0·022	0·0233
5,000	5·874	0·059	0·060	0·054	0·0580
7,500	8·811	0·095	0·099	0·096	0·0960

The following are the values of C from these tests :—

	Hardness. Values of C.
Mild steel, normal	143·5
,, annealed	141·9
,, hardened	186·7
Cast steel, normal	554·0
,, annealed, A	538·0
,, ,, B	503·0
,, ,, C	527·0
,, hardened in oil	866·0

The mild steel hardens very slightly, nor is it much softened by annealing, being clearly as received in a well-annealed condition. On the other hand, the cast steel softens more when annealed, and increases much more considerably in hardness when tempered in oil. The numbers appear to discriminate the qualities sufficiently well.

The Paper is accompanied by seven drawings, from which the *Figs.* in the text have been prepared.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

Since the Paper was written Mr. Bertram Blount has determined for the Author the hardness of some of the specimens by the scratch test, and the comparison of the two methods of determining hardness is interesting. In the scratch test a diamond point balanced at the end of a lever is dragged over a polished part of the specimen. The diamond point is loaded till it just definitely scratches the surface. The load necessary to produce a scratch is taken as the hardness number. The following Table contains the hardness numbers for the same specimens determined by the indentation method and by the scratch method. In order that they may be more easily compared, the relative hardnesses, copper being taken as unity, have been calculated.

Hardness of Metals by Indentation and Scratch Methods.

—	Hardness Number.		Relative Hardness. Copper = 1.	
	Indentation Method.	Scratch Method.	Indentation Method.	Scratch Method.
Cast steel (normal)	554·0	25·0	8·94	4·17
Brass, No. 1	221·0	12·0	3·57	2·00
Mild steel (normal)	143·5	9·0	2·32	1·50
Copper (annealed)	62·0	6·0	1·00	1·00
Aluminium (squirted)	41·8	4·0	0·67	0·66

It will be seen that the relative hardness follows the same order by whichever method it is determined. But the scale of hardness with the indentation method is an opener scale than that with the scratch method. Further, the indentation method is easier, more definite, and requires less skill. Of course for brittle substances the scratch method is more suitable.

APPENDIX II.

Further investigations of the hardness of steel rails have been made by the method described in the Paper. The apparatus has been slightly altered; the scale for reading the indentations has been engraved directly on the plunger above the knife-edge. The readings are then more accurate, and the correction for the compression of the apparatus is smaller. By using a hardening material termed "durol," a much harder knife-edge has been obtained, and one which retains a sharper edge. With rail steel and with loads not exceeding 10 tons per inch width of knife-edge, on specimens 0·5 inch wide, the lateral flow of the material is small, and the relation of pressure per inch of knife-edge in tons, and indentation in inches, is given by the simple relation $p=k\,i$. Pressures and indentations plotted give sensibly a straight line, and the work done in indenting $\frac{1}{2}\,p\,i$ is directly proportional to the volume of indentation, which varies as i^2. With greater loads per inch of knife-edge, the indentations are proportional to p^n, where n is greater than unity, as in the cases given in the Paper.

The following Table gives the hardness number (or value of k) for five rails, determined by the indentation method, and, for comparison, the elongation in 4 inches of tensile test-bars of the same rails:—

Rail Number.	Hardness Number, Indentation Test.	Ultimate Elongation of Tensile Test-Bar in 4 Inches.
		Per cent.
2	252·5	4·8
3	255·9	3·8
4	246·8	7·8
5	228·8	20·6
6	225·2	20·9
7	195·7	22·3
8	195·7	20·4
9	237·4	17·4

It will be seen that there is a general, though not exact correspondence, between the decrease of the hardness number and the increase of percentage of elongation in a tensile test.

(Paper No. 3037.)

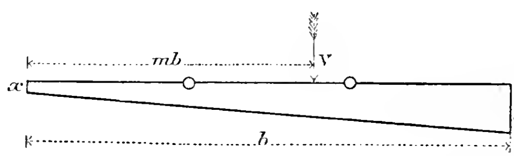
"Fissures in Masonry Dams."

By Ernest Prescot Hill, M. Inst. C.E.

The destructive effect, under certain circumstances, of a horizontal fissure occurring on the water-face of a masonry dam, as exemplified by the failure of the Bouzey dam, has been pointed out by Professor W. C. Unwin.[1] The object of the present communication is to examine the circumstances under which fissures may be formed, and to obtain expressions in general terms which show the effect of a fissure when once formed.

It is necessary, first, to distinguish between two classes of fissures. The first class comprises those due to bad workmanship

Fig. 1.



particularly when new and old work are not properly united, these terms being here used in a relative sense, and referring to the interval during suspension of work from whatever cause, either during the night, the week-end, or public holidays. The effect of the failure to unite the two surfaces (and without the greatest care this may easily occur) is to cause literally a horizontal fissure, into which the water of the reservoir will enter. In certain cases, which will be described, there is no tendency of the fissure to develop, and the effect is merely to tend to vary the stresses along the plane in question within narrow limits. In other cases such fissures may tend to develop. The second class includes fissures due to bad design; these tend to become progressive, as will be presently shown.

[1] Minutes of Proceedings Inst. C.E., vol. cxxvi. pp. 93, 94, and *Cassier's Magazine*, November, 1896.

In *Fig. 1* are shown the vertical components of the stresses for the case when the distance of the resultant of the vertical forces acting at any particular horizontal plane, measured from the inner face of the dam, is less than two-thirds of the breadth of the dam at that plane; V being the vertical component of the resultant for the unit length of dam; b the breadth of the dam at the plane considered; mb the distance of V from the inner face of the dam; x the stress-intensity at the inner face; and y the stress-intensity at the outer face. The ordinates when measured below the horizontal line are positive or compressive stresses; then the following conditions exist:—

$$\tfrac{1}{2} b^2 x + \tfrac{2}{3} b^2 \cdot \frac{y - x}{2} = mb\,\mathrm{V}$$

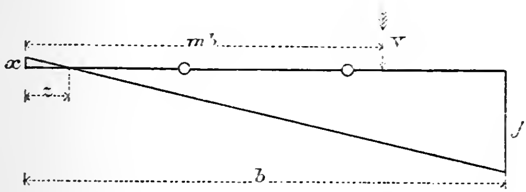
$$b \cdot \frac{x + y}{2} = \mathrm{V}$$

therefore

$$x = \frac{2\,\mathrm{V}}{b}(2 - 3\,m) \quad . \quad . \quad . \quad (1)$$

$$y = \frac{2\,\mathrm{V}}{b}(3\,m - 1) \quad . \quad . \quad . \quad (2)$$

Fig. 2.



When $m = \frac{2}{3}$, then $x = 0$, and $y = \dfrac{2\,\mathrm{V}}{b}$. When $m > \frac{2}{3}$ (a case of bad design), then x is negative, and is a tensile stress. The stress diagram for this case is shown in *Fig. 2*.

The relations here are:—

$$\frac{y}{2}(b - z)\left(\frac{2\,b + z}{3}\right) - \frac{x\,z^2}{6} = mb\,\mathrm{V}$$

$$\frac{y}{2}(b - z) - \frac{x\,z}{2} = \mathrm{V}$$

$$\frac{x}{z} = \frac{y}{b - z};$$

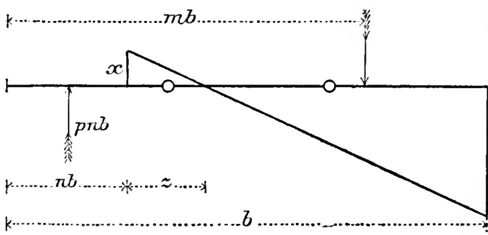
therefore
$$x = -\frac{2\,V}{b}\;(2 - 3\,m) \quad . \quad . \quad . \quad . \quad (3)$$

$$y = \frac{2\,V}{b}\;(3\,m - 1) \quad . \quad . \quad . \quad . \quad (4)$$

$$z = \frac{b}{3} \cdot \frac{3\,m - 2}{2\,m - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

With the exception of the sign of x, the values of x and y in (3) and (4) are identical with those in (1) and (2). It is clear that, in this case, if the value of the stress of which x is the vertical component is greater than the strength of the masonry, a fissure will be formed. If the masonry be well bonded vertically, as well as horizontally, and if the work be of first-rate quality, the strength is very considerable. If this is not the case, the strength

Fig. 3.



of the masonry is that of the mortar, and may be very small indeed.

If a fissure is formed in the manner indicated, another force enters into consideration, viz., the pressure of the water in the fissure. This case requires separate treatment, and the stress diagram is given in *Fig. 3*, where nb is the depth of the fissure, p the intensity of the water-pressure in the fissure, and pnb the resultant water-pressure.

The relations are:—

$$\frac{y}{2}(b - nb - z)\left(\frac{2\,b + nb + z}{3}\right) - \frac{x\,z}{2}\left(nb + \frac{z}{3}\right) + \frac{p\,n^2b^2}{2} = mb\,V$$

$$\frac{y}{2}(b - nb - z) - \frac{x\,z}{2} + p\,nb = V$$

$$\frac{x}{z} = \frac{y}{b - nb - z}$$

therefore $$x = \frac{2\,V}{b} \cdot \frac{3\,m - 2 - n}{(1 - n)^2} + p\,\frac{n\,(4 - n)}{(1 - n)^2} \quad . \quad . \quad (6)$$

$$y = \frac{2\,V}{b} \cdot \frac{3\,m - 1 - 2\,n}{(1 - n)^2} + p\,\frac{n\,(2 + n)}{(1 - n)^2} \quad . \quad . \quad (7)$$

If it were possible that no water should enter it, the fissure would not develop beyond the point at which x (or the stress of which x is the vertical component) is equal to the ultimate tensile strength of the mortar (if the mortar be in the line of least resistance); that value of x is $\frac{2\,V}{b} \cdot \frac{3\,m - 2 - n}{(1 - n)^2}$, so that, if the strength of the mortar is known, then what may be termed the initial and minimum depth of the fissure can be found. When the water enters the fissure so caused, the value of x is, if the profile only of the dam be considered, greater than the strength of the mortar, and consequently the depth of the fissure is increased.

In expression (6) let $p = r\,\frac{V}{b}$, and let $3\,m - 2 = a$, so that $a > 0$, and < 1. Then, by differentiation,

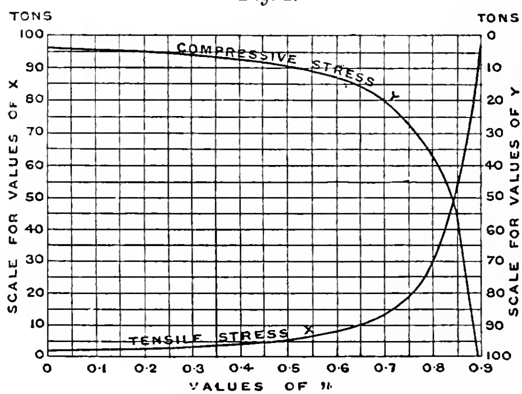
$$\frac{b}{V}\frac{d\,x}{d\,n} = \frac{2}{(1 - n)^3}\,\{2\,a + 2\,r - 1 - n\,(1 - r)\}.$$

Therefore x decreases at an increasing rate, when $2\,a + 2\,r < 1$; increases to a maximum and then declines when $2\,a + 2\,r = 1$; increases to a maximum and then declines when $2\,a + 2\,r > 1$; increases to a maximum and then declines when $2\,a + 3\,r = 2$; and increases at an increasing rate when $2\,a + 3\,r > 2$.

The lower limit of the maximum occurs when $n = 0$, and at the higher limit when $n = 1$, for which value the maximum point is at an infinite distance from the line along which n is measured. Between these limits the maximum point is reached when $n = \frac{2\,a + 2\,r - 1}{1 - r}$. In applying these expressions to practice, it must be remembered that the values of m and r must be such that the initial fissure can occur. The value of m which would allow such a fissure is, even in a very badly designed dam, due to the value of r; and if r is not sufficiently great to give a high value to m, no initial fissure can occur. This condition at once excludes those under which x can have a diminishing value, or a maximum value at or near the lower limit. When m and r have values possible in practice, the maximum point has advanced so far towards the higher limit of n, and is so far distant from the line along which n is measured, that the dam will have been destroyed long before such a point is reached, and therefore very long before that value of n is reached at which, theoretically, the value of x would sink below the tensile strength of the mortar. When the difference of n from unity is infinitely small, the values of x are, in all cases, infinitely great.

The values of x and y at the fissure in the Bouzey dam, are shown in *Fig. 4*, for every value of n up to 0·9, beyond which the values of x and y are too great to show. In this case $2a + 3r > 2$; in fact $2a + 3r = 2 \cdot 513$, so that the curve always rises at an increasing rate. These values hold only when the profile alone of the dam is considered, and the help given by the dam at each end

Fig. 4.



of the fissure neglected. The influence of the ends of the dam in modifying the stresses along the fissure in a transverse direction will be considered separately.

Before complete failure can occur, the overturning force must, as pointed out by Professor Unwin, be sufficient to shear through the dam in a vertical plane at each end of, and above the level of, the fissure. The supporting value of the ends is, however, very small compared with the work which would be thrown upon them by a slight variation in the strength of the mortar accumulating over a long fissure. For instance, the cross-sectional area of the Bouzey dam above the plane of fissure was about 520 square feet; if now the vertical shearing resistance is put as low as $\frac{1}{2}$ ton per square foot, each end would be credited with a power of resistance of 260 tons. The only way in which this resistance can be exerted is through the weight of the materials, added to the tensile strength of the mortar at the plane in question. But the Bouzey dam, above the level of the fissure, only weighed about 29 tons per lineal foot, and $\frac{1}{2}$ ton along the base would only be about 9 tons more per foot, so that the total vertical shearing resistance, which 1 foot in length, taken by itself, could exert, on the above assumption, is under 40 tons. The resistances, therefore, due to a length of nearly 7 feet, applied at the shearing line, would be required to balance a vertical shearing force of only $\frac{1}{2}$ ton per square foot. But those resistances are not available at that line. And, again, the horizontal shearing stresses, which could be exerted by the ends, would go a very small way in resisting the horizontal force of the water, accumulating over a long fissure; for the more the fissure progresses transversely, the more is the part of the dam above the fissure lifted from its seat and carried on a water-bearing, and at the same time, the more is the remaining sound portion at the plane of fissure reduced; so that the duty of resisting the horizontal force is more and more transferred from the base to the ends. It therefore appears that there is no proper shearing action, but rather a rending action, corresponding with a very low shearing stress, which would destroy in detail the dam at the line of fracture. No doubt the mortar in the Bouzey dam had some tensile strength, however low, and, if its value be assumed, it is possible to calculate the resistances required to be exerted by the ends. The moments, the sum of which must be zero, are those of the water in the fissure, the water in the reservoir, the weight of the dam, the shearing resistance of the ends, and the stresses in *Fig. 3*. The sum of the forces and stresses must also be zero. The stress of which x is the vertical component is now equal to the tensile strength of the mortar, so that the value of x is known. With these data, the value of the resistance of the ends, for any assumed value of n, can be found, but the calculation is somewhat long, and leads to no useful result, as in practice the resistance of the ends is, and ought to be, neglected. In any case, the Author believes that it is so small, where the fissure is long, compared with the other resistances and the forces, as not to be worth calculating.

The fissures to be next considered are those due to bad workmanship, occurring in dams of good design. It may be assumed that they are of limited extent, differing in this respect from those previously considered, which, being due to bad design, may extend for the whole length of the dam. The stresses in the case where the inner face of the dam is still in compression across the fissure are shown in *Fig. 5*.

The relations are—

$$\tfrac{1}{2} b^2 x + \tfrac{2}{3} b^2 \frac{y - x}{2} + \tfrac{1}{2} p n^2 b^2 = m b \mathrm{V}$$

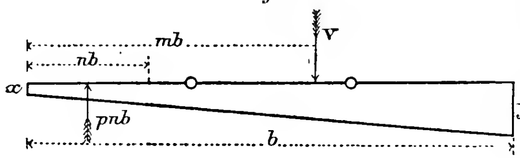
$$b \frac{x + y}{2} + p\, n b = \mathrm{V}$$

therefore $$x = \frac{2 \mathrm{V}}{b} (2 - 3 m) - p\, n\, (4 - 3 n) \quad . \quad . \quad . \quad (8)$$

$$y = \frac{2 \mathrm{V}}{b} (3 m - 1) + p\, n\, (2 - 3 n) \quad . \quad . \quad . \quad (9)$$

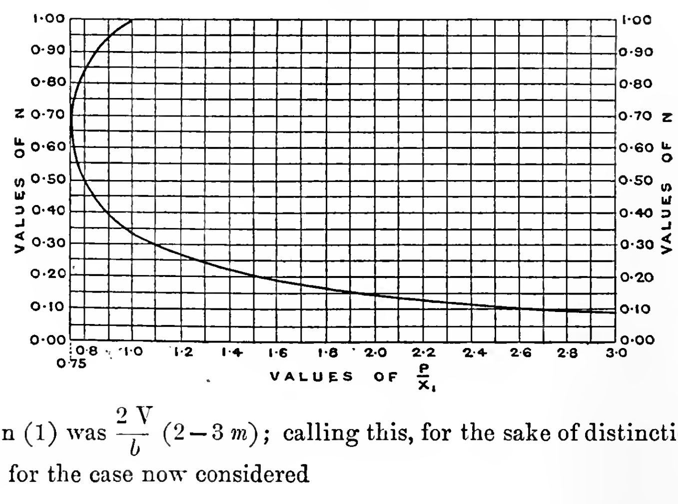
The value of the stress at any other point can be obtained directly from the *Fig.* when the values of x and y have been found.

Fig. 5.



The case when $x = 0$ may be specially noticed. In that case $p = \frac{2 \mathrm{V}}{b} \cdot \frac{2 - 3 m}{n\,(4 - 3 n)}$. Now when there was no fissure, the value of

Fig. 6.



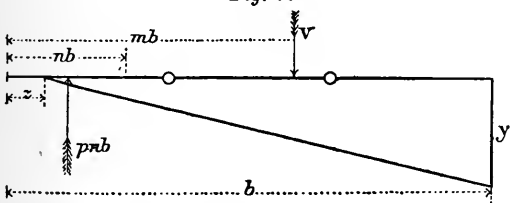
x in (1) was $\frac{2 \mathrm{V}}{b}\,(2 - 3\, m)$; calling this, for the sake of distinction, x_1, for the case now considered

$$\frac{p}{x_1} = \frac{1}{n\,(4 - 3 n)} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

If the value of $\frac{p}{x_1}$ is greater than this quantity the fissure tends to open. The minimum value of the right hand side of (10) is $\frac{3}{4}$, which occurs when $n = \frac{2}{3}$. If the value is less than $\frac{3}{4}$, the value of x will not be zero; conversely, if the value of n is greater or less than $\frac{2}{3}$, the value of the ratio must be greater than $\frac{3}{4}$ in order that x may be zero. Again in (9) an increase in the value of n causes an increase in the value of y until $n = \frac{2}{3}$; any further increase in the value of n causes the value of y to decrease. The relations between n and $\frac{p}{x_1}$ when $x = 0$, are shown in *Fig. 6*.

If the value of $\frac{p}{x_1}$ is greater than that in (10), x will have a negative value in (8), but, as no tensile stresses can exist along the fissure, that equation fails, and the case is that treated under *Fig. 7*, the influence of the ends of the dam being neglected.

Fig. 7.



In this case the positive reactions along a part of the fissure have disappeared in consequence of the water-pressure in the fissure. The relations are

$$\tfrac{1}{2} y (b - z) \left(\frac{2b + z}{3}\right) + \tfrac{1}{2} p n^2 b^2 = mb \text{V}$$

$$\tfrac{1}{2} y (b - z) + p nb = \text{V}$$

therefore

$$z = \frac{b}{2(\text{V} - p nb)} \{2 \text{V} (3m - 2) + p nb (4 - 3n)\} \quad . \quad (11)$$

$$y = \frac{1}{b} \cdot \frac{4(\text{V} - p nb)^2}{2 \text{V} (3m - 1) - p nb (2 - 3n)} \quad . \quad . \quad . \quad . \quad (12)$$

The stress at any point can be obtained directly from the diagram when the values of z and y have been found.

When $z = nb$, $$y = \frac{2 \text{V}}{b(1 - n)} - \frac{2pn}{1 - n} \quad . \quad . \quad . \quad (13)$$

When $p = \frac{2\,V}{b} \cdot \frac{2 - 3\,m + n}{n\,(4 - n)}$, the stress in the sound part of the dam, immediately adjoining and behind the fissure, is reduced to zero. Then, taking the ratio as in (10),

$$\frac{p}{x_1} = \frac{2 - 3\,m + n}{n\,(4 - n)\,(2 - 3\,m)} \quad . \quad . \quad . \quad . \quad (14)$$

If $\frac{p}{x_1}$ has a value greater than in (14), the stress at the point referred to becomes negative.

In all these cases the value to be given to the ratio $\frac{p}{x_1}$ is of considerable importance in the upper part of a dam, as, if the dam at the top be too thin, the value of $\frac{p}{x_1}$ may, at certain levels, be too great for safety; this may be inferred from *Fig. 6.*

In order to show the application of this investigation two numerical examples are given. Any support afforded by the ends of the dam is neglected. That support may have, and in the case of short fissures unquestionably has, some value; but that value, depending on the size of the fissure, is uncertain, and no reliance can be placed upon it in any calculations for determining the stability of a dam. It was suggested above that such support is limited by the rending action to which the ends are liable which would seriously reduce their power of resistance below what it would be in the case of a simple shearing action.

In the first example let a horizontal plane be considered 100 feet below the top of the dam, with a maximum depth of water of 96 feet. Assume $V = 217$ tons, $b = 70$ feet, and $m = 0 \cdot 593$. Then, by (1) and (2), $x = 1 \cdot 37$ ton, and $y = 4 \cdot 83$ tons. The value of p in (10) is $2 \cdot 67$ tons, and the ratio $\frac{p}{x_1} = 1 \cdot 95$. Now if a fissure be assumed, when in (10) $n = 0 \cdot 144$, then $x = 0$, and $y = 5 \cdot 44$ tons. There is as yet no tendency on the part of the fissure to open. But if the fissure were, say, 20 feet deep, instead of 10 feet, the depth given by the value of n last found, it is found from (8) and (9) that $x = -1 \cdot 02$ ton, and $y = 5 \cdot 70$ tons. But, as no tensile stresses can exist across the fissure, the value of y rises to that given by (12), viz., 6 tons, the value of z in (11) being $15 \cdot 38$ feet. From (14), when $n = 0 \cdot 393$, that is, when the fissure extends from the face of the dam for a distance of $27 \cdot 5$ feet, the stress in the sound portion, immediately adjoining and behind the fissure, is reduced to zero, and from (13) $y = 6 \cdot 76$ tons. For the purpose of this investigation, only the vertical component of the pressure is considered. For instance, the maximum unit stress, obtained by taking the resultant pressure acting on a plane at right angles to itself (a projection of a horizontal base) would, in the value of y last given, be 9·12 tons instead of 6·76 tons.

For the second example a plane may be considered 150 feet below the top of the dam, with a depth of water of 146 feet. Assume $V = 536$ tons, $b = 118$ feet, $m = 0 \cdot 53$. Then by (1) and (2) $x = 3 \cdot 72$ tons, and $y = 5 \cdot 36$ tons, the corresponding maximum stresses being 4·86 tons and 7·01 tons respectively. The value of p is 4·07, and that of $\frac{p}{x_1}$ in (10) is therefore 1·09. Assuming a fissure as before, then in (10) when $n = 0 \cdot 3$, that is, when the fissure extends from the inner face of the dam for a distance of 35·4 feet, then $x = 0$, and in (9) $y = 6 \cdot 7$ tons. If now a greater value be taken for n, say 0·4, representing a depth of fissure of 47·2 feet, then from (8) and (9), $x = -0 \cdot 8$ ton, and $y = 6 \cdot 66$ tons. But as no tensile stresses can exist across the fissure the value of y in (12) rises to 6·8 tons, the value of z being 16·87 feet. This value of y is equivalent to 8·89 tons maximum pressure. It is worth noticing that, with the value of m assumed in this example, there is no value of n which satisfies (14), so that the stress in the remaining sound part of the section, immediately adjoining and behind the fissure, is never reduced to zero, however long the fissure may be. The smallest value of m which would have allowed such an effect is 0·55, and the value of n would then have been 0·884, giving a depth of fissure of 104·3 feet.

The values obtained in the preceding examples are the result of considering special cases, and depend upon what may be called the characteristic values of V, b and m. Still, they are sufficient to show that with a well-designed profile it is possible to over-estimate the detrimental effect of a fissure if the subject be approached, as it usually is, from a statical point of view; and, from this point of view, honeycombing of the material, allowing percolation of water, would be less detrimental than a fissure of equal area; and this is perhaps more likely to occur as the result of bad workmanship than an absolute fissure, although it does not require very great carelessness in joining up work to create a fissure. These remarks apply only to those cases in which the fissure has not been originated by the water-pressure acting on a dam of faulty design; and it is also assumed that there is some margin in the profile, beyond the net area required, to allow for contingencies of every sort. This is only saying that the dam must have a good ordinary profile as now understood, in which the value of m does not too nearly approach two-thirds. Lastly, the thickness of the dam at the top must not be so small that the value of $\frac{p}{x_1}$ becomes at any level unduly large. In neither of the two numerical examples taken was any dangerous result arrived at, though the depth of the fissures assumed was considerable, and far exceeded anything likely to occur in practice.

The following Table shows all the characteristic quantities for the Periyar dam on the assumption that the weight of the masonry and concrete is equivalent to an average of 150 lbs. per cubic foot. The last two columns show the depth of fissure necessary to reduce x_1 to zero in equation (10), the values of n being taken from *Fig. 6.*

Level T.W.L. = 155 Feet.	V.	b.	m.	x_1.	p.	$\frac{p}{x_1}$	$x_1 = 0$ when	
							n.	nb.
Feet.	Tons.	Feet.	Tons per Sq Foot.	Tons per Sq. Foot.	Tons per Sq. Foot.	Tons per Sq. Foot.	Tons per Sq. Foot.	Feet.
145	10 38	12·00	0·544	0·637	0·279	0·438	..	..
135	19·09	14·00	0·588	0·644	0·557	0·865	0·424	5·936
125	29·80	18·00	0·618	0·483	0·836	1·731	0·168	3·024
115	43·86	24·00	0·619	0·523	1·114	2·130	0·129	3·096
105	62·27	30·60	0·625	0·509	1·393	2·737	0·099	3·029
95	85·12	37·20	0·634	0·448	1·672	3·732	0·070	2·604
85	112·57	43·87	0·641	0·395	1·950	4·937	0·053	2·325
75	144·78	50·64	0 645	0·372	2·229	5·992	0·043	2·188
65	182·25	58·53	0·638	0·536	2·507	4·677	0·056	3·278
55	226·58	69·57	0·606	1·186	2·786	2·349	0·117	8·140
45	279·06	80·80	0·584	1·713	3·065	1·789	0·159	12·847
35	340·08	92·26	0·568	2·182	3·343	1·532	0·191	17·622
25	410·07	106·99	0·539	2·936	3·622	1·234	0·250	26·747
15	496 09	117·49	0·544	3·108	3·900	1·255	0·244	28·668
5	578·29	128·00	0 536	3·542	4·179	1·180	0·265	33·920

From this point of view the level at which the minimum strength of the dam occurs is 75 feet above datum, or 80 feet below top-water level. Concentrating attention upon the conditions at this level, and referring to the remarks upon equation (6), it is found that the quantity $\overline{2a + 3r} = 2\cdot139, > 2$; consequently, the negative value of x (the stress at the inner extremity of the fissure) in (6) increases when the value of n is increased. Then in (6) $x = 0$ when $n = 0\cdot127$, the depth of the fissure being 6·43 feet; this result may also be obtained from (14). When the negative or tensile value of x in (6) is as great as, say, 1 ton per square foot, the value of n is 0·3326, and the depth of the fissure is 16·84 feet. If, however, the weight of the masonry and concrete were only 135 lbs. per cubic foot, the value of m at the level under consideration rises to 0·6811, and the inner face is therefore in tension, the value of x_1 being $-0 \cdot 223$ ton. If the top of the profile were cut down, in order to form an overflow weir, the result would be still less favourable. The value of $\overline{2a + 3r} = 3 \cdot 042, > 2$, and therefore, if there be a fissure, any increase in the depth of that fissure is accompanied by an increase in the tensile stress at its inner extremity. It is therefore clear that this profile, though proper for a dam in which, as at Periyar, the materials have a fairly high specific gravity, would not be satisfactory where that is not the case; and it is to be remembered that the weight of 135 lbs. per cubic foot is not a minimum weight, for that at Bouzey was only 125 lbs. per cubic foot. This instance is sufficient to show that careful consideration is necessary, before accepting any formula for determining the profile of a dam, in which the result is independent of the specific gravity of the materials. The quantity $\frac{p}{x_1}$, regarded as a sort of fourth dimension in the process of designing a dam, affords an exact measure of the margin of safety against imperfect workmanship provided in any particular case.

The foundations of a dam are (or ought to be) always carried some distance into solid rock; when that is the case, the rock sides against which the masonry is flushed, hold that masonry so that it may be considered a part of the rock rather than of the dam proper; and for this reason and for reasons already stated, it is, in the Author's opinion, unnecessary to consider the lifting action of any water which may be present in the rock beneath the foundations, for any circumstances likely to occur in practice, although, if these limitations be not taken into account, alarming conditions can no doubt be arrived at by calculation.

This is not the case, however, with vertical fissures, caused by the contraction of the material when the temperature is lower than that obtaining when the work was constructed. Pure theory and fact in this case go hand in hand; there are no natural limitations in practice, neither have any yet been devised. It has indeed been suggested that, if the dam be curved in plan, it is free to expand and contract without unduly stressing the masonry; if this is true in some cases, it is a fact that it is not so in others. If the data, such as the tensile strength, modulus of elasticity, and coefficient of expansion of the masonry be known, and theory predicts temperature cracks, those cracks will occur. Attention has, not infrequently, been directed to the possibility of such cracks occurring, but the Author believes that there is a general impression that this possibility is so remote that it need not be considered. When these cracks occur, they begin at the exposed face, and extend into the work, gradually disappearing at a distance from the face corresponding to the penetration of the low temperature. If the work be comparatively thin, and the temperature very low, the cracks may extend from one face to the other. Masonry dams, besides being more exposed to variation of temperature than ordinary retaining walls, have this further disadvantage, that their ends, by being carried into the rock, are fixed, and therefore the length of the surfaces exposed to variation of temperature is also fixed. It appears that in some cases nutation of the top of the dam has been observed, corresponding to some extent with the variation of temperature, and possibly to some extent relieving the temperature stresses. This can perhaps be understood if it takes place when the variation of temperature, whether above or below the normal, on both sides of the dam, is not the same. It is, however, difficult to see how nutation can take place, at any rate in a dam, of which the line is straight, when this is not the case. It does not, however, appear probable that, even if the dam be curved, the stresses can be relieved to any considerable degree, as the variation in temperature which produces cracks is a local variation; it is not uniform throughout the width of the dam, neither does it vary uniformly from one side to the other. Cracks of this nature cannot be avoided even in work of first-class quality; only in that case they may pass impartially through stone and mortar, instead of following the joints as when the mortar is weak. It is fortunate that they do not, by themselves, in any way reduce the stability of a dam, but, unless these facts are realized, their appearance is certain to cause disappointment.

The Paper is accompanied by two tracings, from which the *Figs.* in the text have been prepared.

OBITUARY.

GEORGE BUCHANAN, born on the 21st May, 1827, obtained his engineering training in the office of Messrs. Robinson & Sons, of Fenchurch Street, and subsequently at the works of Messrs. Duffus & Co., of Aberdeen. In 1845 he went to Bengal, where he was employed for three years in erecting machinery on sugar estates, and afterwards for twelve months in Calcutta, on engine work for the Ganges Steam Navigation Company. He was next for five years in Java, first as Engineer to the Netherlands India Steamship Company, and subsequently erecting machinery on sugar estates.

Mr. Buchanan began to practise on his own account in London in 1854, and from that time was engaged in the design and construction of machinery specially suited for colonial use. Between 1858 and 1860 he was employed on the construction of the railway from Durban to Port Natal, and from 1863 to 1867 he was responsible for the design and construction of steamers, dredgers, rice and sugar factories for the King of Siam, while several iron bridges, piers, and wharves were erected from his designs in Burma and in Siam. Mr. Buchanan made a special study of machinery for sugar factories, in which he effected great improvements, and he designed and superintended the erection of plant for the treatment of sugar in Spain, India, South America and the West Indies. At the Paris Exhibition of 1878 he obtained the first prize and only gold medal for sugar machinery in the British section.

Mr. Buchanan died at his residence, Towerfields, Keston, Kent, on the 7th June, 1897. Apart from his professional duties, he took a lively interest in charitable and philanthropic work, and he devoted much time and money to improving the neighbourhood of Keston, amongst other things, planting with trees a portion of the road between that place and Bromley. Mr. Buchanan was elected an Associate on the 5th May, 1857, and was transferred to the class of Members on the 31st March, 1885.

ROBERT CARR, born on the 29th November, 1827, at South Shields, served an apprenticeship of seven years (1841 to 1848) to Mr. T. D. Marshall, Mechanical Engineer of that town, after which he entered the employment of Messrs. Sir W. G. Armstrong & Co. of Newcastle-on-Tyne, and was identified with the earliest work and development of hydraulic power by that firm, for whom he had charge of the erection of hydraulic machinery for the London and North Western Railway Company at Haydon Square depôt, Minories; for the Great Northern Railway Company at King's Cross; and for the St. Katharine Dock, London. He also assisted in the management of the supply of steam and hydraulic power which the same firm had undertaken to provide for the Exhibition of 1851. In 1856 Mr. Carr was appointed Resident Engineer to the St. Katharine Dock Company, with the responsible superintendence of all works, buildings and machinery. In 1864, on the amalgamation of the St. Katharine Dock Company with the London Docks Company, the engineering of the latter was added to his duties, and many important works, such as new jetties, buildings and the remodelling of the swing-bridge, were carried out under his direction.

On the incorporation, in the following year, of the Victoria Dock with the London and St. Katharine Docks Company Mr. Carr became engineer of them all. Three years later a scheme was brought forward by the Company for an extensive enlargement of the Victoria Dock together with a new and deeper entrance into the Thames at Gallions Reach. With this scheme also Mr. Carr was closely identified, in the preparation both of the original plans and of the estimates, in conjunction with Sir Alexander Rendel, at that time Consulting Engineer to the Company. In 1875 the contract for the Victoria Dock Extension was let to Messrs. Lucas and Aird, under the superintendence of Sir Alexander Rendel, and on its completion in 1880 the care of this extension, now renamed the Royal Albert Dock, devolved on Mr. Carr, who had closely watched its construction and had rendered considerable assistance to the London and St. Katharine Docks Company, in view of the future development of the dock.

In 1880 one of the earliest installations of refrigerating machinery, at Jetty A, Victoria Dock, was put down, and, proving successful, the demand for cold storage of meat from abroad increased so rapidly that Mr. Carr was called upon to enlarge the accommodation, and by the year 1892 the storage capacity had risen to 564,000 cubic feet, capable of holding

161,000 carcases.[1] In 1883 new tobacco warehouses (T, V, W, & X) and extensive granaries at the Victoria Dock were erected, and in the following year the powerful pumping-plant at Gallions, capable of throwing 125,000 gallons per minute, was completed; by means of which the water in the Royal Albert Dock is maintained at Trinity high-water, or above it when required.

In 1884, in consequence of the large increase in trade and the greater size of vessels coming into the Royal Albert Dock, it was decided to construct an additional entrance-lock 550 feet in length, 80 feet in width, with a depth of 36 feet, and at the same time to enlarge the basin from 12 to 15¼ acres and to construct a river wharf near the entrance 1,120 feet long, with a depth of 46 feet alongside. Plans for these extensions were prepared by Mr. Carr, who carried out and completed them in 1886, assisted by Mr. J. Thomas, as resident engineer, and by the staff of the Dock Company without the intervention of a contractor. One very interesting feature in connection with these works was the removal of a concrete wall, 520 feet long, to effect the junction of the new part of the basin with the old. This wall was reduced in thickness to about 6 feet, drilled with some 1,430 holes, which were filled in with gelatine dynamite—of which 2,900 lbs. were used—and early on the morning of Good Friday, the 23rd April, 1886, the whole of these charges were fired simultaneously and the wall successfully demolished.[2]

In 1888, on the formation of the London and India Docks Joint Committee, Mr. Carr was appointed their first Chief Engineer, and early in 1892 he was called upon to prepare plans for a new entrance and enlargement of the basin at the West India Docks, Blackwall. These were at once adopted, and in the autumn of the same year Messrs. Lucas and Aird commenced to carry out the work. In October Mr. Carr went to Liverpool to inspect some new pumping machinery and on the return journey was seized with a slight paralytic stroke, doubtless the result of overwork and severe mental strain. With rest and care he was fortunate enough to throw off the effects of this illness and shortly afterwards was able to go about as usual, but the Joint Committee at this juncture suggested his retirement from active duty, and at the same time the Chairman was directed to inform him how highly they appreciated his services and that they felt it impossible to allow him to be subjected to further strain. They

[1] *Ante*, p. 1.

[2] Minutes of Proceedings Inst. C.E., vol. lxxxvi. p. 329.

therefore offered him the appointment of Consulting Engineer, especially with regard to the completion of the Blackwall entrance, the design of which he had been entirely responsible for up to that time. This work, with its lock, 480 feet long, 60 feet wide and 30 feet deep, was finished in September, 1894, and shortly afterwards Mr. Carr retired on a well-earned pension. At a meeting of the London and St. Katharine Docks Company in 1892, the Chairman, Mr. W. E. Hubbard, in mentioning the matter to the shareholders, had said:—

"Before closing my address, I must allude to one change among our principal officers. Our Engineer, Mr. Robert Carr, who has served you most faithfully and efficiently for thirty-six years, is about to retire shortly, having all but attained the age at which he is entitled to a pension and being in somewhat impaired health. He has spent himself freely in your service, and by shrewd common sense and by most conscientious economy must have saved your pockets many thousand pounds. We all, I am sure, wish that he may long be spared to enjoy the leisure he so well deserves."

Mr. Carr's illness in 1892 caused him considerable debility, and although he enjoyed moderate health for three years, symptoms of gradual decay developed themselves. In December, 1896, serious illness with great weakness supervened, and although he rallied sufficiently to be able to remove to Bournemouth, no permanent improvement took place, and, taking cold through the inclement weather of the following spring, he died there on the 6th April, 1897.

Mr. Carr was elected a Member on the 2nd March, 1875, and was a frequent attendant at the meetings. He was also a Member of the Institution of Mechanical Engineers. He took a keen interest in the volunteer movement, and was one of the first to be enrolled, retiring in 1885 from the 15th Middlesex (Customs and Docks) Corps, with the honorary rank of Major after twenty-five years' service. He also took a considerable amount of interest in civic, local and political matters. He was a Liveryman of the Shipwrights Company, a Member of the Limehouse District Board of Works, a ruling Councillor of the Primrose League, and Churchwarden of St. John, Wapping, from 1882 to the date of his death. Mr. Carr's indomitable perseverance and industry were a noble example to the large number of men whose work it was his office to direct and control. He was necessarily possessed of considerable influence and power, which were often exerted on behalf of those who sought his good offices, and there are many who owe their present positions to his friendly intervention. He was true, just and loyal. He delighted in his work and entertained a great regard for those who served under him, by whom he was in turn respected and esteemed. His widow and children mourn a devoted husband and father, while many have suffered the loss of a staunch and constant friend.

JAMES CRAIG, born in Aberdeen on the 24th July, 1844, became a pupil, at the age of seventeen, to Mr. William Boulton, of Montrose, under whom he was employed on survey and drainage work. He was afterwards engaged, during the year 1865, as Assistant Borough Engineer to the corporation of Dundee on the extensive sewerage works then in progress in that town.

In 1866 Mr. Craig obtained by competitive examination the post of an Assistant Engineer in the Public Works Department of the Government of India. He was posted to the Province of Hyderabad and served as Assistant Engineer in the Secunderabad Division for six years. During that time he was employed chiefly on the construction of new barracks for British troops, and in 1871 he received the commendation of the Government for the zeal and energy displayed by him in cleansing and purifying the Hussar barracks at Secunderabad after an outbreak of cholera. Another important scheme—the water-supply of South Trimulgherry—was also projected and carried to successful completion by him. In 1872 he was selected to assist Major Swetenham, R.E., in the construction of a complete set of new barracks for a British cavalry regiment in North Trimulgherry. The whole of the estimates and details were framed and elaborated by him, and for five years the construction of two-thirds of the project was carried on under him, for some time as Assistant Engineer, and at others as Executive Engineer, the quality of the work being acknowledged to be unsurpassed in India. The general scheme for the water-supply of North Trimulgherry was also prepared by him, and was afterwards supervised and carried out by another officer, with but slight modification from the original design.

Early in 1878 Mr. Craig was posted to the executive charge of the West Berar Division, where he was employed on the construction of roads, buildings and impounding reservoirs, in addition to the ordinary maintenance works of a District Division. Among other works upon which he was engaged may be mentioned the construction of 150 miles of new roads, and of two reservoirs of considerable magnitude at Sheogaon and Akutwarra, in the Akola District; the water-supply of the town of Khamgaon; and the Akola-Hingoli railway survey. During 1893 and 1894 he was employed in Burma on the construction of important waterworks at Moulmein.

Mr. Craig retired from the service of the Indian Public Works Department in 1895. After residing for a few months in Aberdeen, he settled at Newport, a suburb of Dundee, where he died on the 3rd May, 1897. Mr. Craig was a man of kind and genial disposition, and was specially attentive to young men about to go out to India, readily placing his experience and hospitality at their service. He was elected a Member on the 3rd April, 1883, and two years later contributed a Paper on "Flood-Discharge from Catchment-Areas,"[1] for which he was awarded a Telford Premium.

LAVINGTON EVANS FLETCHER was born on the 9th June, 1822. In 1839 he was articled to the firm of Messrs. Barrett, Exall and Andrews, of the Katesgrove Ironworks, Reading, with whom he remained nearly two years after his pupilage was completed. During that period he had charge of the erection of the first engine, boiler and biscuit machinery used at Messrs. Huntley and Palmer's manufactory, and of a steam-engine, boilers and pumps, to drain one of the shafts, 200 feet deep, of the Box Tunnel on the Great Western Railway. He also took up the subject of improvements in steam-engines and boilers, to secure economy of fuel, and repaired and adjusted engines for several paper-makers. While still at Reading Mr. Fletcher designed and made a steam-carriage,[2] the running of which had to be discontinued, owing to defects in the boiler. After this he went to Nassau for a time, and on his return to England was employed during 1845 on surveys for several railway schemes.

During the five years, 1846–50 inclusive, Mr. Fletcher was engaged under Mr. I. K. Brunel[3] as an Assistant Engineer on the South Wales Railway, being stationed at Swansea. He designed several bridges and tunnel fronts, as well as the mechanical arrangements of the Carmarthen Iron Swing Bridge and of the Lloughor

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[1] Minutes of Proceedings Inst. C.E., vol. lxxx. p. 201.

[2] *Engineering*, vol. lxiv. p. 21, and *The Times*, 18 April, 1843.

[3] Minutes of Proceedings Inst. C.E., vol. xix. p. 169.

Swing Bridge. He also designed and superintended the erection of the Landore Viaduct, for an account of which, contributed to the Institution in 1855,[1] he was awarded a premium of books by the Council. This viaduct was a compound structure of wood and iron trussing, and was then one of the largest in the kingdom, being $\frac{1}{3}$ mile in length. It was the last of the old wooden viaducts to be replaced by an iron structure.

On the completion of the South Wales Railway, Mr. Fletcher practised as a Consulting Engineer, turning his attention chiefly to the construction of marine engines and boilers. He went very fully into the subject of economy of fuel, and experimented in ice-making machinery. In the year 1851 Mr. John Frederick Spencer, manager of a Clyde shipyard, who was a fellow-pupil at Reading and the steersman of the steam carriage already referred to on its run to London, joined Mr. Fletcher in partnership. They practised as Consulting Engineers at 22 Cannon Street, and designed and superintended the erection of iron screw steamers and prepared plans for the engines and boilers. The "Arthur Gordon" and other vessels were built for Mr. H. W. Schneider,[2] the proprietor of iron mines at Ulverston and Barrow. They also altered the engines and fitted new boilers to steamers for Mr. Schneider and others, among which was the "Augusta" belonging to the English and Australian Copper Company, of Llanelly, the result being a considerable saving of fuel. In the latter part of 1855 the partnership was dissolved and Mr. Fletcher was employed by Messrs. Gwynne & Co., then of Essex Street, Strand, where he had charge of the Drawing Office. After that he was engaged by the Electric and International Telegraph Company, under Mr. Latimer Clark, in designing and erecting a pumping-engine for exhausting the air from the pneumatic despatch tubes laid under the streets.

In 1861 Mr. Fletcher was appointed Chief Engineer—or, as it was then called, Chief Inspector—to the Association for the Prevention of Steam-Boiler Explosions and for effecting economy in the raising and use of steam, now known as the Manchester Steam Users' Association. In 1867 he conducted experiments to ascertain the result of injecting cold water into circulating household boilers when red hot, and found that under certain conditions[3] no explosion resulted; and in the following year, in collaboration with the late Dr. Richardson of Newcastle, he

[1] Minutes of Proceedings Inst. C.E., vol. xiv. p. 492.

[2] *Ibid*, vol. xcii. p. 406.

[3] Reports of the Manchester Steam Users' Association, February, 1867, and December, 1878.

conducted a series of trials of the evaporative efficiency of South Lancashire and Cheshire coals, the object being to show the suitability of those coals for use in H.M. Navy. The trials were carried out at the expense of the South Lancashire and Cheshire Coal Association. A copy of the report, called the Wigan Coal Trials, was presented to the Institution.[1]

In 1874–5–6 a Lancashire boiler, designed by the Manchester Steam Users' Association and made by Mr. Thomas Beeley of Hyde Junction, was submitted to a series of hydraulic bursting tests, with a view to ascertain the strength of various riveted joints and the value of different methods of strengthening the plate round manholes, as well as the value of cast-iron fitting branches. Tests were made with single machine-riveted seams, double machine-riveted seams, and double hand-riveted seams. The boiler was also tested with an unguarded manhole, with a manhole supported by a cast-iron ring and with a wrought-iron ring. It was also tested with cast-iron branches for the fittings. Subsequently some tests of riveted joints were made to compare the results obtained in the testing-machine with those obtained from the hydraulic bursting tests. Simple strips of double and single riveted joints, made from plates cut from the boiler, were pulled asunder in the testing-machine, and plain strips cut from the boiler were also tested to show the strength of the plates so as to compare the strength of the riveting with that of the plates. The results of these tests were embodied in a Paper on the Lancashire boiler read before the Institution of Mechanical Engineers.[2]

In 1876 Mr. Fletcher assisted the Hampshire Coroner at Portsmouth as scientific assessor, in investigating the explosion which occurred on board H.M.S "Thunderer" on the 14th July of that year, by which thirty-three persons were injured and forty-five killed.[3] In 1881 a Bill was successfully introduced into Parliament by the late Mr. Hugh Mason, then Member for Ashton-under-Lyne, and at that time President of the Association, enacting that the Board of Trade shall hold an inquiry into every boiler explosion on land, those of boilers in mines excepted, and publish a report thereon. The Commissioners have power to make any one concerned to whom they consider blame attaches pay all or part of the expense of the inquiry. In 1882 Mr. Fletcher returned to the

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[1] This report is in the Library of the Institution.

[2] Institution of Mechanical Engineers Proceedings, 1876, p. 59.

[3] See Monthly Reports of the Manchester Steam Users' Association, July–October, 1876.

subject of turning cold water into red-hot boilers, and a series of experiments was carried out by the Manchester Steam Users' Association of a far more elaborate nature than the early ones in 1867. These "Red-hot Furnace Crown Experiments" with a Lancashire boiler were carried out at Preston, with the result that no explosion occurred. A report thereon, published in 1890, is in the Library of the Institution.

Mr. Fletcher was taken ill on Christmas Day, 1896, but was so far better that he was able to come up to London in January and spend some hours in the Lobby of the House of Commons in connection with the Association's Boiler Inspection Bill introduced by Sir William Houldsworth. He became ill again that same evening, but in a fortnight was well enough to go to Hastings, where he remained till Easter, after which he was able to return to business. His health, however, soon broke down again, and after several fluctuations he died on the 14th June, 1897, at his residence, Fairfield, Alderley Edge, Cheshire.

Mr. Fletcher was regarded as an authority on all matters connected with steam-boilers and machinery, and the influence he was able to bring to bear on legislation relating to the subject was very great. The Association of Manchester Steam Users was formed to bring about the periodical inspection of boilers, and Mr. Fletcher spared no effort to inculcate and enforce that principle. The reports[1] published by the Association, for which he was responsible, have been the means of disseminating much valuable information as to the causes of boiler explosions. Mr. Fletcher was elected an Associate on the 4th March, 1851, and was transferred to the class of Members on the 27th April, 1880.

JOHN FRANCIS HALL, son of Mr. John Hall, of Norbury, Sheffield, was born on the 18th February, 1854. After being educated in Sheffield, and at Neuwied, in Germany, he entered the works of Messrs. William Jessop & Sons, of Brightside, Sheffield, as a pupil in 1870. He remained with that firm for twenty years, during the last twelve of which he was responsible for the general management of the works. After mastering the details of the various branches of crucible steel-making, Mr. Hall turned his attention to steel castings as a substitute for iron in work connected with naval architecture. Propeller-blades, stern-posts,

[1] These reports are in the Library of the Institution.

rudders, cranks, anchors and shells were cast in steel under his supervision with great success, and he produced an anchor which has been adopted by the British Government, by several foreign powers and by some of the largest ship-building firms.

Mr. Hall subsequently turned his attention to the development of nickel steel and visited America in 1890 with the object of opening a connection with the nickel mines of Canada, to supply the raw material, and of negotiating for patent rights in the United States. In addition to the anchor already referred to, he effected improvements in the manufacture of armour-plates, in steam-engine cranks, adjustable couplings for marine shafts, and in the treatment of steel generally.

Mr. Hall died at Norbury on the 27th May, 1897. He was an ardent sportsman, both with rod and gun, and in his youth was well known as an athlete. To the Institution of Naval Architects, of which he was a member, he contributed Papers on "Cast Steel as a Material for Crank-Shafts,"[1] and "Flexible Crank- and Propeller-Shafting in lieu of Rigid Shafting for Marine Propulsion."[2] He was elected a Member of this Institution on the 1st December, 1885.

WILLIAM HUNT was born at Banbury on the 8th January, 1843, and was educated at the Bedford Commercial (now called the Modern) School, where he gained an Exhibition prize of £200. In November, 1858, he was articled to Mr. Henry Daniel Martin, who was at that time, besides having a large practice, Engineer of the East and West India Docks, of the North London Railway and of the then East India Company. Mr. Hunt was engaged for about three years at the East and West India Docks, and then entered the locomotive works of the North London Railway at Bow, where he worked first in the shops, and afterwards in the drawing-office. From 1862 to 1865 he was engaged on the construction of railways in the Isle of Wight.

Mr. Hunt next became chief assistant to the late Mr. John Smith Burke in Westminster, an engineer who had considerable practice. For three years he was engaged under Mr. Burke in laying out new lines of railway, preparing the parliamentary plans and estimates for the same, and performing the necessary

[1] Transactions Institution of Naval Architects, vol. xxv. p. 173.

[2] *Ibid*, vol. xxvii. p. 338.

engineering work in carrying the bills through Parliament. He was then appointed Assistant Resident Engineer, under Mr. Benjamin Burleigh,[1] for the construction of works on the East London Railway on the south side of the Thames, and was afterwards engaged by Sir John Hawkshaw,[2] Past-President, as Resident Engineer in responsible charge of the whole of the works on that railway on the north side of the Thames, including the construction of the line under the eastern basin of the London Docks, under the warehouses on the north side of those docks, and under the London and Blackwall Railway. In carrying out this work, neither the warehouses on the north side of the dock nor the viaduct of the London and Blackwall Railway was interfered with.

In June, 1876, Mr. Hunt was appointed Chief Assistant Engineer to the Lancashire and Yorkshire Railway Company. During the six years he held that post many important works were carried out, or concluded, under his supervision, among which the following may be mentioned:—The Brighouse Branch, the Hollinwood Branch, the Shepley to Clayton West Branch, the Shawforth Branch Extension, the Sowerby Bridge to Rishworth Branch, the Bacup Branch Widening, the Cheetham Hill to Radcliffe Branch, a heavy retaining wall at Todmorden to stop the movement of a hillside, the carriage works at Newton Heath now being enlarged, and a new tunnel at Farnworth. The retaining wall at Todmorden was a work of great difficulty, owing to the presence, in addition to the railway, of a canal, highway and river, all situated in the lower part of a contracted valley, the traffic on the railway and the canal having to be kept free from obstruction and interruption during the construction of the wall.

On the retirement of Mr. Meek in 1882, Mr. Hunt was appointed Chief Engineer to the Company. Among the works he carried out in that capacity are the following:—The large grain elevator at Fleetwood, the first in England built on the American system; the reconstruction of goods yards and the extension of passenger and goods stations at Bradford; the widening between Heaton Lodge Junction, Mirfield, and the London and North Western station at Ravensthorpe; extensions and great alterations at Victoria Station, Manchester; a loop-line at Liverpool; the Liverpool and Waterloo widening, including the Bankfield Branch and goods yard; the reconstruction of the Exchange Station, Liver-

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[1] Minutes of Proceedings Inst. C.E., vol. xlvii. p. 301.

[2] *Ibid*, vol. cvi. p. 321.

pool; the locomotive works at Horwich; the Hindley and Pendleton Railway, with the extension to Pemberton and the Westhoughton connecting lines; gravitation sorting sidings at Aintree, having an aggregate length of 22 miles; heavy works on the Manchester, Bolton and Bury Canal, owing to subsidences due to colliery workings; the widening of the Preston and Wyre line between Preston and Kirkham, including diversion of the railway at Poulton; the widening of the line between Manchester and Miles Platting; the Farington connecting line; the Oldham Road goods line viaduct widening between Livesey Street and Collyhurst Street (between Manchester and Miles Platting), and a high-level line between the former street and Miles Platting Station crossing over the Hunts Bank Incline; the widening of the line between Manchester and Windsor Bridge, Salford, including a branch to the Manchester Ship Canal and a diversion of the Company's old canal; and also many station extensions and enlargements, warehouses, goods yards, engine and carriage sheds, and bridge renewals.

Mr. Hunt died at his residence, High Lea, Crumpsall, Manchester, on the 29th March, 1897. He was elected an Associate on the 3rd March, 1868, and was transferred to the class of Members on the 25th January, 1876. He took considerable interest in the local Association of Students at Manchester, of which he was President in 1894. He also interested himself in the Permanent-Way Institution, acting as President of that body in the same year. In social life Mr. Hunt was courteous, kind hearted and hospitable, popular with his staff and liked by all who had the privilege of knowing him.

FRANCIS JONES was born on the 27th July, 1815. After being engaged for eight years on the Ordnance Survey of Ireland, he began to practise on his own account in 1844. For the next ten years he was occupied in Ireland in connection with main drainage works, road making, bridge building and railway construction.

In 1855 Mr. Jones proceeded to India, having obtained an appointment in the Public Works Department of the Bombay Presidency. He was engaged principally on canal and irrigation works, amongst which may be mentioned the survey and plans for the Karachi Canal and for the improvement of the Bigarree Canal in Upper Sind, the construction of the Sukkur Canal and of embankments and groynes on the Indus; several canals in Sind;

and the management and maintenance of the canals in the Karachi Division. In August, 1864, he was promoted to the rank of Executive Engineer, first grade, and was subsequently placed in charge of the Irrigation Department in Guzerat.

Mr. Jones was compelled by ill-health to retire from the service of the Bombay Public Works Department in 1872. He died at his residence, Beau Séjour, Jersey, on the 19th February, 1897. Mr. Jones was elected a Member on the 10th January, 1871.

ALAN MACDOUGALL, third son of the late Lieutenant-Colonel John Macdougall, was born in India on the 22nd May, 1842. After being educated at a private school, and at the Edinburgh Academy, he was articled in 1859 to Mr. Charles Jopp, who was at that time carrying out various works for the North British Railway Company. On the expiration of his pupilage in 1863, he was engaged on the Galashiels and Peebles branch of the North British Railway, and subsequently acted as Resident Engineer on the construction of the Dalkeith branch of that system.

On the completion of that undertaking in 1869, Mr. Macdougall went to Canada. His first work in the Dominion was the preliminary survey of the Toronto, Grey, and Bruce Railway, on the construction of which he was afterwards engaged as Resident Engineer. From 1871 to 1873 he was in charge of the North Grey extension of the Northern Railway of Canada, and in the latter year he entered the service of the Department of Public Works. In that service he was employed on harbour and river improvements on the western lakes and on the St. Lawrence until 1877, when he returned to Scotland and was engaged for a time on the North British Railway.

Settling again in Canada in 1883, Mr. Macdougall began to practise as a Consulting Engineer in Toronto, where he was largely employed in designing sewerage and waterworks for a number of towns all over the Dominion. He was engaged by the City of Toronto to report on the sanitary condition of Ashbridge Bay, and prepared plans for sewerage systems at St. Catharine's, Stratford, Peterboro', Belleville, Vancouver (B.C.), Brandon (Man.), and other places. The valuable assistance rendered during an outbreak of diphtheria at St. John's, Newfoundland, was such that he was solicited by the authorities of that city to accept the position of City Engineer, which, however, he declined. To the Institution, of which he was elected a Member on the 4th December, 1877, Mr.

Macdougall presented in 1883, in conjunction with the late Mr. J. C. James, a Paper on "The Western Division of the Canadian Pacific Railway,"[1] on which he was engaged as a Divisional Engineer, and subsequently, in 1896, a description of repairs to a submerged main at the Toronto Waterworks.[2]

Mr. Macdougall was a Fellow of the Royal Society of Edinburgh and of the Royal Scottish Society of Arts, and in 1880 received the last named Society's silver medal for his Paper on "Canadian Light Railways."[3] He was prominently connected with the Canadian Society of Civil Engineers, the organization of which was effected largely through his persistent efforts in 1887. For many years he served as a Member of the Council, and in 1894 was elected Vice-President. From the time of the organization of the association until his death he laboured faithfully to obtain such legislation as would make the Society a close corporation, not with the object of personal advantage, but in the hope that by this means the professional status of engineering would be elevated. He was without doubt the most enthusiastic and earnest advocate of professional ethics in the Society, and a perusal of the transactions of that body will show the time and attention which he devoted to the cause. An interesting Paper on the subject, entitled "The Professional Status, a Plea for a Close Corporation,"[4] was read at the annual meeting in 1892, and elicited much discussion. Mr. Macdougall died at Exmouth, South Devon, on the 23rd April, 1897.

PHILIP JOHN MESSENT, born at Dover on the 7th December, 1830, obtained his engineering training partly from Mr. Joseph Gibbs[5] and partly in the office of Messrs. Walker,[6] Burges and Cooper.[7] While with that firm he was engaged in making the preliminary survey and the contract drawings for the Tyne Piers, and in April, 1855, he assumed charge of the work as the representative of Messrs. Walker, Burges and Cooper. The North Pier was commenced in October of the same year and was carried out

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[1] Minutes of Proceedings Inst. C.E., vol. lxxvi. p. 266.
[2] *Ibid*, vol. cxxv. p. 317.
[3] Transactions Royal Scottish Society of Arts, vol. x. p. 451.
[4] Transactions Canadian Society of Civil Engineers, vol. vii. p. 242.
[5] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 528.
[6] *Ibid*, vol. xxii. p. 630. [7] *Ibid*, vol. xxii. p. 624.

by Mr. Lawton under a contract which expired in 1864. After that date the work was done by the Tyne Improvement Commissioners under the charge of Mr. Messent. The South Pier was commenced under the same conditions as the North Pier, the work beginning in the year 1856, and the contract was carried out by Mr. Lawton until 1864, since when the entire work has been carried on by the Commissioners under Mr. Messent's direction, without a contractor. On the retirement of Mr. J. F. Ure,[1] in 1873, Mr. Messent was appointed engineer to the Tyne Improvement Commissioners, and has since had entire charge of their large and important works.

Mr. Messent's name will remain associated with the improvement of the River Tyne. In a report,[2] dated December, 1888, on the works carried out up to that time, he gave a description of the former state of the river, from which it may be of interest to quote the following extract:—

"Previous to the year 1860, except in the construction of the Piers and the Northumberland Dock, the works of improvement had been confined chiefly to groynes and training walls advanced into the river (behind which land was reclaimed), and a comparatively small amount of dredging. The state of the river for navigation may be briefly described as follows, beginning at the mouth or entrance:—Here there was a bar, having a depth of water of about 6 feet at low-water spring-tides, which gave a depth of about 21 feet at high-water spring-tides, and about 17 feet at high-water neap-tides. The bar or diminished depth of water extended 800 feet from west to east, and the width of channel over it was about 600 feet. No vessel drawing much more than 20 feet of water could therefore enter or leave the Tyne even at high-water spring-tides, and whenever an east wind occurred the available depth was diminished according to the height of the sea waves. Vessels drawing between 17 feet and 18 feet of water have been detained two or three months after they were loaded on account of a succession of east winds occurring on the days of the high spring-tides. About 1,100 yards above the outer bar was an inner bar, called the 9-feet bar, and stones. About 400 yards above the 9-feet bar the channel was abruptly reduced in width to 400 feet opposite the Low Lighthouse, the contracted channel being called the Narrows. Shields Harbour, about a mile and a half in length, which commences above the Narrows and extends to the high end of South Shields, opposite Whitehill Point, consisted of a comparatively narrow, tortuous, deep-water channel, with large shoals on either side dry at low water, some of which, the In-sand and Middle Ground on the south, and the Dortwick Sands on the north side of the harbour, extended from the shores to and beyond the middle of the river. It required very careful navigation to take a laden vessel out of Shields Harbour at high water (the only time possible) and keep clear of the shoals. The river, from Shields Harbour to Newcastle, was then a series of shoals, with a narrow and generally serpentine channel between and past them,

[1] Minutes of Proceedings Inst. C.E., vol. lxxiii. p. 370.
[2] This Report is in the Library of the Institution.

through which vessels of about 15 feet draught could get up at high-water spring-tides, whilst at low water it was not an uncommon occurrence for small river steamers, drawing from 3 feet to 4 feet of water, to be aground in their passage between Shields and Newcastle for two or three hours for want of depth of water. Above bridge, from Newcastle to Newburn, the river was navigable for keels and small craft alone, and for these only at the time of high water."

All this is now changed. Great docks have been constructed; the river has been straightened; it has been deepened as far upwards as Elswick works for the passage of the largest iron-clads; the Tyne Piers have been finished, and there is a deep-water channel at all states of the tide. The length of the super-structure of the North Pier is 3,059 feet, and that of the South Pier 5,317 feet. The width of the entrance between the pier-heads is 1,300 feet, and the depth of water in the channel is about 50 feet at high-water spring-tides. As originally proposed, the piers were to terminate in 15 feet of water, and, compared with the length subsequently decided upon, were to be comparatively short. In 1859, however, when it was projected to make the Tyne a national harbour of refuge, new and extended designs were submitted by Mr. Walker, by which the piers were to be carried out to a depth of 30 feet at low spring-tides, or a length of 2,900 feet for the North, and 5,400 feet for the South Pier. In 1864 Mr. Lawton's contract expired, and the Commissioners decided to continue themselves the further extension of the piers. It was at this juncture that the Commission permanently secured the services of Mr. Messent, as acting Engineer for the Piers, he having till then been resident engineer from the commencement of the work. From that time to their completion in 1895 he had the piers under his particular charge. His initiative and technical knowledge, supplemented by an unwearying attention to the details of supervision, proved that he was the right man for the post.

In addition to the construction of the Tyne Piers Mr. Messent designed the lighthouses at their heads and the Groyne light-house at the entrance to the river. He also designed the mammoth cranes for extending the masonry superstructure of the piers with-out staging, and a concrete mixer which gave excellent results.[1] The improvements in the river were chiefly effected by dredging, the plant used being most extensive and powerful. The quantity of material dredged from the bed of the river up to the end of 1896 amounted to more than 99 million tons. Important

[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 3.

results of the improvement and deepening of the river have been the increase and development of shipbuilding on the banks of the Tyne and the reduction of the height of land floods.

Mr. Messent died in London on the 5th April, 1897. He had for some time been in indifferent health, and exposure during the previous winter, while engaged in inspecting a serious breach in the North Pier, aggravated the complaint from which he suffered. In addition to his duties on the Tyne, Mr. Messent was engaged frequently as a witness before Parliamentary Committees and as arbitrator or consulting engineer in connection with important works, among which may be mentioned the construction of the Manchester Ship Canal, Aberdeen Pier and Graving Dock, Swansea Harbour, Cardiff Docks, Port Talbot Docks, the Ribble Navigation, the Aire and Calder Navigation and the Lower Thames Navigation.

Mr. Messent was elected a Member on the 5th February, 1861. Although he never contributed a Paper to the Proceedings he frequently took part in discussions on subjects relating to river, harbour and sea-works.

EDWARD ORPEN MORIARTY, born on the 11th October, 1824, was the second son of Lieutenant (afterwards Commander) Merion Moriarty, R.N. He was educated at private schools in Cork and Dublin, and at Trinity College, Dublin, where he graduated B.A., subsequently proceeding to M.A. He became an articled pupil of Mr. William Morgan (the inventor of the feathering float for paddle-steamers), of Acraman, Morgan and Company, of Bristol, and, while serving his indentures, had the opportunity of working on the design and construction of several steamers of the highest class of that day, among others the "Little Western," the "Avon," the "Severn" and the "Archduke Frederick," a large steam yacht built for the Austrian Government.

Mr. Moriarty was next employed for some time under Sir John Macneill [1] in the laying out and construction of railways in Ireland. During that period he passed the prescribed examination for County Surveyor under the Board of Works. In 1848 he followed other members of the family to New South Wales; but finding on his

[1] Minutes of Proceedings Inst. C.E., vol. lxxiii. p. 361.

arrival no immediate opening in the profession, he accepted an appointment offered him by Sir Thomas Mitchell, the Surveyor-General, and was employed for a time in the geodetic survey of the Darling Downs and the adjacent districts, which now form part of Queensland.

About 1849 Mr. Moriarty began to practise on his own account in Sydney as a Civil Engineer. Many important undertakings soon occupied his attention and were carried out with marked success; among others schemes for the opening and development of coal mines at Wollongong, a masonry weir or dam across the valley of Hunt's Creek for impounding water for the supply of the town of Parramatta, a timber bridge with iron swing-span (still in existence) across Darling Harbour, connecting the then suburb of Pyrmont with Sydney, and timber bridges over the Murrumbidgee at Wagga Wagga and the Nepean at Richmond. His advice was asked on nearly all local engineering projects of importance, and it was at his instance that an efficient system of inspection of marine steam machinery was introduced which contributed much to prevent accidents and disasters previously not uncommon.

Sir William Denison,[1] who became Governor of New South Wales in 1855, soon after arriving entrusted Mr. Moriarty with the survey and preparation of designs for improving the navigation of the Hunter River, which is subject to great and destructive floods. He was also consulted by the Government with regard to the opening and improvement of other harbours and rivers on the coast; and the Government eventually decided to secure Mr. Moriarty's whole time and attention. On the 10th October, 1858, he was appointed Engineer-in-Chief for Harbours and River Navigation, and he thereupon formed that branch of the Department of Public Works, which he directed till his retirement in December, 1888. During his service under the New South Wales Government Mr. Moriarty carried out many important harbour and hydraulic works. The Hunter River at Newcastle was converted from a shallow tidal port, with shifting, narrow and tortuous approaches, navigable only by a few colliers and steamers of light draught, into a safe and commodious harbour. Extensive wharves were built, and numerous powerful steam and hydraulic cranes and appliances for rapidly shipping coal were erected. Other works of less importance have been the construction and excavation of breakwaters, basins and docks at Wollongong and Kiama, and coast works still in progress, including improvements at the

[1] Minutes of Proceedings Inst. C.E., vol. xxxiii. p. 251.

mouth of the Clarence and Richmond estuaries, and a harbour of refuge at Trial Bay. The harbour of Sydney has been improved by extensive wharfage, the entrance has been deepened so as to admit at all times vessels of the greatest draught, and increased docking accommodation at the Sutherland dry dock, which is 638 feet long, has been designed and constructed under Mr. Moriarty's direction.

Mr. Moriarty held the position of Chairman of the Steam Navigation Board from April, 1861, until March, 1872, when the old Board ceased to exist, and was superseded by the present Marine Board. He also rendered valuable service as a member or chairman of various Royal Commissions, such as those for the prevention of damage from floods in the Hunter and Hawkesbury, the sewerage of Sydney and suburbs, and (more important than any) for devising means for the improvement of the water-supply of Sydney. From the last emanated the proposal of the Prospect scheme, which was conceived and carried nearly to completion by Mr. Moriarty before his retirement, and from the responsibility of which his health suffered severely. This great undertaking has been for some time in complete and successful operation. As an indication of its importance, it may be sufficient to add that during a recent period of hot weather over 20 million gallons of water per day were conveyed into Sydney by these works.

At different periods Mr. Moriarty's advice was sought by the Governments of adjacent colonies on works projected or in progress. He reported on the water-supply of Melbourne from the Yan Yean, on the supply to the mining districts of Victoria from the Coliban, on that of Auckland, and on harbour improvements at Greymouth, New Zealand. Mr. Moriarty paid a brief visit to England and America in 1878, and having been obliged about the year 1888 by failing health to retire from the active duties of his official position, returned to England, where he had many warm friends, by some of whom the hospitality of the Monastery at St. Leonard's (his home near Sydney) was remembered. He died at Southsea on the 18th September, 1896, leaving a widow, but no family. Mr. Moriarty was elected a Member on the 5th December, 1865.

JOHN RAMSBOTTOM was born on the 11th September, 1814, at Todmorden (on the Lancashire side of the border), where his father, a small cotton-spinner, owned the first steam-driven mill in the valley. Beyond a little schooling in his native town, and the opportunities which the neighbourhood afforded of noting and to some extent practising the various handicrafts as then carried on, he was an entirely self-educated man, and it was due solely to energy and perseverance that he rose to the front rank of the profession as an eminent locomotive engineer. The first twenty-five years of his life were spent in Todmorden, where he took a very active interest in all kinds of mechanical and scientific pursuits. He had a small workshop in one of the rooms of his father's house, where he experimented in many directions, and produced a number of interesting working models, amongst them being a model of a condensing beam-engine and a quaint model locomotive. He also carried out such works as the rebuilding of his father's mill-engine, and a complete installation of the then new illuminant, gas, in the mill. At that time he schemed, made, and successfully worked an automatic nail-cutting machine; but, probably, the most noteworthy result of this period was his invention of the now universal weft-fork or weft-stopper, so well known throughout the textile manufactures as an indispensable adjunct to the power-loom.

Mr. Ramsbottom went to Manchester about the year 1839 and entered the service of Messrs. Sharp, Roberts & Co. (afterwards Messrs. Sharp Stewart & Co.), where he at once obtained journeyman's employment and pay, without any preliminary apprenticeship, and first gained practical knowledge of the design and construction of locomotives. He rapidly became a most efficient workman, and his ability and energy attracted the attention of Mr. Charles Frederick Beyer,[1] who was then in charge of the locomotive department of the firm.

After three years in the service of Messrs. Sharp, Roberts & Co., Mr. Ramsbottom, on the recommendation of Mr. Beyer, was appointed, in 1842, locomotive superintendent of the Manchester and Birmingham Railway, which in 1846 was amalgamated with the London and North Western. He remained for fifteen years in charge of the works at Longsight, and on the retirement of Mr. Francis Trevithick in 1857, was transferred to Crewe as Locomotive Engineer for the Northern Division, with which was

[1] Minutes of Proceedings Inst. C.E., vol. xlvii. p. 290.

amalgamated the North-eastern, his old division. In the following year he turned out several new goods engines, which, with larger boilers, are still at work. In 1859 he designed and constructed his first express engine, the "Problem," No. 184, which was the first of the well-known "Lady of the Lake" type. So efficient was the work he turned out that, after thirty years, locomotives of the "Lady of the Lake" class were used for light loads at high speed, between Euston and Crewe, in the race to Scotland of 1888.

In 1862 the Directors of the North Western decided to centralize the locomotive work at Crewe and to utilize the Wolverton shops for carriage building. In the re-organization of the Crewe works Mr. Ramsbottom had full scope for his mechanical ability. He paid the greatest attention to facilities for the economical manufacture and maintenance of engines. He recognised to the full the advantages of reducing the number of types to a minimum and to as great a degree of uniformity as possible, not merely in respect of a thorough interchangeability of parts in engines of the same class, but to a great extent throughout the different classes, and he carried out the system of working to standard gauges to an extent which was then quite new in railway practice. Not only were new parts made accurately to standard dimensions, but a series of graduated sizes was adopted for the renewal of worn details. Special tools also were freely introduced at Crewe, and particular attention was paid to the convenient handling of work and to its transport from one department to another. Among the improvements he effected was the extensive introduction of cranes driven by high-speed cotton-ropes[1]—particularly of the Ramsbottom single-rail crane—and the development of the 18-inch gauge railway system which performs such useful work at Crewe.[2] At an early period of his career at Crewe he recommended the Company to adopt the manufacture of Bessemer steel; and the steelworks at Crewe, which were erected under his auspices, were among the first to be established in the country away from Sheffield.

Some idea of the manner in which Mr. Ramsbottom turned his experience and ingenuity to practical account may be gathered from reference to the numerous Papers he contributed to the Institution of Mechanical Engineers, of which he was one of the originators and President in 1870 and 1871. So far back as 1849

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[1] Proceedings Institution of Mechanical Engineers, 1864, p. 44.
[2] *Engineering*, vol. lxiii. p. 751.

appeared a description of an improved locomotive boiler,[1] in which he sought to obtain a larger area of flue-room and large heating-surface with less weight. Six years later he published an account of an improved coking crane for supplying locomotives,[2] and this was followed by particulars of the piston-ring,[3] with which his name is associated, and of the construction of packing-rings for pistons.[4] Then came descriptions of an improved safety-valve[5] and a safety escape-pipe for steam-boilers.[6] Perhaps the invention which caused him to be most widely known was the trough laid in the track to supply water to locomotives while running.[7] This apparatus, which was first adopted on the North Western system, is of great value in enabling traffic to be worked without delay for taking in water, and without it the long runs now made by express trains would be impossible. In addition to the high-speed cranes already referred to, he introduced at Crewe an improved reversing rolling-mill[8] and a new system of manufacturing steel tires,[9] the latter suggested to him by Mr. F. W. Webb. When in 1871 the endless-rope traction through the Edgehill passenger tunnel at Liverpool was done away with, and the tunnel was worked by locomotives in the ordinary way, he devised and successfully carried out a system of ventilation by mechanical means.[10]

In 1871 Mr. Ramsbottom was compelled by failing health to retire from active work. Subsequently, however, in 1883, he became connected with the Lancashire and Yorkshire Railway Company, acting as their consulting engineer in the design and construction of the works at Horwich. He was elected a director of the Company in 1885, on the death of Lord Houghton, and only recently resigned. He was also a director of Messrs. Beyer, Peacock & Co. Mr. Ramsbottom, during the period of his connection with Crewe, took an active interest in the Mechanics' Institution, of which he was President. In 1873 he founded the Ramsbottom Scholarship for mechanical engineering at Owens College, Manchester. The Scholarship is available for two years, the income being £40 per annum, and may be competed for by young men employed in the Locomotive Department of the North Western Railway Company. Some years ago the honorary degree

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[1] Proceedings Institution of Mechanical Engineers, 1849, p. 3.
[2] *Ibid*, 1853, p. 122.
[3] *Ibid*, 1854, p. 70.
[4] *Ibid*, 1855, p. 206.
[5] *Ibid*, 1856, p. 37.
[6] *Ibid*, 1857, p. 179.
[7] *Ibid*, 1861, p. 43.
[8] *Ibid*, 1866, p. 115.
[9] *Ibid*, 1866, p. 186.
[10] *Ibid*, 1871, pp. 22 and 66.

of Master of Engineering was conferred upon him by the University of Dublin.

Mr. Ramsbottom died at his residence, Fernhill, Alderley Edge, Cheshire, on the 20th May, 1897, in his eighty-third year. He was elected a Member on the 10th April, 1866.

Sir JAMES RAMSDEN,[1] whose name is identified with the rise and progress of Barrow-in-Furness, died at his residence, Abbots Wood, overlooking Furness Abbey, on the 19th October, 1896.

James Ramsden, born in Liverpool on the 25th February, 1822, was a son of Mr. W. Ramsden, civil engineer, of that city. He was apprenticed early in life to Mr. E. Bury, of the firm of Bury, Curtis and Kennedy, of Liverpool, and subsequently obtained experience of locomotive engineering at the Wolverton works of the London and North-Western Railway. His first introduction to the district of Furness was in March, 1846, when he found the railway from Barrow to Dalton and Kirkby in course of construction. The line was opened for traffic in that year. The quantity of ore raised and sent away prior to the opening of the railway was about 3,000 tons; the quantity shipped at Barrow during the year 1846 was 120,000 tons. The rolling stock in the first instance was of a very limited character—two four-wheeled engines and several mineral wagons. The line was opened for passenger traffic in the year 1847, and Mr. Ramsden was appointed Secretary and General Manager in 1850. Passengers were allowed to travel in a sheep-van on Sundays only. One engine only being needed for the traffic, only one driver and fireman were employed. Mr. Ramsden observed one Sunday that the engine was running too fast, and, making signals for the train to stop, he found that the driver was intoxicated. He afterwards wrote to the locomotive superintendent of the Liverpool and Manchester Railway and begged a man; and, in the meantime, worked the traffic himself. Prior to the railway, Furness could only be reached by coaches crossing the sands to Ulverston, or by steamer to Bardsea from Fleetwood. Ore was brought down in carts from the mines at Lindal and was tipped into the yard on the shore above high-water mark. It was then run down in small bogies worked by hand,

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[1] This Obituary has been compiled mainly from notes written from Sir James Ramsden's dictation early in 1890.

and was tipped into vessels which lay dry at the end of the jetty. The carts laden with ore made a procession of a mile long on the roads between Lindal and Barrow. The traffic increased so rapidly that a larger class of vessels had to be employed, and the objection of the owners to their running aground led to the first docks being commenced, which were opened in September, 1867.

At an early date Mr. Ramsden made a plan of an imaginary town, with streets marked out equal to a population of about 100,000 people. To show that this was not so wild a scheme as it then looked, it may be observed that even now the population is over 60,000. All the landowners gladly availed themselves of this plan, and fell readily into the proposal of selling land to the Railway Company. In 1856 the Company bought the Hindpool estate, consisting of 70 acres, with a mile of water frontage. The Park Mines had been in the hands of Messrs. Schneider,[1] Hannay [2] & Co. for many years, under a license to search for ore. When the railway came into operation it was found to be far in advance of the requirements of the traffic, and the owners of the royalties determined to reduce the areas of search so as to bring in fresh people. Messrs Schneider, Hannay & Co. decided to give up the whole estate, but before doing so determined to put in a bore hole in a meadow immediately in front of the farmhouse, which, being a rich pasture, the steward of the estate had hitherto prevented them from doing. The result of this trial was that ore was found within 35 yards of the surface. Since then, as much as 300,000 tons have been raised in one year. Originally, the ore went to South Wales, a small quantity going to Ellesmere Port for Staffordshire, by the Shropshire Canal. The vessels returned with copper dross as ballast, which dross was deposited at the back of the quays, and eventually formed the Devonshire and Buccleuch Docks. The question of return freights had become a serious one, inasmuch as the vessels were obliged to return from Wales in ballast, and in 1860 Mr. Ramsden made the suggestion to Messrs. Schneider, Hannay & Co. that it would be a good thing to put up a few blast-furnaces in Barrow, in order to give the vessels return freight of coal or coke.

In 1864 the steelworks, now known as the Barrow Hæmatite Steel Company, were formed, with the idea of purchasing pig-iron from Messrs. Schneider, Hannay & Co. That arrangement was not found to work very well, and it resulted in the purchase of

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[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 406.
[2] *Ibid*, vol. xl. p. 261.

the ironworks and the mines in 1866. In that year ten furnaces were in operation. The Duke of Devonshire[1] was chairman of the united concerns, and Mr. Ramsden was managing director. The first order for rails was a contract with the Furness and Midland Companies for the line from Carnforth to Wennington. Steel rails were also made for the Grand Trunk Railway of Canada, and large sales in pig-iron were effected. When the steelworks were first contemplated, rails were at £17 per ton, but when the first rails were made the price was £10 10*s.* per ton. After this followed the great years of prosperity, in which the proprietors received back their money with 5 per cent. interest. In the first years of the steelworks rails only were manufactured; but later arose the demand for steel for shipbuilding purposes, and this led to the erection of a number of Siemens-Martin furnaces, and eventually to the rolling of plates and angles, and all the necessary material for shipbuilding. The steel took the place of iron and tin plates, which led to a considerable trade with South Wales. The tin plates are shipped in small steamers of about 300 tons burden, the return cargo being coal. The trade having increased so much and the ships becoming of a larger class, it was found desirable that there should be a wet dock. This necessitated the purchase of Barrow Island by the Railway Company. The price of the island was £10,000 and subsequently a site of 50 acres was sold for the shipyard and engine works.

With the development of the steelworks and the demand for labour, difficulty arose in attracting and retaining skilled workmen, and on investigation Mr. Ramsden found this was mainly due to the want of employment for women and children. Casting about for a trade which would largely employ this class, he pitched upon the jute trade as being suitable, and on further inquiry this idea was confirmed, and jute works were established. In a very short time after the works came into operation an entire change was wrought in the character of the population. Instead of being dependent on single men who were constantly moving, very frequently on the slightest pretext, steady, married men were obtained whose families could earn wages from 5*s.* to 15*s.* per week, employment being found for three or four hundred women and children in sewing sacks at their homes. Whilst the manufacture of jute has not been very profitable, it has had a very beneficial interest on other companies and on the town generally.

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[1] Minutes of Proceedings Inst. C.E.. vol. cvii. p. 393.

In view of the possible future requirements of the town, in 1865 the Duke of Devonshire expended considerable sums in building a Market Place and Town Hall, which were handed over to the town at cost price. Up to 1865 the town was governed in the way of an ordinary village, for parish purposes under Dalton-in-Furness and for township purposes under the Ulverston Union. It received a charter of incorporation in 1867, Mr. Ramsden being elected first mayor, which office he held for six years. In 1872 he received the honour of knighthood and was appointed High Sheriff of the county.

In 1878 the necessity for further church accommodation became very pressing, and the outcome of a conference with the Dukes of Devonshire and Buccleuch[1] on this subject was the building of four churches. The Duke of Devonshire undertook to provide funds for two churches, the Duke of Buccleuch for one church, and Sir James Ramsden made himself responsible for the fourth. These, with a suitable residence for the clergyman attached to each, were opened on the 26th September of that year.

Barrow-in-Furness, either for the town or railway, was almost every year in Parliament for extensions and privileges which a new and growing town demanded. With a view to encourage the importation of grain to the docks a steam corn-mill was erected. The Company had the Duke of Devonshire as its chairman, but as it was soon found that the building was much too small for the requirements, it was doubled in size. Although of immense importance to the docks and the town generally, the mill in its early stages was not a financial success. Eventually the original proprietors were bought out, and the property let on a long lease to a private firm, by which it is now carried on successfully.

Prior to the opening of the docks in 1867, and the improvement in the channel, the Irish steamers, the property of the Midland and Furness Railway Companies, jointly with Messrs. James Little and Co., sailed from Morecambe. The improvement of Barrow Harbour led to their transfer to Piel, and on the further improvement of the navigation and the opening of the Ramsden Dock, the steamers were removed to Barrow, whence they now sail daily for Belfast. There is also a daily summer service between Barrow and the Isle of Man. The steamers were originally built for the projected Waterford Line, but the line being abandoned by the Great Western Railway Company, they were bought by the Midland Railway Company for this traffic. The increase in the shipping

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[1] Minutes of Proceedings Inst. C.E., vol. lxxvii. p. 347.

at Barrow demanded a certain accommodation for repairs, and this led to the formation of a Company, with the Duke of Devonshire as Chairman, for shipbuilding and engineering. This Company purchased 50 acres of land on Barrow Island. Steamers have been constructed for the Ducal, Red Star and Pacific Lines. The "Pembroke Castle" and the "City of Rome" were built at this yard; also the "Normandie," which at that time was the largest ship in the French Mercantile Marine. In 1888 the Company was reconstructed, and is now known as the Naval Construction and Armaments Company, Limited. It has built many vessels for the Royal Navy, including the 1st class cruiser "Powerful."

In the construction of the Ulverston and Lancaster Railway, which was commenced by Messrs. John Brogden and Sons,[1] great difficulties were met in forming the embankments at the Leven and Kent estuaries, but with characteristic perseverance these difficulties were overcome.[2] Eventually the line, which extended from Carnforth to Ulverston, was bought by the Furness Railway Company and now forms part of that system. In order to make the connection with the Furness line, it became necessary to purchase the Ulverston Canal. Of this canal, it has been said that it is the shortest, widest, and deepest canal in the kingdom. It is now very little used except in connection with the works of the North Lonsdale Iron and Steel Company, a large paper manufactory, and an ironfoundry.

Sir James Ramsden was a man of large ideas and indefatigable energy. Gifted with excellent judgment, ability and resource, he devoted himself to the development of Barrow-in-Furness, the present position of which town affords abundant testimony to the success of his efforts. In 1846 a small fishing village of about 100 inhabitants, it has now a population exceeding 60,000, supported mainly by the various industries which he was instrumental in establishing. He was elected a Member on the 2nd December, 1856.

RICHARD CHRISTOPHER RAPIER, son of the Rev. Christopher Rapier, of Morpeth, Northumberland, was born there on the 7th June, 1836, and was educated at Christ's Hospital, London. On leaving school he was apprenticed to Messrs. Robert

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[1] Minutes of Proceedings Inst. C.E., vol. xv. p. 94.

[2] *Ibid*, vol. xiv. p. 239.

Stephenson & Co., in whose works at Newcastle-on-Tyne he spent seven years, being responsible during the latter part of that time for the construction of a number of caloric engines for the production of compressed air.

In 1862 Mr. Rapier entered the service of Messrs. Ransomes, of Ipswich, and for six years was in charge of the railway department at the Orwell Works. Meanwhile, the number of partners in the firm had increased, and with a view to accommodate them, an amicable arrangement was made in 1868, by which the two classes of business—agricultural implement and railway-plant making—were divided. Mr. Rapier became the engineering partner in the railway business, which was carried on under the style of Ransomes and Rapier at the Waterside Ironworks, and from that time he was the moving spirit of the firm. In the spring of 1896 the undertaking was formed into a limited company, Mr. Rapier being the managing director and holding the greater part of the ordinary share capital.

Mr. Rapier was not only an engineer, but also a keen man of business, possessed of great power of application, foresight and judgment. He took a leading part in 1875 in the negotiation and construction of the first railway in China, a narrow-gauge line from Shanghai to Woosung, which, after being worked successfully for fifteen months, was acquired by the natives and dismantled. He was also one of the chief promoters of the Southwold Railway, a 3-feet gauge line from Halesworth to Southwold, and ultimately became its chairman. In 1878 he published a book entitled "Remunerative Railways for New Countries,"[1] in which he advocated the use of light railways of narrow gauge for opening up new countries and for developing the resources of thinly populated districts in old countries. He took considerable interest in the management of railways, and in 1874 presented to the Institution a Paper on "The Fixed Signals of Railways,"[2] in which he advocated the division of traffic into fast and slow, rather than the provision of separate lines for passengers and goods. For that Paper he was awarded a Telford medal and premium.

In conjunction with Mr. F. G. M. Stoney, Mr. Rapier devoted much attention to the improvement of river navigation. The large sluices on the Manchester Ship Canal, including those at the entrance to the River Weaver, and the movable weir on the Thames at St. Margaret's, near Richmond, were constructed by the

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[1] This work is in the library of the Institution.

[2] Minutes of Proceedings Inst. C.E., vol. xxxviii. p. 142.

firm from Mr. Stoney's designs, and a much larger movable weir on the Clyde is now in course of erection at Glasgow.

Mr. Rapier died on the 28th May, 1897, at Folkestone, whither he had gone for the benefit of his health, which had been failing for some months. He was of a most genial disposition, and was always ready to listen and respond to any appeal for assistance, large numbers of old workmen and their widows owing the comforts of their declining years to his liberality and consideration. In 1893 he initiated a system of allotments for his workmen on land adjoining the Waterside Ironworks which he let at a nominal rent, at the same time offering annual prizes for cultivation.

Mr. Rapier was elected an Associate on the 14th April, 1863, and was transferred to the class of Members on the 17th April, 1877. He was a frequent attendant at the meetings, and, in addition to contributing the Paper above referred to, occasionally took part in discussions.

JAMES REW SHOPLAND, born on the 17th December, 1841, was articled in 1857 to Messrs. Robert Dymond & Sons, of Exeter, under whom he was engaged on railway and other engineering works. On the expiration of his pupilage he came to London, and entered the office of Messrs. Gotto [1] & Beesley, by whom he was employed on various waterworks.

In 1870 Mr. Shopland began to practise on his own account at Swindon. In conjunction with Mr. W. J. Kingsbury, he acted as Engineer to the Swindon, Marlborough and Andover Railway, and to the Swindon and Cheltenham line, and when these undertakings were amalgamated in 1884, as the Midland and South Western Junction Railway, he was appointed Consulting Engineer to the Company. He also acted for the Bridport Railway, the Bill for which he successfully carried through Parliament against great opposition. At Bridport he constructed water and drainage works, and at the time of his death was engaged on improvements to the harbour. He also carried out drainage and waterworks at South Molton, Briton Ferry, Clifton-on-Teem, and other places, and was Engineer to the Swindon Water Board.

Mr. Shopland died at his residence, Walton House, Swindon, on the 22nd April, 1897, after a long illness. He was elected a Member on the 4th February, 1896.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxviii. p. 346.

WILLIAM EDWARD BURGESS was born in Bedfordshire on the 22nd May, 1868, and was educated at Bedford Modern School and at the City and Guilds of London Institute, where he gained considerable distinction. After taking charge for a time of the testing of materials at the Royal Indian Engineering College, Coopers Hill, he entered in 1889 the service of Messrs. Willans and Robinson, with whom he remained until December, 1893. During that period he assisted Mr. Willans[1] in carrying out the series of condensing steam-engine trials, which formed the subject of a Paper read before the Institution in April, 1893,[2] and in the same year he superintended the erection and running of Messrs. Willans and Robinson's exhibit of engines at the World's Fair, Chicago.

At the end of 1893 Mr. Burgess entered the service of the M. C. Bullock Manufacturing Company, of Chicago, which had secured the right to construct the Willans engine in the United States. From that time he had charge of the Willans engine department of that Company's works, and assisted in the design and erection of important electrical installations, such as the Pabst plant at Milwaukee, the street railway in Terre Haute, and the Hyde Park works in Chicago. While engaged on work for the Englewood and Chicago Street Railway Company he was attacked by typhoid fever, which proved fatal on the 10th November, 1896. Mr. Burgess was elected an Associate Member on the 1st May, 1894.

PAUL AUGUSTE DIMIER was born at Geneva on the 23rd May, 1863, his father being Swiss and his mother German. At the age of five he came to England, and, after attending a private school at Blackheath, was for three years at St. Olave's Grammar School. In 1879 he entered the Applied Sciences Department of King's College, London, and, after going through the usual course, was admitted an Associate of the College. He then served a pupilage under Dr. John Hopkinson, with whom he subsequently remained as an assistant. During that time he was employed on electric-light work at the hospital ships near Dartford and at the Tilbury Docks.

In January, 1886, Mr. Dimier was engaged by Messrs. Mather and Platt, of the Salford Ironworks, to assist Dr. Edward

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[1] Minutes of Proceedings Inst. C.E., vol. cxi. p. 395.

[2] *Ibid*, vol. cxiv. p. 2.

Hopkinson in some experiments with dynamo-electric machinery, and was afterwards placed in charge of the testing department of the firm. He was then engaged, during 1890 and 1891, in assisting Professor Henry Robinson in connection with the St. Pancras electric lighting installation. Early in 1892 a severe attack of influenza forced him to rest for some months. In August he resumed work, entering the service of the Charing Cross and Strand Electricity Supply Corporation, and, in spite of impaired health, faithfully discharged his duties until in May, 1893, he completely broke down. Hoping that change of air and rest might restore him to health, he went to Switzerland, where, after lingering four years, he died on the 13th May, 1897.

Mr. Dimier was elected an Associate Member on the 4th December, 1888. He had previously been a Student and had taken great interest in the proceedings of that class.

HENRY JOHN GIRDLESTONE, younger son of the late Rev. William Ewen Girdlestone, of Kelling Rectory, Norfolk, was born on the 18th August, 1824. At the age of seventeen he was articled for five years to Mr. James Simpson,[1] Past-President. He was then employed under Mr. T. Earle on the contracts for the South Staffordshire Railway, the wall at the Trinity Buoy Wharf and the foundations of Chelsea Suspension Bridge. From 1857 to 1863 he was engaged under Mr. John Addison as Resident Engineer on the Cannock Mineral, the Mount Sorrel and the South Leicestershire Railways.

In 1864 he entered into partnership with his cousin, Mr. J. W. Girdlestone, with whom he practised in London for thirteen years. During that period he was engaged on Parliamentary work, and in surveying and setting out railways. In 1877 Moule's Patent Earth-Closet Company was formed, to work improvements in earth-closets devised by his cousin, and of this Company Mr. Girdlestone became Engineer and Manager. He held that post until his death, which took place at Highgate on the 15th May, 1897. Mr. Girdlestone was elected an Associate on the 4th February, 1862, and was subsequently placed in the class of Associate Members.

[1] Minutes of Proceedings Inst. C.E., vol. xxx. p. 457.

THOMAS WILLIAM HORN, Jun., eldest son of Mr. Thomas William Horn, Assistant Engineer of the Great Northern Railway, was born on the 21st April, 1864. He was educated at Barnet Grammar School and by private tutors. After serving his pupilage under Mr. Richard Johnson, the Chief Engineer of the Great Northern Railway, in the offices of that Company, he was transferred to the staff of the District Engineer at Leeds, where he was engaged in the construction of heavy retaining-walls, bridges and other important works, in connection with the widening of the existing lines in Yorkshire.

In January, 1890, Mr. Horn left England for South America, having been appointed District Engineer on the Buenos Ayres Great Southern Railway. First on the Tandil section (322 miles), and afterwards, from April, 1891, to 1895, on the Bahia Blanca section (389 miles), he obtained varied experience, and the Chief Engineer certified that the way and works under his care were well and cheaply maintained during the time he had charge of them. In July, 1895, Mr. Horn returned to England, and after a stay of three months proceeded to India, as District Engineer, in charge of the Nagpur Section of the Bengal-Nagpur Railway. In March, 1897, he was transferred to the more important section of Chakardharpur. On the 24th April following, his carriage was placed next the engine of a mixed train, and he left Chakardharpur at three o'clock for Asansol Junction. At about a quarter to eight o'clock, it being dark, at a station called Kantadih, he unfortunately attempted to alight on the side on which there was no platform; he fell, and, from some unexplained cause, was caught by a wagon and dragged a distance of 54 yards. He was found, much mutilated, under the ninth wagon, and expired after a few minutes. His body was brought back to Chakardharpur, a distance of 70 miles, during the night, and he was buried the next afternoon, the Bengal-Nagpur Volunteers, of which corps Mr. Horn was a lieutenant, giving him military honours.

The Agent and Chief Engineer of the Company, Mr. T. R. Wynne, in reporting the sad occurrence, wrote:—"I valued his services very highly indeed. He was a very able engineer and most enthusiastic in his work. He was very popular with all his brother officers and with the staff, and his death is deeply regretted. The Railway Company have certainly lost a most valuable officer." Mr. Horn took a prominent part in all the sports and pastimes organized for the railway staff, and was much liked for his candid and amiable manner. He was elected an Associate Member on the 2nd February, 1892.

FREDERICK PURDON was born on the 24th April, 1853, at Kingstown, co. Dublin, where his father, Mr. Wellington Purdon,[1] was then occupied as Resident Engineer on the construction of the Dublin, Wicklow and Wexford Railway round Bray Head. He was educated at Blackheath School, and afterwards went through the Applied Sciences Department of King's College, London. He was articled to his father, and after obtaining some special office training and drawing experience, spent two years in the works of Messrs. Beyer, Peacock & Co. at Gorton. He subsequently had a short experience of locomotive work on the London, Chatham and Dover Railway, under the late Mr. William Martley.[2] The year 1874 was spent, still as a pupil, with Messrs. De Bergue and Co., occupied in the sinking under compressed air of the cylinders for the foundations of the original Tay Bridge. In one of these cylinders he met with a serious accident, being struck on the head by some earth falling from a "skip." His complete recovery occupied some months. From 1875 Mr. Purdon was engaged for nearly four years as one of the Resident Engineers on the Waterford, Dungarvan and Lismore Railway, where, amongst other work, he had charge of the erection of the Blackwater River Viaduct and the bridge over the Dungarvan Estuary, the latter involving a difficult foundation for the southern abutment. After this he travelled in the United States. From 1880 to 1885 he was continuously engaged as Resident Engineer on the construction of tramways, being successively in charge of the North London Suburban, the Stockton and Darlington district, and the Manchester, Bury, Rochdale and Oldham steam tramways.

In 1885 Mr. Purdon entered into partnership with Mr. H. E. Walters. They carried on practice as Civil Engineers at No. 2, Great George Street, Westminster, and took out several patents for mechanical inventions and improvements; amongst these being a water-motor for utilizing the current of running streams and tideways; also patents for roller bearings, at which, in conjunction with friends, Mr. Purdon worked assiduously for some years. These last-named inventions have been acquired by the Roller Bearings Company, which is now carrying out many widely varying applications of them for avoiding rubbing friction of axles by substituting a rolling action. The Electric Railway

[1] Minutes of Proceedings Inst. C.E., vol. xcvii. p. 407.
[2] *Ibid*, vol. xli. p. 221.

Companies have been amongst the earliest to recognise the large economy thus obtained.

In 1887 Mr. Purdon visited India and reported upon tramway projects for Madras. His wide experience and practical knowledge of the subject led to his being fully occupied with parliamentary schemes for tramways, and upon these he was busily engaged when his premature death occurred on the 11th March, 1897, after a few days' illness. Mr. Purdon's genial and sympathetic nature, straightforwardness of character and abundant energy, combined with his varied training, helped him greatly in his professional career and brought him a large circle of friends. He was elected an Associate Member on the 2nd March, 1886.

CHARLES WARREN ROBERTS, born on the 13th July, 1852, was the son of Mr. H. Beaver Roberts, solicitor, of Bangor. In September, 1871, he was articled to the late Mr. C. E. Spooner, the Engineer of the Festiniog Railway, under whom he was engaged in surveying and laying out the North Wales Narrow Gauge Railway. After the expiration of his pupilage, he managed a slate quarry in Carnarvonshire belonging to his father, and was subsequently employed in constructing railways at various quarries in Wales and Cumberland. At the end of 1880 he proceeded to Brazil, and was for some years in the service of the Donna Theresa Christina Railway Company.

Mr. Roberts returned home in 1887, having been offered by Messrs. J. W. Greaves and Sons the management of their extensive slate-mines at Festiniog. He soon made for himself a reputation as a most able manager, and became known as an authority on the working of slate-mines. Mr. Roberts died at his residence, Plas Weunydd, Blaenau Festiniog, on the 11th May, 1897. He was elected an Associate Member on the 31st May, 1881.

JOHN THORNHILL, born on the 1st June, 1853, was the third son of the late Mr. John Thornhill of Cork. After going through the engineering course at Queen's College, Cork, he proceeded to India, and in April, 1874, obtained an appointment in the Public Works Department, being posted to the North-Western Provinces, where he served up to the time of his death. He was first employed on general provincial works in the Allahabad District, and in 1875 was transferred to the Kumaon District, where he remained for over seven years and gained considerable experience in the construction of hill roads. He was in charge of the cart road to Ranikhet, a military station, situated at an elevation of over 6,000 feet, and also of other works of communication, in a difficult mountain country, which involved the erection of several suspension, lattice-girder and other bridges, at considerable elevations, in situations where the difficulties of carriage and labour were considerable. He was subsequently employed as District Engineer in the Allahabad, Banda, Cawnpore, Shahjahanpur and Bareilly Districts, and officiated as Divisional Engineer in the Allahabad and Agra Divisions, in which latter charge he was employed when he died on the 17th September, 1896, having contracted fever while on inspection duty in the district. Mr. Thornhill was elected an Associate Member on the 4th December, 1883.

GEORGE WYLIE, born at Kincardine on the 9th October, 1860, was educated at the Dollar Academy and at the Royal Indian Engineering College, Coopers Hill, where he gained the scholarship of the Public Works Committee of the Council of India in 1881, and the Fellows' Scholarship in the following year, being also made a Fellow of the College. After the usual practical course he joined the Public Works Department of the Government of India in November, 1883, and was employed on special duty in the Aligarh Division, on the Ganges Canal and on the Machua Weir. In January, 1885, he was transferred to the Mainpuri Division, and after six months' service there was posted to the Etawah Division, Lower Ganges Canal, where he remained for seven years, gaining much experience in the working of silt traps. In 1892 Mr. Wylie was transferred to the Anupshahr Division for a few months and thence to Hardwar, where he superintended the putting in of the headworks of the Ganges Canal. In January, 1894, he was appointed Executive Engineer, third grade, and was posted to the Meerut Division, where he served first as subdivisional and afterwards as divisional officer until his death, from enteric fever, on the 23rd December, 1896. Mr. Wylie's services were fully appreciated by those under whom he acted and by whom his early death was much regretted. He was elected an Associate Member on the 14th January, 1890.

WILLIAM CAWKWELL,[1] joint Deputy-Chairman and formerly General Manager of the London and North-Western Railway Company, died at his residence, Fernacre, Maresfield Gardens, South Hampstead, on the 24th June, 1897, in his ninetieth year.

Mr. Cawkwell came of a Lancashire family, and was born on the 17th November, 1807. His father was a stage-coach proprietor at Manchester, and owned some of the conveyances which ran between that city and certain towns in Lancashire and Yorkshire, so that the subject of this notice may be said to have been born and bred amid the surroundings of the carrying trade before the advent of railways. It was not till the year 1840, however, that Mr. Cawkwell entered upon active railway work as clerk in charge at Brighouse Station, on the opening of that portion of the Manchester and Leeds (now the Lancashire and Yorkshire) system which extends from Hebden Bridge to Normanton. The previous year had seen the opening of the first section of the undertaking, namely, from Manchester to Littleboro, a distance of about 13 miles, but between the latter town and Hebden Bridge communication was kept up by coaches. No less than twenty-six were running at the time between Manchester and Leeds daily, and the Company had to piece their disjointed railway together by a free use of vehicles of this kind.

Mr. Cawkwell remained about seven years at Brighouse, by which time the Manchester and Leeds Railway had grown into a line 343 miles long. Promotion was rapid in those days, and he quickly rose to distinction. He was appointed goods manager of the Yorkshire section of the line towards the end of 1847, and was transferred to Oldham Road, Manchester, in 1848, whilst in January, 1850, the superintendence of the goods department of the Lancashire section of the line was added to his other duties. In 1853 Captain Laws, the first general manager of the Lancashire and Yorkshire Railway, retired and Mr. Cawkwell was made traffic manager. Four years later, the Lancashire and Yorkshire and the East Lancashire Railway Companies entered into such close relationship as practically to amount to amalgamation, and Mr. Cawkwell and the late Mr. Smithells were made traffic managers of the combined undertaking, each being assigned a separate district. In September, 1858, Mr. Cawkwell was offered and accepted the more important and lucrative office of general

[1] Parts of this Notice have been taken from *The Railway News*, 26th June, 1897.

manager of the London and North-Western railway, leaving to his coadjutor the entire management of the Lancashire and Yorkshire system. In the short space of eighteen years Mr. Cawkwell had climbed from the bottom to the top of the service.

Mr. Cawkwell held the position of general manager of the London and North-Western Railway between fifteen and sixteen years. These constituted a stirring epoch in British railway history and witnessed many a conflict between companies old and new, both inside and outside the walls of Parliament. Additional lines were promoted one after another in quick succession, amalgamations were projected, fresh combinations formed, and extensions sought in every direction. It required a cool head and sound judgment, combined with physical stamina, to withstand the strain of the work which had to be performed. The former Mr. Cawkwell possessed in an eminent degree. His robust common sense never forsook him, but his health was far from good, although by extraordinary care and a self-restraint which amounted almost to asceticism, he managed to keep going and to outlive many of his younger and apparently stronger contemporaries. His position during the period of his management of the North-Western Railway obliged him to take an active part in much of the Parliamentary warfare of the time, and for many years his face and figure were familiar in the lobbies and committee rooms at Westminster. He had qualities of head and heart which stood him in good stead there. Of reserved disposition and unimpassioned nature, he was invariably quiet and self-possessed in the witness-box, and whilst not fluent of speech, was at all times concise and guarded in reply. Rarely did counsel succeed in extracting from him more than it was politic to disclose. Except when intermittent attacks laid him up at intervals, he continued almost to the last to attend at his office at Euston. There his many good qualities endeared him to his colleagues, and his presence was always welcome, for he gave the Company of his best, and gave without stint. His intellect was not, perhaps, of a quick, incisive, penetrating character. It was rather of a judicial order, fitted for patient investigation and quiet, mature deliberation. In the closing years of his life he seemed to lose much of the reserve, amounting almost to austerity, which characterised him in earlier days, and became cheerful, kindly, and genial. At the relation of some unusual incident in his younger days, his face would light up with a smile at once humorous and expressive, and he would laugh in a manner infectious to those around. In his remarkable evenness of temper, cheerfulness of disposition and relish for employment, Mr. Cawkwell may be said to have remained young to the last. His letters were models of conciseness, full of pith and force, but he would not allow himself to be hurried into hasty answers. "Second thoughts are best" was the principle which commended itself to his mind, and whether he was preparing to give evidence, negotiating agreements, or replying to correspondents, deliberation was the cardinal principle he observed throughout life. His diplomatic ability was of a high order and was frequently called into play. Many important contracts were entered into by the London and North-Western Company during his tenure of office, and he acquired a reputation for driving good bargains when the interests of the Company were at stake. In 1874, when Mr. Cawkwell joined the board, his brother officers, headed by Sir George Findlay,[1] entertained him at dinner, and presented him with an oil painting of himself. More recently the directors invited him to sit to Mr. Herkomer for a three-quarter length portrait, which has a place in one of the committee-rooms at Euston Station. He was the recipient of a gold watch and chain from the Queen, presented to him in 1862 in recognition of the care and attention he had for many years devoted to carrying out the arrangements for Her Majesty's Scotch journeys.

Mr. Cawkwell was elected an Associate on the 23rd May, 1865.

EDWARD MILLER GARD EDDY, who died at Brisbane on the 21st June, 1897, was the Chief Commissioner of Railways for New South Wales and one of the most distinguished Colonial railway officials. Born on the 24th July, 1851, he entered the service of the London and North Western Railway Company in May, 1865, at fourteen years of age. After eight months as a junior in the Audit Department at Euston Station he was removed as a clerk to the office of Mr. G. P. Neele, the Superintendent of the line, under whom he acquired the groundwork of his railway knowledge, both in the indoor and outdoor departments. Always anxious to advance, he exhibited an energy and smartness which soon caused him to be selected as one of the corps of cadets whom the late Chairman of the line (Sir Richard Moon) desired constantly to recruit as the school for rising railway men, ready to act as

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[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 362.

assistants to the older officers and capable of occupying their positions in case of death or removal. Attached in this way to Mr. Neele's office, he obtained a thorough insight into the intricate working of the various divisions of the North Western line, and his suggestions were often found of the greatest value.

In April, 1875, Mr. Eddy was removed from London to Chester, and became assistant to Mr. Binger, Superintendent of the Chester and Holyhead division. For three years he occupied that position, when, a vacancy having arisen in the southern division of the line, he was appointed to the responsible post of District Superintendent at Euston, having control of the line between Stafford; *viâ* the Trent Valley and Rugby, including Leicester, Northampton, Oxford, Cambridge, Bedford, Aylesbury and the whole of the suburban lines of the company in the Metropolis. His capability for work and organization became increasingly apparent during the eight years he filled this position, and the efficiency of the train service and discipline in the district were highly appreciated alike by the public and the Directors.

In April, 1885, Mr. Eddy was advanced to the position of Assistant Superintendent of the line, thus again entering the office of his old friend and chief, Mr. Neele. He now had the opportunity to put all his vigour into the train working of the entire London and North Western system, and both the goods-train and the passenger-express services were the subject of his constant watchfulness and beneficial remodelling. The energy displayed in connection with the through trains between England and Scotland brought him under the notice of the Caledonian Railway officials, and when, through the illness of the General Manager of that Company, it became necessary to have an Assistant Manager, Mr. Eddy was selected to fill the post, and he accordingly, in April, 1887, left the London and North Western and joined the Caledonian Company. His grasp of railway working and vigour in administration soon found full scope for activity in Scotland, and without loss of time he commenced to put in force north of Carlisle the economies and changes he had seen in beneficial operation south of the border.

Mr. Eddy's service with the Caledonian Company was not of long duration. In July, 1888, the Government of New South Wales applied to Sir George Findlay,[1] then the General Manager of the London and North Western Railway, to aid in the selection of an officer suitable for the position of Chief Commissioner

[1] Minutes of Proceedings Inst. C.E., vol. cxiii. p. 362.

of Railways at Sydney. Sir George had no hesitation as to his recommendation, and in August, 1888, Mr. Eddy left England to occupy the distinguished post of Chief Commissioner of Railways for New South Wales. Before leaving he had fully posted himself in the history of railways in Australia, the abuses which had existed in Sydney, and the political discussions which had led to the determination to keep the railway administration free from political bias; and he wisely resolved to keep himself clear from the slightest suspicion of partizanship, and to make his sole aim the efficient carrying out of the duties of the Railway Commission for the benefit of the traders and community of the colony. After explanatory conferences with the authorities he obtained permission to enlist the services of some trustworthy officials from England to take charge of some of the most important departments, and he then set to work to combat the difficulties surrounding him. He found all the departments in a grave state of disorganization. Mr. Eddy, however, was not the man to be daunted by the prospect. He found among the Commissioners comrades who thoroughly supported him when they saw his masterful capabilities. Having ascertained the necessity for obtaining new rolling stock on an extensive scale, he made numerous experiments to decide upon the most suitable class of locomotives for the nature of the traffic and the gradients of the lines. He weeded out inefficient men, rearranged the hours of working, raised the pay of the deserving, and rapidly applied to all lines the most approved methods of signalling.

Such changes could not be carried out without giving rise to much opposition. Charges of nepotism, favoritism, personal interest in contracts, were freely made. They were soon found to be false, however: one apology after another had to be made, and at length Mr. Eddy silenced all opponents. The reports[1] submitted annually to the Parliament of New South Wales by the Railway Commission showed a constantly increasing receipt per mile for the train earning, and a constantly decreasing cost of working; as well as recording instances of the careful adjustment of rates for the benefit of traders—results in all departments were shown by means of tabulated coloured diagrams in addition to the columns of figures, and these pages gave an increased interest to the Commissioners' Annual Reports. Improved train services, improved rolling stock, the introduction of sleeping saloons on the night trains, and a general smartening of the service gave evidence

[1] These Reports are in the Library of the Institution.

of Mr. Eddy's energy, and the business men of Sydney and the colony felt that in him they had a reliable and valuable officer, who not only understood the requirements of the public but was able to give effect to them in the working of both the tramways and the railways.

In 1895 Mr. Eddy was granted leave of absence for twelve months, in order that he might attend the International Railway Congress, which was held in London in July of that year. In the previous year, probably annoyed by the unceasing attacks of the labour party, he had listened to the request of some English friends to allow himself to be put forward for the office of Chairman of the South Eastern Railway. The proposal, however, proved abortive, and, while staying in England for the Congress, he arranged with the authorities in Sydney for a renewal of his term of office as Chief Commissioner of Railways. His return to Sydney was warmly welcomed by the whole of the commercial interests of the colony, and the energy of his active supervision was again evidenced by the continued success of the Railway Department, now becoming a valuable contributing element to the Colonial Treasury. The question of adopting a uniform gauge throughout the whole of Australia, or at least as between New South Wales with Queensland on the north and Victoria in the south, was a subject on which he had bestowed much thought; and, had he lived, in all probability some mode of meeting the difficulty for main-line through traffic, as a commencement, would have been achieved.[1] In the last year or two improvements in the lines by adopting deviations to reduce gradients, and by flattening many severe curves, occupied much of his attention, the record of each year's work being very clearly shown in plans attached to the reports.

Mr. Eddy's residence was at Colebrook, Double Bay, in the immediate neighbourhood of Sydney. He was a man of powerful frame, and upwards of 6 feet 2 inches in height, his robust presence and large flowing black beard forming a striking figure at railway gatherings. The public funeral of Mr. Eddy at Sydney is reported to have furnished the largest demonstration of a similar character ever seen in that city, and the presence of three thousand railway men following the procession to the cemetery formed a well-deserved tribute to his memory.

Mr. Eddy was elected an Associate on the 4th December, 1888.

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[1] Minutes of Proceedings Inst. C.E., vol. xx. p. 111.

*** The following deaths have also been made known since the 12th May, 1897:—

Members.

ABERNETHY JAMES; *died* 30 May, 1897, *aged* 53.

BELL, JOHN MCKENZIE; *born* 10 June, 1848; *died* 4 December, 1896.

DUNDAS, ROBERT; *born* 31 December, 1838; *died* 28 June, 1897.

GREW, NATHANIEL; *born* 6 October, 1829; *died* 11 July, 1897.

Associate Members.

OGILVIE, ARTHUR GRAEME, B.A.; *born* 31 January, 1851; *died* 29 July, 1897.

PAGE, WILLIAM; *died* 28 June, 1897.

SACRÉ, ALFRED LOUIS; *died* 25 July, 1897, *aged* 56.

SCOTT, FRANK WALTER, Jun.; *born* 3 November, 1864; *died* 22 July, 1897.

Associate.

CASEBOURNE, CHARLES TOWNSHEND; *born* 28 June, 1836; *died* 17 May, 1897.

Information as to the professional career and personal characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 31 July, 1897.

Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

Cement Testing during the Years 1893-94—1895-96.

M. Gary.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1896, p. 256.)

The results of the tests on Portland cement carried out during the three years at the Royal Testing Laboratory are given in tabular form, the makers' names being suppressed, and the origin of the various cements indicated by reference-letters or numbers, so that results below the average might be published without prejudice to the business of the makers in question.

The gradual improvement in Portland cement effected since 1879, as shown by tenacity, compressive strength, fineness of grinding, is briefly discussed and illustrated by curves.

A. S.

Sand and Cement Sieves. M. Gary.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1896, p. 294.)

It had often been noticed that different deliveries of normal sand—the size of grain of which lies between the limits of 60- and 120-mesh sieves—were perceptibly different; and since the size of grain of sand affects the strength of the cement mortar in which it is mixed, it was resolved to see whether the normal sieves agreed with the specifications to which they were supposed to be made. The investigation shows that all the sieves examined differ widely from the ideal sieve, particularly in uniformity of pitch of the wires.

The Author describes an experimental sieve formed of parallel rectangular slots in a flat plate, and which, therefore, would allow disk-shaped particles to pass through which would be retained by the ordinary wire-sieve of equal width of opening.

The Paper is accompanied by numerous photographic reproductions, to an enlarged scale, of many of the sieves examined.

A. S.

On the Resistance of Natural and Artificial Stones to Attrition by Friction. S. Canevazzi.

(Il Politecnico, 1897, p. 155.)

This is a record of a series of experiments carried out at the University laboratory of Bologna, to determine the relative wearing resistance of various paving materials. In the testing-machine employed (Dorry's) pressure of varying extent could be applied in a continuous succession of contacts at varying speed; the surface of contact being constantly supplied with a fine powdering of sand and sprinkled with water. The circumference of the pressure wheel was 5·37 feet. The speed at which it was worked averaged 34 revolutions per minute; but for the investigation of special cases varied from 20 to 80 revolutions per minute. The general pressure was maintained at a constant rate for each experiment, varying from 1·42 lbs. to 3·55 lbs. per square inch. The process was stopped at every 200 revolutions and the result recorded. The general duration of the experiments was from 1,000 to 4,000 revolutions.

Granite was taken as the standard of reference; and the principal typical results, selected from the full report, are here tabulated:—

Material.	Power Applied.	Number of Revolutions.	Thickness of Material Worn.	Coefficient of Wear.	Coefficient of Resistance.
	Lbs. per Sq. Inch.				
Granite (best quality) . .	2·84	..	..	1·00	1·00
"Macigno" from Ponetta (limestone) (lower miocene)	2·84	3,000	0·0132	3·64	0·275
"Macigno" from Burcianella (fine conglomerate) . .	2·84	4,000	0·0085	1·76	0·568
Sandstone (Pesaro) . . .	2·13	3,000	0·0147	5·40	0·185
Bergamo brick	2·13	5,000	0·0067	1·48	0·676
Paving tile, brown	2·84	3,000	0·0058	1·60	0·625
,, ,, white	3·55	2,400	0·0103	2·84	0·352
Compressed paving brick (1st quality)	2·13	600	0·0112	20·56	0·048
Paving cube, red	2·84	1,200	0·0146	10·00	0·100
,, ,, white . . .	2·84	1,200	0·0068	4·68	0·214
Asphalt slab	2·13	1,200	0·0150	13·77	0·073
Cement ,, ...	2·84	1,200	0·0095	6·54	0·153

P. W. B.

Experiments on the behaviour of Cast-Iron Columns in Fire.

H. SCHÜLER.

(Deutsche Bauzeitung, 1897, pp. 232, 242.)

In consequence of the warehouse fire in Hamburg in 1891 the Senate of the city caused experiments to be made with wrought-iron and timber stanchions [1] which were continued, in 1895, with cast-iron columns 10 feet 8 inches long, $10\frac{1}{2}$ inches diameter, and $1\frac{1}{8}$-inch or $\frac{1}{2}$-inch metal, centrically or eccentrically loaded, with or without fireproof casing. They were furnished with spherical ends and placed upright, gripped by the two halves of an oven, 2 yards high, swinging on door-hinges and containing twelve gas-burners which emitted flames at least a yard high. A hydraulic press was below the column and its crosshead above it. The oven was furnished with apparatus for measuring heat, &c., with peep-holes and with the nozzle of a fire-engine. On an average a load of 3·2 tons per square inch, with a red heat of 1,400° F., obtained in thirty-five minutes, produced deformation in a centrically loaded column without casing, which showed itself by bulging all round in the middle of the heated part, especially where the metal happened to be thinner; fracture occurred finally in the middle of the thickest point of the bulge. If the load was less this occurred at a higher temperature, and *vice versâ*. Jets of water had no effect until deformation heat was reached. The casings tried were of Monier structure, of patent "Korkstein," of asbestic silicious marl and of asbestic cement. These had the effect of increasing the time, till deformation heat was reached, from thirty-five minutes to four hours or five hours, with a measurable temperature of 2,000° F. to 2,500° F. The best result gave a casing of asbestic silicious marl, as a temperature of 2,000° F. was maintained for seven hours, and the deformation diagram justified the conclusion that the column might have stood two hours longer. It is the most expensive casing. The greater thickness of metal in the columns had comparatively little effect on the time, but on the whole a thickness not less than $1\frac{1}{8}$-inch seems advisable. Ventilation through the column had a beneficial effect. The behaviour of hollow cast-iron columns, even without casing, is superior to that of ordinary wrought-iron stanchions.

M. A. E.

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[1] Deutsche Bauzeitung, 1895, pp. 274, 290.

Resistance of Bars to Compression. DUPUY.

(Annales des Ponts et Chaussées, 1897, p. 1.)

This Paper forms a sequel to a similar one on tensile tests which appeared in the "Annales des Ponts et Chaussées" of January 1895,[1] and describes the tests of three sets of bars, 0·39 inch, 0·59 inch, and 0·79 inch thick respectively, and all 1·18 inch wide, 14·11 inches long in the reduced portion, with ends 3·94 inches long and 2·36 inches wide. Each set comprised ten bars, numbered consecutively from one to ten. Of these No. 1 was reserved untested. Nos. 2, 4, and 5 were tested under tension to determine the coefficient and limit of elasticity of the material. These tensile tests, in addition to confirming the conclusions already arrived at, brought out the fact that the molecules of a bar submitted to tension up to the elastic limit, recover their equilibrium slowly. The remaining bars were for the most part submitted to compressive tests—some with fixed ends and supported in the middle to prevent bending, and others free—and a large portion of the Paper is devôted to a detailed description of each of the tests.

The conclusions of the Author, as a result of these experiments, are that when a bar is compressed it shortens proportionately to the compressive stress up to a certain limit, termed by the Author the compressive elastic limit. Beyond this the bar continues to shorten to a certain amount with no increase of stress, and beyond this again the shortening only continues with increased pressure. If the compressive elastic limit is not exceeded the bar will, on the removal of pressure, recover its original length, but if strained beyond this limit it will be permanently shortened. The compressional and tensional limits of elasticity are nearly the same, the former appearing to be slightly the higher; and tensile stresses applied to a bar do not seem to affect the compressive elastic limit. The safe limit of load on bars under compression and not fixed at the ends should be not more than one-third of the compressive elastic limit when this is less than $E\,I\,\frac{\pi^2}{l^2}$, and not more than one-third of $E\,I\,\frac{\pi^2}{l^2}$ when this latter expression is less than the elastic limit. In this expression E is the coefficient of elasticity, I the least moment of inertia of the bar at its centre, $\pi = 3\cdot 14159$, and l is the length of the bar. When the vertical axis of the bar does not coincide with the line of pressure, the calculation of the stresses in the several fibres of the bar is described by the Author in the "Annales des Ponts et Chaussées" of September 1896.[2]

Two sheets of elasticimeter (Klein's) diagrams, and several small cuts illustrate the Paper.

R. B. M.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxi. p. 402.
[2] *Ibid*, vol. cxxviii. p. 365.

An Arrangement of Joints in Braced Girders to avoid Secondary Stresses. MESNAGER.

(Annales des Ponts et Chaussées, December, 1896, p. 750.)

This article deals with a method of attachment for the bracings of triangulated girders with a view to avoid the stresses due to internal bending moments at the riveted joints when the girder is loaded, and consequently slightly deformed. The proposal of the Author is to substitute, in the place of the vertical gusset plates by which these attachments are usually made, single plate connections in planes at right angles to the plane of the girder, these plate connections allowing of a certain amount of flexure near the points of attachment when the girder is deformed. The Author calculates the amount of this flexure, and the consequent length of plate required to allow of the bending taking place with safety, and he illustrates his proposals by details of such joints in a girder of 178 feet 10 inches span (centres of bearings).

The Author discusses the details of this girder very thoroughly and the article is illustrated by two sheets of details of the girder, as well as several explanatory diagrams in the body of Paper.

R. B. M.

Recent Tests of Bridge Members.

J. E. GREINER, M. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, May, 1897, p. 237.)

This paper describes some tests made of the tensile strength of built-up bridge members, and the following are some of the results arrived at:—

Built I-shaped tension members, composed of four angle-bars connected in pairs by single lattice bars, or by batten-plates, spaced at short intervals, and having end connection plates, riveted to the projecting legs of the flange angles, developed an ultimate tensile strength which bears a ratio to that of specimens cut from the member, comparable with the ratio of the ultimate strength of annealed eye-bars to that of unannealed specimens; similar members, with solid web-plates, were fully as strong per unit section, provided the area of the web-plate did not exceed half the area of the four angles, although with double latticed-webs they were inferior. Such members, with open webs, having the lattice bars arranged alternately perpendicular to and inclined to the long axis, showed the least distortion when pulled to destruction, and gave the highest ultimate strength. Box-shaped sections, composed of two web-plates and four angle-bars, connected top and bottom by lattice or battens, and having pin connections through the web-plates, are no stronger than I sections.

A. W. B.

Statutory Regulations concerning Iron Bridges in Austria and Prussia. F. STEINER.

(Technische Blätter, 1896, p. 10.)

The regulations for the design of iron bridges issued by the Prussian Minister of Public Works in 1895, and those issued by the Austrian Board of Trade in 1887 and 1892, are compared and discussed by the Author. The extracts selected for discussion are printed in parallel columns; the Author's remarks then follow. Among the subjects discussed are: working loads, calculation of bending moments and of shearing forces on main girders, wind pressures, secondary stresses arising from stiffness of riveted joints of members, temperature changes, curvature of the track, &c., and stresses allowed on material.

The Paper is accompanied by numerous Tables and figures of illustrations.

A. S.

Suspension Bridge over the Ohio River at East Liverpool, U.S.

HERMANN LAUB.

(Engineering News, New York, 1 April, 1897, p. 198.)

The bridge has a channel span of 705 feet, and two side spans of 420 and 360 feet, the latter being followed by a 140-feet steel viaduct. The stiffening girders, 20 feet deep and 20 feet apart, are suspended every 15 feet from the cables and fixed to the latter in the centre, while the expansion joints are at the towers. These consist of two uprights 30 feet apart across the bridge, 70 feet high above the bottom flanges of the girders, and 106 feet above the masonry piers, which are 54 feet above low water. The uprights are composed of two steel members of tubular section connected by lattice bracing, 12 feet apart at the bottom and 6 feet at the top. The uprights are connected crossways by diagonal bracing. The cables are laid on cast-iron saddles resting on rollers. They consist of seven strands of 200 wires, No. 8, B.W.G., having a strength of about 200,000 lbs. per square inch. The strands terminate in links at the top of the anchorage, with 6 inches adjustment, and are attached to the anchorage chain, which is entirely embedded in concrete. In making the strands the wires were supported every 50 feet by a U-shaped casting on a small post; but there was an interval of 225 feet, so as to obtain a measurable sag, and thus the means of adjusting the wires to equal length. The wires were then clamped with tongs and bound with short pieces of wire every 14 inches, and the strands were laid aside. Two $1\frac{1}{8}$-inch carrying-ropes had meanwhile been placed 5 feet higher than the final position, and the strands were furnished every 50 feet with a two-wheeled trolley for travelling on the carrying-ropes, and hauled across by means of a hauling-rope and an engine opposite. Each strand was lowered into the saddle after hauling across, and its length adjusted at the end links. The binding-wires were then removed, beginning in the middle, and immediately clamped every 15 feet to make the cable, which was wrapped by machinery. It took thirty-three days to make the fourteen strands, eight hours to raise a strand, and an hour to wrap 3 feet of the cable at each of the machines.

M. A. E.

The Suspension Bridge over the Ohio River at Rochester, U.S.

E. K. Morse.

(Engineering News, New York, 1 April, 1897, p. 194.)

The bridge has a channel span of 800 feet and two side spans of 400 and 416 feet, supported by two cables, also a viaduct 570 feet long, and is designed to carry 80 lbs. per square foot, and two 15-ton coupled tramcars on each of the two tracks of a 22-foot roadway, on each side of which is a 6-foot footpath.

The construction differs in some important points from ordinary practice. The stiffening girders, 18 feet deep in the middle and at the anchorages, are 28 feet deep at the towers, and both flanges are fixed to them, while the expansion takes place in the middle and at the ends. The steel towers extend 80 feet above the bottom flange, giving a versed sine of 72 feet to the cable, and about 50 feet below the bottom flange, resting on masonry piers. The four uprights, of which each pillar of a portal is constructed, form a square of 15 feet at the bottom to 5 feet at the top, and are braced together only by stays and gussets, while crossways the two pillars are connected by diagonal bracing. The cables are also fixed to the pillars, so that the latter are compelled to follow the movements of cable and flanges at the connections. This exceptional mode of construction is the result of the Author's observation of existing suspension bridges under the load, and he expects to obtain by it greater stiffness without injurious effects. Each cable is composed of seven strands of 222 wires, No. 8, B.W.G., having a breaking strain of 200,000 lbs. per square inch. They were made on the site, the parallel wires being lashed every 3 feet, and placed in position by being supported by $1\frac{1}{4}$-inch carrying-ropes by means of hangers and sheaves about 50 feet apart. The strands had then to be adjusted and clamped with some difficulty, on account of the changing temperature. After adjustment the lashings were removed from the strands and the wires clamped and bunched into cables, and then wrapped by machinery. The Author remarks upon the irregularity of tension in the wires, consequent upon this method of cable-making, and also upon the slowness of the process, and mentions his intention to use manufactured ropes for the strands in a bridge for which he is now making the plans. The cost of the bridge, including rights of way, etc., is $175,000.

M. A. E.

The New Huron Street Lift-Bridge, Milwaukee, U.S.

M. G. SKUIKE.

(Engineering News, New York, 22 April, 1897, p. 253.)

A creek or navigable channel from the great lakes penetrates into the heart of the commercial centre of Milwaukee city.

As business increased, there arose a pressing demand for a bridge across the waterway, to connect the two portions of the town, and accommodate the constantly-increasing traffic. At the same time, the water-area being limited and the tonnage considerable, it was important to avoid, in every possible way, any obstruction to navigation and to shipping and docking operations. The channel at site is 220 feet wide with a head-way of about 12 feet only. The substructure consists of two abutment walls, 80 feet in length, and of four piers, 25 feet by 10 feet in plan; all resting on piles driven 57 feet below datum into the solid stratum.

The superstructures consist of two approach-spans, 87 feet and 42 feet respectively in length, and two equal parts of a lift-span each 46 feet long. The clear width of the roadway is 34 feet with side-walks 9 feet wide on the stationary, and 7 feet wide on the movable sections of the bridge.

The special feature in the bridge is thus described by the Author and designer. A triangular supporting girder, anchored at its near end into the abutment, carries a pair of rollers on its top and forward end, which support the rear end of the girder. The forward support of the main girder is formed by a swinging strut, pin-connected to it at the upper end, and to the base of the triangular girder at the lower end. The main girder is double for the rear and middle frame.

Each of the two parts for the rear panel is provided with a curved track, which runs on the supporting rollers when the bridge is swung. The whole movable part is counter-weighted so as to bring the centre of gravity to a certain point, and the curved track is laid out so that this point moves in a horizontal line when the bridge is swung. The rule for constructing the curved tracks may be thus expressed: A perpendicular line through the centre of gravity, the centre line of the swinging strut, and a line rectangular to the tangent of the curve intersect in one point for any position of the movable part. In consequence of this rule, the weight of the movable part and the two-end reactions (compression in swinging strut and pressure on rollers) are in equilibrium for any position of the movable part.

The amount of counter-weight required for one movable part is a little over 100,000 lbs., the total weight of one movable part is about 225,000 lbs., including counter-weight.

To those acquainted with lift-bridges, the Author says, the advantages of his system as regards counter-weight will be apparent. All other existing types of lift-bridges (excepting those lifted vertically on towers) require such an amount of counter-weight as to bring the centre of gravity over the supporting piers. In cases where the height of structure is limited, this condition not only forms a difficult task for the designer, but also adds greatly to the weight of the moving parts.

The operating machinery is of the simplest kind. The two inclined working struts are provided with steel racks, into which two pinions engage, mounted on the ends of the main shaft, which is $5\frac{1}{2}$ inches in diameter. The main shaft carries a cast-iron gear-wheel 87 inches in diameter, which is worked by a 9-inch pinion mounted on the $3\frac{1}{4}$-inch counter shaft, which is driven by the gear of a 25-HP. Gibbs electric motor. A separate set of gearing for the purpose of working the bridge by hand-power is also provided. The time of opening or closing the bridge by the motor ordinarily ranges from twenty-five to thirty-five seconds, the average being thirty seconds. The amount of power consumed is 9 to 10 electrical horse-power on an average according to measurements taken by Messrs. Goltz and Sinclair, electricians of Milwaukee. The contracts for the sub- and super-structures of the bridge amounted to close on £10,000. The Paper is illustrated by photographs, a general small scale elevation, and a sheet of details.

W. A. B.

Painting Metallic Structures.

(Engineering, 14 May, 1897, p. 650.)

Experience shows that pigments, usually metallic oxides or carbonates, act as carriers of oxygen from the air to the underlying iron, causing it to rust. An ideal paint should have a toughness which does not depend on a perishable ingredient; its elasticity should not be diminished by cold; it should not soften but rather harden by heat; it should contain no solvents but turpentine, which experience proves to be safe and not disagreeable; and it should contain nothing which will act as a carrier of oxygen to the metal. The writer maintains that the maximum durability is only to be reached by a compound of hard asphaltum, copal gum and linseed oil, thinned, if necessary, with pure turpentine. In America large steel waterpipes have been japanned with great success. In the case of a 38-inch steel pipe laid at

Rochester, New York, in 1893, twelve 28-foot sections of pipe, each weighing $2\frac{1}{4}$ tons, were japanned in a specially constructed furnace in one charge. A special baking japan was used, and the coating formed was very thin. It was extremely adherent and was not removed under the blow of a hammer, while the pipes stood transportation without abrasion. The danger of corrosion appears to deter English engineers from using steel pipes to the extent they are used in America. Possibly the japanning method would obviate this difficulty, which is a very real one, especially in view of the great extension of electric tramways.

A. P. H.

The Coast near the New Port of Heyst. C. van Mierlo.

(Annales de l'Association des Ingénieurs sortis des Écoles spéciales de Gand, 1896–97, p. 5.)

This essay is intended to show hydrographically what is the general tendency of the currents opposite Heyst. This port lies midway between Ostend and Flushing, and the object of the Paper is rendered easier by the very complete set of observations made by Lieutenant Petit in 1882, supplemented by those taken in 1894–95 by the Author.

The Author endeavours to prove that the action of the tides, waves and currents have a general tendency to carry the sand and sediment along the shore from the mouth of the Scheldt westwards, with the result of gradual shallowing of the water opposite Heyst. After briefly describing the method in which the soundings and observations were made, Mr. van Mierlo draws attention to the differences between his soundings contours and those of Lieutenant Petit, twelve years earlier, and he quotes the remarks of this officer on the differences between these 1882 contours and those taken at an earlier date.

Not content with this, however, the Author has taken careful observations of the direction and velocity of the tidal currents at different states of water (from high to low, and from spring to neap tide) from the two lightships "Wandelaar" and "Wielingen"—which lie about west-by-north and north-by-west respectively of Heyst—and the consideration of the effects of these currents occupies a large portion of the Paper. The general effect he concludes to be a slight tendency towards the west, while any counteracting effect of high winds cannot be serious.

Then follows the discussion of how this tendency of the tides is affected by the conformation of the sea bottom, and by the changes which have taken place in latter years at the mouth of the Scheldt. Mr. van Mierlo compares the several charts of this part of the coast covering the period from the commencement of the century to the present time, and he shows how during the earlier portion of this time no serious changes took place. Then, however, some works were carried out at the mouth of the river, resulting in considerable changes in the contour of the banks round Flushing, and he points out how these river currents have been diverted towards the west with a tendency to deposit silt along the shore in front of Heyst, thus assisting considerably the action of the tides. The Author goes very carefully into all the circumstances, and the Paper has an additional interest as showing the influences which must be considered in a case similar to that of Heyst.

The following charts of the coast accompany the Paper:—one prepared by the Author from his own observations, on which are also shown the contours taken by Lieutenant Petit; the charts of 1801, 1825, 1842, 1855, 1865, 1878 and 1882, as well as three small charts of the mouth of the Scheldt dated 1800, 1862 and 1892. R. B. M.

The Effect of Wind and Atmospheric Pressure on the Tides.

F. L. Ortt.

(Nature, 27 May, 1897.)

The Author recognizes the work of the British Association Committee of 1895 appointed to consider the subject,[1] but thinks that, owing to the method of investigation employed not sufficiently eliminating the effect of wind, the results obtained are not satisfactory. The hypothesis is that wind blowing in the direction of the tide increases the range of tide, the high-water being raised and the ebb lowered, whilst wind blowing in a direction opposite to the tide has the contrary effect. These considerations do not accord with the observations of the Dutch engineers on the coasts of Holland, which show everywhere that both high- and low-water are raised or depressed by the wind, so that the range of tide is not considerably affected. Another point of difference is that the most important influence is not felt when the wind is blowing in, or opposite to, the direction of the tide, as was supposed by the British Association Committee, but, on the contrary, when the wind is blowing at right angles to the coast-line.

In support of these objections the Author gives the results of elaborate observations made at Hoek van Holland, and at Ymuiden, which tend, with surprising clearness, to the conclusion that the raising or depressing is proportional to the pressure of wind, and that the advance or retardation in time is proportional to the velocity of wind. F. G. D.

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[1] Report of the British Association for the Advancement of Science, p. 1896, pp. 503 *et seq.*

Dredging on the Sand-Bar of the Loire. De Joly.

(Annales des Ponts et Chaussées, 1897, p. 193.)

The shipping trade of Saint-Nazaire, having suffered much from the gradual shallowing of the water at the mouth of the Loire, it became necessary to take some steps to open and maintain a channel of sufficient depth across the bar, to allow vessels to enter the river at longer periods at high tide, as well as in all states of the weather. The first part of this Paper deals with the state of the bar during the years preceding 1889, its formation and character, and the effect on it of the weather, tides and currents. It was finally decided to dredge experimentally, in order to see if a channel formed in this manner would keep open with a reasonable amount of maintenance; and the experiment being successful, the necessary powers were obtained to form a channel 656 feet wide on the bottom, which was to be at the level of 16 feet 5 inches below water line (French sea datum); and the amount to be dredged was estimated at 1,308,000 cubic yards.

The trial work was let to Messrs. Volker and Bos, of Holland, at 6·19*d.* per cubic yard, being 15 per cent. below the estimated cost, and the same firm took the final contract at a price 2 per cent. below the estimate of 5·8*d.* per cubic yard, formed on the results of the experimental work. When the 1,308,000 cubic yards had been removed, however, it was found that the channel, although of the required depth, was neither of the full width, nor straight, and first 216,700 cubic yards, and then 196,000 cubic yards were further removed, partly to straighten and widen the channel, and partly to ascertain the amount of dredging which the channel would require to keep it open. The contract amount of 1,308,000 cubic yards was removed by four suction hopper-dredgers in fourteen months, the spoil being dropped at sea about 3 miles from the bar. The additional work was done with one dredger in eleven months, the price for the last portion being 4*d.* per cubic yard.

The Author gives very complete tables of the work done by the several dredgers, which varied from 100 to 150 HP., 114 feet 9 inches to 137 feet 9 inches long, with a hopper capacity of from 270 cubic yards to 434 cubic yards up to the top of the coamings. The vessel which carried out the supplemental dredging was the largest of the four first used, and was enabled to work for the first portion during 81 days out of the available 148 days it occupied over the work, while for the second portion, during only 68 days out of 181 days. The average daily amount dredged was slightly over 2,600 cubic yards, at a cost of from 1·25*d.* to 1·22*d.* per cubic yard, including no allowance for profit, interest, or cost, or sinking fund.

With the experience of their contractors before them, the port authorities then ordered a suction dredger 160 feet 9 inches long, 30 feet 6 inches wide, and drawing 11 feet when fully loaded.

The hopper capacity to the top of the coamings was 565 cubic yards, the HP. 400 (on trial 482 HP.), and a speed of 7 knots (on trial 7·86 knots). The suction tube was 23 inches diameter, and could dredge to a depth of 39 feet 6 inches. The cost was £14,120, including the bonuses to the contractors on the trial results. During the seventeen months for which this vessel worked, in 1894 and 1895, 466,000 cubic yards were removed, although for nearly two months it was lent to the Loire Navigation Service to try the effect of dredging near Paimbœuf. During 1895 the dredger worked 122 days, with a daily average of 2,054 cubic yards, at a cost of 1·46*d.* per cubic yard, not including any interest or sinking fund charges. The crew consisted of a superintendent, captain, three sailors, an engineer, two stokers, a coal-trimmer, and a boy, and they received a bonus per 1,000 cubic yards dredged in addition to their pay.

The Paper concludes with a description of the buoying and lighting of the channel, and the considerations to be borne in mind when determining the lights. The Paper is illustrated by three charts of the mouth of the Loire, two sheets of diagrams of winds, tides, and currents, six plans of soundings taken at various times on the line of the channel across the bar, and a sheet of details of the new dredger for the service of the port.

R. B. M.

The Construction of the König Albert Harbour at Dresden-Friederichstadt. G. Grosch.

(Zeitschrift für Architektur- und Ingenieurwesen Hannover, 1897, p. 1.)

This article describes in full these works, and is illustrated by two large lithograph plates showing the general arrangement of the harbour sidings, &c., and two other plates showing the details of the quay walls and of the steam-excavator used on the works; in the text also are various small diagrams.[1]

The commercial position of the harbour since 1874 is described, and the development of trade necessitating its enlargement, followed by a description of the position of the harbour with regard to the river Elbe, and the arrangement and direction of the entrance as best adapted for navigation. The excavation and dredging operations are given in detail; the total amount removed from the basins and entrance was 1,936,291 cubic metres (2,536,540 cubic yards), used either for the filling at the harbour quays, &c., or for the embankment of the Dresden-Friederichstadt station yard.

The quantity of masonry, &c., in the quay walls is given, and

[1] An abstract on this subject, from an article in an earlier weekly number of the same journal, appeared in the Minutes of Proceedings Inst. C.E., vol. cxxviii. p. 377, but the above deals with the matter much more in detail.—D. G.

includes 39,900 cubic metres (52,270 cubic yards) of granite and 51,740 cubic metres (67,780 cubic yards) of concrete.

The details of the quay walls are described, as also the bridges and new roadway, warehouses, cranes, &c. In this article, the cost of the harbour works (exclusive of sidings, marshalling-yard, &c.) is given as 4,595,000 marks (£229,750).

D. G.

The Construction of the Kaiser Wilhelm Canal. Fulscher.

(Zeitschrift für Bauwesen, 1897, p. 275.)

The article of which these chapters form a portion is of considerable length, appearing from time to time in the above journal, and not yet completed. The portion here referred to deals principally with a description of the excavators, or steam navvies, used, and of the various forms of dredgers and elevators.

There are eight photogravure illustrations in the text, one of which refers to an excavator, and the remainder to dredgers and elevators. In the "atlas" accompanying the journal are large plate engravings, numbered 33, 34 and 35, giving details of the above.

A comparative Table, extending over twelve months, is given of the amount of stuff dredged each month by five of the dredgers, the total being 1,310,000 cubic metres (1,713,480 cubic yards) in 1,239 working days of twenty-four hours. Each machine is fully described, and particulars are given as to the mode of working and results.

Twenty-eight excavators were used, of which twenty-four were supplied from Lübeck, three from Utrecht, and one from Berlin. Among the dredgers used was one suction dredger. All these were supplied either from Mannheim, Berlin, Utrecht, Lübeck or Hamburg. Besides the above were numerous smaller dredgers.

D. G.

Canal from the Baltic to the Black Sea.

(Zeitschrift für Binnenschiffsfahrt, 1897, p. 247.)

The preliminary surveys and estimates for the construction of this canal between Riga on the Baltic and Kherson on the Black Sea, a distance of 1,000 miles, are complete, and the work is shortly to be commenced.

The width at water-level will be 213 feet and at bottom 115 feet, with a depth throughout of 28 feet, so that it will be capable of carrying the largest ships at a rate of 6 nautical miles per hour. The transit will thus occupy six days and six nights.

The canal, for the most part, follows the course of the Dwina, Beresina, and Dnieper, and the deepening and regulating these rivers is the principal work, only a short length between Dunaburg and Lepel will require to be excavated.

There will be eighteen principal harbours and seven large railway bridges, and only two locks at each end. The tributaries will likewise be deepened and regulated for traffic and so become feeders to the main canal.

It is estimated that the canal will be completed by 1902 at a cost of £100,000,000.

The commercial and industrial results anticipated from this great undertaking are incalculable. A sketch map illustrates the Paper.

W. A. B.

The St. Lawrence Hydraulic-Power Scheme.

(The Engineer, 28 May, 1897, p. 553.)

In the neighbourhood of Massena the St. Lawrence River falls a height of over 56 feet in a distance of about 7 miles. The Grass River flows near to the St. Lawrence River, and flows into it some miles farther down. At Massena, however, it is 50 feet below the St. Lawrence River. Permission to cut a canal to utilize the fall between the two rivers has been obtained. This canal will be about 3½ miles long, 220 feet broad at the water-surface, and 26 feet deep. With a working head of 40 feet, it will carry enough water into the Grass River to develop 150,000 HP. It is proposed to put down fifteen sets of turbines and dynamos, each having an output of 5,000 electrical HP. The turbines and generators will be placed on horizontal shafts, and the speed will be 150 revolutions per minute.

A. W. B.

Sections of Masonry Dams. PELLETREAU.

Masonry Dams. L. DURAND-CLAYE.

(Annales des Ponts et Chaussées, p. 90.)

In the first of these articles, the Author commences the consideration of his subject by the determination of the form of a dam, rectilinear in outline, in which the line of resultant pressure shall not fall outside the middle third of any horizontal section, so that no portion of the masonry shall be subjected to tensional stress. For this he obtains the well-known formula :—

$$\tan^2 \theta = \frac{1}{D} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(i.)}$$

in which D is the specific gravity of the masonry, and θ the angle between the up- and down-stream faces of the dam, the up-stream face being vertical.

This section, however, he points out, is liable, owing to the possible formation of horizontal cracks, to allow a tensional strain to come on portions of the up-stream face; and any such horizontal cracks will, owing to the existence of this tension, tend to spread into the work, resulting in the final failure of a portion or the whole of the dam.

Mr. Pelletreau therefore proceeds to examine to what extent it is necessary to reinforce the dam in order to avoid this liability to tensional stress; and the formula he gives is:—

$$\tan^2 \theta = \frac{4}{12D - D^2 - 16} \quad . \quad . \quad . \quad \text{(ii.)}$$

In a dam constructed in accordance with this formula, the presence of a horizontal crack in the up-stream face will not cause tensional stresses in the masonry (that is to say, it will not tend to increase) until it has extended through nine-tenths of the horizontal section; but the amount of masonry will be increased by from 13 per cent. when $D = 2 \cdot 5$, to 25 per cent. when $D = 2 \cdot 2$. He also gives an intermediate formula:—

$$\tan^2 \theta = \frac{9}{12D - 11} \quad . \quad . \quad . \quad . \quad \text{(iii.)}$$

and in a dam of this section the crack can extend over one-third of the horizontal section before the material is subjected to tension. The increase in this case is 8 per cent. when $D = 2 \cdot 5$, and 13 per cent. when $D = 2 \cdot 2$.

He then discusses the possibility of so forming a dam as to prevent horizontal face-cracks, containing water under pressure, from extending into the main body of the masonry. This he thinks only satisfactorily feasible by a system of vertical piers covered on the up-stream face with masonry arches, so that any leakage through the face would drain away between the piers. He calculates the dimensions of these piers and arches for a dam 98 feet high with a distance of 33 feet between the piers, and covered in from pier to pier on the up-stream side with a facing of vertical semi-circular arches. The piers are highest on the up-stream side, and slope downwards on the down-stream side; while in order to steady them in the case of any accident to the arched facings, they are connected across by horizontal arches at intervals on the down-stream faces. Including these cross-arches, the Author calculates that the cubic contents of a dam 98 feet high on this arched system, and of equivalent solid ones in accordance with equations (i.) and (ii.), would be 378, 395, and 443–490 cubic yards per linear yard respectively, the last two figures depending on the density of the masonry.

There is a sheet of drawings showing the 98-feet dam referred to above, on the arched principle proposed, and also eighteen small explanatory diagrams in the body of the text.

The second Paper is a short note, with three explanatory cuts, showing how *vertical* cracks in the up-stream face of masonry dams will, by admitting water under pressure, have a tendency to spread into the work, and may extend in the direction of the length of the dam, thus causing partial instability, endangering the safety of the work as a whole.

R. B. M.

The Water-Supply of Magdeburg. PETERS.

(Gesundheits-Ingenieur, 30 June, 1897, p. 193.)

The pollution of the Elbe by the manufacturing waste waters discharged from the potash and soda works of Aschersleben and Bernburg had long been recognised as serious, and during the drought of 1892 the state of the river was such as to render the water quite unsuited for drinking purposes. This was partly due to the enormous increase in the impurities caused by the calamitous inflow of the water of Lake Mansfeld into the adjacent mines, out of which it had to be pumped into the Schlenze, a tributary of the Saale, but not before it had become saturated with salt in the vast rock-salt deposits of that district. Though every effort was made to minimise the evils caused by the discharge of industrial waste waters into the Elbe and the Saale, it was felt that the nuisance could not be further abated without striking a fatal blow at the prosperity of populous manufacturing districts higher up the river, and therefore attempts were made in 1893 to have recourse to springs. For this purpose Dr. Beyschlag was directed by the Government to investigate the geological conditions in the vicinity of Magdeburg, and to advise whether it would be possible to obtain from the subsoil a supply of suitable water for a population of 220,000 persons. An account is given of these researches, which have been conducted in 1893 and 1894, and have needed numerous borings over a wide range of country. Sufficient water has been encountered at a depth of 17 metres to yield a satisfactory supply, which can be brought into the town by gravitating mains, 30 kilometres in length, to the intake of the present waterworks, supplied from the Elbe. Mr. Thiem, of Leipsic, has been called in to report upon this source of supply, and as to the possibility of substituting the spring-water for that of the Elbe or of utilizing a mixed supply. In the meanwhile, the existing works, upon which enormous sums have been expended, must be kept up to the highest level of efficiency. Three new filter-beds are to be added to the eight already in existence, and these new beds may possibly have to be covered in for use in the winter-time.

G. R. R.

Water Supplies in Southern California. J. L. Van Ornum.

(Journal of the Association of Engineering Societies, February, 1897, p. 128.)

Among the most novel of the water supplies described in this Paper is that of the Verdugo Cañon Water Company, which has developed the low-water flow in the Verdugo Cañon by means of a submerged dam. This canon lies to the west of the San Gabriel Valley, on the south of the Sierra Madre. During the greater part of the year there is sufficient surface-flow to supply the consumers; but for a number of weeks in the year it is too small, thus necessitating artificial works. The dam was built in the bottom of the Verdugo Creek, where the latter is only 600 feet wide. The trench was excavated to the solid rock and a water-tight wall built from the bottom to near the surface of the bed of the creek. An unjointed pipe above the dam collects the water, and it is conveyed below the dam by a jointed pipe.

For the water supply of the city of Los Angeles two lines of 24-inch pipes with open joints are laid nearly parallel to the river, about 1,000 feet from it, and at a level of about 12 feet below the river bed. The service reservoir into which the pipe discharges is not covered, and there is consequently a tendency to luxurious plant growth; the best means of preventing its fouling the water has been found to be, to allow the growth of one particular plant, which prevented the multiplication of all other noxious growths, and to remove it every six or eight weeks when it reaches maturity.

An interesting feature in the water-supply of Lamanda Park, and of the great ranches to the north-west, which are supplied with water from the Precipice Cañon, is the automatic raising of the water collected by a tunnel at too low a level for gravitational supply, by means of water from a smaller tunnel at 370 feet additional elevation. This water passes through a 5-inch pipe, which is contracted at one point to about 3 inches, in front of which contraction a $\frac{3}{8}$-inch nozzle is placed in the centre of the 5-inch pipe, through which the high-pressure water passes, and easily raises the whole flow from the first tunnel the necessary 30 feet.

A. W. B.

The Cleansing of the Hamburg Open Filter-beds in Times of Frost.

(Gesundheits-Ingenieur, 31 May, 1897, p. 157.)

There are at the Hamburg Waterworks eighteen open filter-beds, each one having an area of 7,650 square metres of sand-surface; their arrangement is shown by means of a block plan. The engineer, Mr. E. Mager, has recently published an account of a dredging apparatus which he has designed, capable of being used under the ice in times of severe frost. Full details are given of the construction of this dredge, which is attached to a float, and is worked by means of wire-ropes inserted at either end of the tank. The action of the dredge is to remove the impervious skin or scum from the surface of the sand, and the apparatus can readily be emptied from time to time, whereby the impurities are deposited in heaps along the sides of the beds. It is shown by a tabular statement of results that, by the use of this apparatus, the filter yield was prolonged while the bacteriological analyses were entirely satisfactory. Full details are given in a series of photographs of the method of operating the dredge, and of the appearance of the sand-surface after the ice had melted and the water had been drawn off. The thickness of the ice varied from 10 centimetres to 33 centimetres, and it was only necessary to break a small groove along each side of the bed for the passage of the wire-ropes. The cost of the working compared favourably with the former plan of using lighters and upright dredges.

G. R. R.

Lead-Poisoning in connection with a Domestic Water-Supply.

V. Schneider.

(Gesundheits-Ingenieur, 31 March, 1897, p. 87.)

An account is given of a case of lead-poisoning which occurred in a forester's lodge situated in a bathing-resort in the mountains. The supply of water was formerly taken from a spring, distant about 50 metres or 60 metres from the house, but for the sake of convenience a pump was fitted up in the house, and a lead suction-pipe was connected with the spring. It came out in the evidence that the plumber, when laying the pipe, allowed a lot of the lead filings to remain in the joints, soldered in the usual way. A very few days after the completion of the work the daughter of the forester fell ill, and subsequently the mother and the father suffered acutely from colic. Finally the girl died, lead-poisoning was diagnosed, and a government inquiry was instituted into the water-supply. The post-mortem had demonstrated the presence of lead in several of the organs, and the water, which was extremely pure, was found to contain 0·95 milligramme of dissolved lead per litre. The degree of hardness was only 1·4. The Author directs attention to the facts of this case as elicited in the course of the inquiry, and to the manifest danger of the use of lead service-pipes in the case of a water-supply of great purity and freedom from hardness.

G. R. R.

The Distortion of riveted Pipe by Backfilling.

D. D. CLARKE, M. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, May, 1897, p. 221.)

In 1893 a conduit, 30 miles long, was constructed to bring the waters of the Bull Run River to the city of Portland, Oregon; 24 miles of this conduit consists of a riveted steel pipe 33 inches to 42 inches in diameter. The former were 0·22 inch thick, and the latter varied from 0·22 inch to 0·375 inch thick. After nine miles of the pipes had been laid, and the trench refilled, it was found that the crown of the pipe had been flattened by an amount varying from $\frac{1}{2}$ inch to 4 inches; the greatest depression not being coincident with the greatest depths of filling seemed to prove that the filling had not been properly consolidated. To confirm this, a plank box 20 feet long was constructed, in the bottom of which, and projecting at each end, a length of the pipes, 29 feet 3 inches long, was placed and tested under the following conditions: A length of the 33-inch pipe was filled around and above with sand, carefully consolidated to a height of $5\frac{2}{3}$ feet above its top; it deflected $\frac{3}{8}$ inch at the crown; after removing the sand it regained its original form. The thicker 42-inch pipe treated in the same manner deflected about the same amount, and the thinner 42-inch pipe deflected about $\frac{1}{2}$ inch. The pipes regained their former diameter when the sand was removed. More severe tests of a similar nature were also made, but, in subjecting the pipes afterwards to pressure of water, no leaks appeared.

A. W. B.

The Sewerage of Paris, together with the Purification of the Sewage Water.[1]

(Annalen für Gewerbe und Bauwesen, 15 May, 1897, p. 195.)

These works, begun in 1865, resulted finally in the Law of July 10th, 1894, which decreed for the whole of Paris that all excreta should pass into the sewers. The sewerage scheme naturally divides itself into two sections: (1) the system of sewers, and (2) the irrigation works for the utilization of the sewage water. The fouled water passes away in three main outfalls, termed "collecteurs," viz., those of Asnières, Biévre, and the Northern outfall. These outfalls, together with the areas for which they serve, are shown on a block plan. Sections are given of the different sewers, and a plan of the Plain of Gennevilliers, indicating the arrangements for irrigation, is appended. The Law of July 10th, 1894, is explained, and details are given of the alterations in the sewers, which have been rendered necessary by

[1] Minutes of Proceedings Inst. C.E., vol. cxxii. p. 438.

the introduction of this legislation. The main impulse to this extension of the drainage was the outbreak of cholera in 1892, which was attributed to the defective state of the sewers. In order to carry out the alterations rendered necessary under this Act, a loan of upwards of 117 millions of francs has been authorized. Irrigation areas and access to the same have cost about 30·8 millions; completion and extension of existing sewers and the provision of new intercepting sewers 35·2 millions; for the completion of the flushing services, the construction of the reservoir tanks, and the improvement of smaller sewers and connecting drains 50 millions, and expenses of loan $1\frac{1}{2}$ million of francs. Details are given of the cost of laying out and preparing the new areas for irrigation in the vicinity of Achères, and of the outfall to the same from Clichy. This sewer crosses the Seine in three different places, and the sewage-water has, on two occasions, to be raised by powerful pumps, involving the use of 1,200 HP. at the Clichy station, and 1,500 HP. at the works at Colombes, where the lift is 36 metres. A further extension of the areas under irrigation will embrace the land adjacent to the Seine at Méry, and further down the river, which can be commanded by gravitation. It is anticipated that the entire works will be completed by the year 1900, and when this is the case, the whole volume of the sewage of Paris will be diverted from the Seine.

G. R. R.

The Existing Methods of Clarifying Sewage-Water and their Respective Values. Dr. Marx.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1897, p. 260.)

The various chemical and other processes for the treatment of sewage are discussed, and the objects to be attained are examined. At the present time most of the authorities are agreed that the best results can be secured by means of irrigation, and the importance of the process of nitrification, due to the "action of a living ferment of the bacteria family" present in the soil, as pointed out at an early date by Mr. H. Robinson, is insisted upon. The opinions of numerous Authors are cited, and, from the point of view of the purifying power of rivers, attention is called to the part played by minute vegetable organisms, the action of which upon the polluting matters present is parallel to that of the bacteria in the soil. The lime process is explained, and the results attained by the use of this precipitant at various places are examined. A brief account is given of Scott's cement process, as also of the black-ash treatment of Hanson, and the systems advocated by Whitthread, Bird, Stothert, Anderson and others.

Passing on to methods of treatment where lime is not employed, allusion is made to the ferrozone-polarite process and the methods of treatment involving the use of electricity.

The Author sums up the results of his investigations in a series of eight conclusions, and he states that, while no absolutely perfect system of treating sewage is yet known, the best plan is, undoubtedly, that of irrigation on suitable well-prepared areas. Simple deposition in tanks, although the most imperfect of the modes of dealing with sewage, is advisable as a preliminary to the discharge of raw sewage into rivers. Both physical, chemical, and biological agencies play their part in the self-purification of rivers, but the most important factors are the species of algæ devoid of chlorophyl. Special advantages are attained by the Rothe-Röckner process, and the system introduced by Hulwa destroys all germs. The ferrozone-polarite process has proved itself to be the best of all systems which do not involve the use of lime. The treatment by means of electricity has not hitherto answered the expectations of those who anticipated that this process would afford a convenient, effective, and cheap method of clarifying sewage-water.

G. R. R.

The Conversion of Fæcal Matters into Poudrette.

Dr. Vogel.

(Gesundheits-Ingenieur, 15 March, 1897, p. 74.)

An account is given of the different processes in use for the preparation of poudrette from human excreta. It is stated by the Author that he has made an estimate of the total population of Germany resident in towns with over 5,000 inhabitants using the various sewage systems, and he finds that 95 per cent. resort to cesspools, 2 per cent. employ a tub system, and only a very small fraction enjoy the water-carriage system of sewerage. Mention is made of the Liernur process at Amsterdam, Podewils' system in use at Augsburg, the method of removal and manufacture practised at Warrington, and the process of Messrs. Venuleth and Ellenberger, introduced some years ago, in Darmstadt, and quite recently employed at Bremen. The excreta, collected in tubs, under this last system are acidified to prevent the loss of ammonia, and the amount of sulphuric acid employed had of late been doubled, leading to a considerable increase in the percentage of nitrogen in the manure. It is shown that owing to the treatment with acid and the boiling process, the latter occupying from 120 hours to 135 hours, all disease-germs are destroyed. The anticipation that the bulk of the dejections would be secured by this process for the benefit of the agriculturist is proved to be fallacious, and under the best conditions, in towns employing the tub system, only from one-third to one-half the excreta reach the factory. The manufacture of poudrette is recommended in the case of all small cities.

G. R. R.

The Dissemination of Infectious Diseases by Means of the Atmosphere.—I. Typhoid Fever. Dr. Eduardo Germano.

(Zeitschrift für Hygiene, 1897, p. 403.)

The majority of those who have written concerning the pathology of typhoid fever are of the opinion that air is one of the commonest mediums for the conveyance of typhoid germs; indeed, some consider that it plays such an important part in disseminating this disease that even water takes quite a secondary place. The Author reviews the conclusions formed by various writers and the cases upon which they founded their opinions. Concerning the vitality of the typhoid bacillus in a dry state, numerous observations are extant, which, however, are somewhat discordant.

In order to investigate this subject more fully, the Author conducted a series of experiments, the results of which are here set forth in Tables. His conclusions are, briefly, as follows:—

Contrary to the usual opinions, the germs of typhoid fever are unable to withstand complete desiccation. A case of infection through the air at a distance of several hundred metres would thus appear most improbable. On the other hand, these germs can preserve their vitality for a lengthened period where slight and scarcely apparent moisture exists. It is from clothing, wood, particles of dirt or excrement, and substances of this nature, which may contain the vital germs for a very long time, that the danger of infection is liable to arise. It is, in fact, owing to the possibility of storing up the germs for an indefinite period in a semi-dry state that this disease seems likely to be spread.

G. R. R.

Atmospheric Infection. C. Flügge.

(Zeitschrift für Hygiene, 1897, p. 179.)

It is stated that the conditions under which living disease germs are given out into the atmosphere by dry and moist surfaces, as also the facts relating to the transport of the particles of dust or moisture which act as carriers of such germs by means of air-currents, have not so far been studied with the care and attention which the subject deserves. The Author, after describing the experiments of previous investigators, and setting forth the results of their observations, gives an account of his own inquiries into this subject, extending over the past five years.

In the first instance he ascertained the strength and velocity of the air-currents needed to detach the germs of various known bacilli from surfaces of water, clothing, sand, &c., and the effect of damp or moisture in the air in hindering the same. He next gives the results of numerous experiments undertaken to ascertain the motion in the air of particles of dust and moisture which serve as the carriers of infected germs, and he describes the contrivances of which he made use in order to observe the velocity and character of the air-currents. In a third series of tests he examined the nature of the air-currents which occur in dwellings and which influence the spread of particles of dust or moisture containing germs. Diagrams are given to explain the position of the test-pieces in the room in which the experiments were conducted. Finally, he explains the conclusions which result from his investigations and which govern the dissemination of diseases due to parasitic germs. These latter he divides into two groups, and shows how much the relative moisture of the atmosphere can influence the transport by the air of disease germs under certain conditions.

G. R. R.

A New Method of Disinfection by means of Formalin.

Dr. Hans Aronson.

(Zeitschrift für Hygiene, 1897, p. 169.)

Reference is made to the almost simultaneous investigations by Trillat and by the Author in the early part of 1892 concerning the antiseptic properties of formic aldehyde, and to the subsequent efforts made to employ formic aldehyde gas for disinfecting purposes.[1] The difficulties arising from the tendency of the gas to polymerise in formalin solutions which exceed 40 per cent. in strength are pointed out, and the various ways in which it has been attempted by experimenters to avoid this danger are described. A simple apparatus, recently introduced by Messrs. Schering, and one which can safely be employed by persons who are not specially conversant with chemical manipulation, is described by reference to a diagram. This firm employs the stable polymerised variety of formalin known as Trioxymethylene, the vapours of which have already been shown to possess antiseptic properties. The substance in question, in lieu of being supplied in powder, is sent out in the form of tabloids, each weighing 1 gram. The action of the apparatus depends upon the transformation of the solid polymerised formic aldehyde into gaseous formic aldehyde by the heat evolved by burning methylated spirit in a lamp with three wicks. The hot gases from this lamp pass upwards through a metal stove, in the upper part of which is suspended a small cylindrical vessel to hold the tabloids of formic aldehyde. The vertical sides of this vessel are perforated so that the products of combustion from the spirit-lamp pass into it, and there mix with the vapours evolved by the heated tabloids, and there are then discharged into the space to be disinfected. The apparatus employed by the Author was capable of dealing with a charge of from 100 to 150 of the tabloids, and it was found that the spirit-lamp needed

[1] Minutes of Proceedings Inst. C.E., vol. cxxv. p. 471.

about twice as many cubic centimetres of spirit as there were tabloids used for the process. It is stated that no other known form of apparatus for disinfection can compete with the one herein described either in the certainty of its results or in the simplicity of its handling. A number of experiments conducted by the Author with various test-objects and bacilli are set forth in detail. A small form of the apparatus, in which one tabloid only can be used at a time, is well adapted for deodorising sick-rooms, closets, &c.

G. R. R.

The Use of Formic Aldehyde Gas for the Disinfection of Large Apartments. Dr. E. Pfuhl.

(Zeitschrift für Hygiene, 1897, p. 289.)

It is observed by the Author that, at the conclusion of his previous communication,[1] he called attention to certain results, stated to have been obtained by Trillat's process, by the use of an autoclave or digester, in which apparatus the formalin gas is evolved under a pressure of 3 to 4 atmospheres. The construction of the autoclave, which consists in the main of a copper vessel having a capacity of about 5 litres, with a flanged cover, secured in position by means of six thumbscrews, and which is furnished with a long delivery tube, is explained. The delivery tube is closed by means of a stop-cock, which is only to be opened when the internal pressure, as indicated by the accompanying manometer, reaches 3 or 4 atmospheres. The long tube, which has a bore of about 1 millimetre, can be passed through the keyhole of the door of the apartment to be disinfected, and this is in itself an obvious advantage when dealing with such a suffocating gas. The copper vessel must be filled about three parts full with a mixture of 35 per cent. to 40 per cent. formic aldehyde solution, decomposed by the addition of finely-powdered calcium chloride, in the proportion of 150 grains of the powder to each litre of solution. This mixture is called by Trillat "Formochlorol." The advantage of this procedure is that for reasons explained the polymerisation of the resultant formic aldehyde is prevented.

The Author calls attention to the results of previous investigations, and explains his own experiments to verify Trillat's facts by reference to a plan of the building in which they were conducted.

Numerous varieties of bacilli were subjected for various periods in the different rooms to the action of the gas. In some cases the bacilli were dried on to silk threads, in others, fresh cultures on agar were used, or fresh and dried samples of tuberculous sputum were deposited in selected places on floors and tables, rubbed into

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[1] Minutes of Proceedings Inst. C.E., vol. cxxvi. p. 440.

linen, &c. Seven sets of experiments are recorded, and the Author states that Trillat's process is applicable for surface disinfection under conditions set forth and only when the sample of formic aldehyde is such that the germs of *Staphylococcus aureus*, dried on to silk threads, are destroyed by it. This process is not advisable in the case of clothes, bedding, mattresses, &c.

G. R. R.

The Action of Formic Aldehyde as contained in Holzin and Steriform. Dr. PAUL ROSENBERG.

(Zeitschrift für Hygiene, vol. xxiv. pt. iii. p. 488.)

It is here pointed out that formalin must only be employed for the purposes of disinfection in a very dilute aqueous solution, and its applications are thus extremely limited. Formic aldehyde, however, now occupies the foremost rank as a disinfectant. As is apparent from the researches of Pfuhl,[1] formalin should not be used to produce vapour. From various considerations alluded to by the Author, it is evident that some change is needed, both in the existing processes of vaporization and also in the form in which formic aldehyde is employed; and it is here pointed out that in both these respects all that is required can be secured by the use of holzin and the special arrangement of vaporizer designed by the Author. This apparatus is here illustrated by a diagram. Moreover, by the employment of steriform, it becomes possible to enormously extend the applicability of formic aldehyde and to adapt it for therapeutic purposes. The composition of holzin (of the blue type) is explained. A detailed description of the apparatus used by the Author is given, and the results of a series of experiments are indicated. These investigations included tests, not only of the vapour, but also of the use of formic aldehyde in dilute solutions. Finally, to complete the tests of the effect of this substance upon the human subject, the Author treated himself with doses, increasing in strength, for a period of six weeks. Latterly he used internally steriform, a substance nearly free from taste and smell, and containing 5 per cent. of formic aldehyde. In conclusion, it is stated that, owing to the recent extraordinary improvements and simplification of disinfection by means of this process, it is possible, in the course of half-an-hour, to disinfect entirely a sick-chamber and all the contents with absolute certainty and to destroy every pathogenic germ. The use of this substance can also be recommended for agricultural purposes; such, for instance, as the disinfection of cattle-trucks.

G. R. R.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxvi. p. 440.

Alcohol as a Disinfecting Agent. DR. FERDINAND EPSTEIN.

(Zeitschrift für Hygiene, 1897, p. 1.)

Among the many preparations which have in recent years been recommended for disinfecting purposes, scarcely any have occasioned so much controversy as alcohol. The question of whether or no alcohol, used alone, is capable of destroying germs has received the most varied replies. Latterly the opinion has been mainly adverse to it, notably since Koch in 1881 proved that anthrax spores could remain for months uninjured in absolute alcohol or in dilute solution of the same; and, even more than this, that powerful antiseptics, such as carbolic acid, when dissolved in or admixed with alcohol, lose entirely their disinfecting action. A brief review is given of the opinions expressed by different writers on this subject, and the Author details the results of a series of special experiments undertaken by him to set this matter at rest. These tests took the form of cultures of various bacteria dried on to silk threads and exposed to the action of pure, absolute and diluted alcohol of four different degrees of strength, namely, 80 per cent. spirit, 50 per cent., 40 per cent., and 25 per cent. The results are set forth in Tables, and parallel experiments for the sake of comparison were made with other well-known disinfectants, such as corrosive sublimate, lysol, and carbolic acid in alcoholic solutions. Allusion is made to the recent investigations into the same subject by Mr. W. Poten. The Author draws the following conclusions from his experiments:—

(1) While absolute alcohol is devoid of disinfecting action, the same is not true of its solutions.

(2) Solutions of about 50 per cent. strength give the best results, when alcohol is used alone; when more concentrated and more dilute solutions are employed the disinfecting action is diminished.

(3) Antiseptics, which when dissolved in water are more or less active, lose their disinfecting action entirely when they are dissolved in highly concentrated alcohol; but, on the other hand, corrosive sublimate, carbolic acid, lysol and thymol, when employed in a 50 per cent. solution of alcohol, disinfect better than in an aqueous solution of equal concentration.

G. R. R.

The Germicide Properties of Ferric Sulphate.

Dr. ERHARD RIECKE.

(Zeitschrift für Hygiene, 1897, p. 303.)

This has reference to some tests conducted by the Author, at the instance of the German Agricultural Society, to discover how far the use of a given sample of ferric sulphate was capable of rendering infected human excreta free from danger. The substance in question was a fine powder of a dirty-white colour, nearly free from smell, but having an intensely acid and strongly-astringent taste. It was soluble in about ten parts by weight of water, and it was stated by the manufacturers to contain about 70 per cent. of sulphate of the peroxide of iron, readily soluble in water, a small quantity of ferrous sulphate and from 4 per cent. to 5 per cent. of free sulphuric acid. The actual analysis is given; the amount of ferric sulphate being only 58·53 per cent. It is pointed out that the free sulphuric acid present (equivalent to 5·14 per cent.) would in itself possess notable disinfecting properties, apart from the action of the iron salts, and some account is given of the investigations of former experimenters with dilute solutions of this acid. The Author, having in the first case ascertained that the substance itself was free from germs capable of cultivation, tried the effect of a 10 per cent. solution on bouillon-cultures of cholera and typhoid fever bacilli, to which it proved in all cases fatal. Subsequently a 5 per cent. solution gave similar results. The facts are recorded in a series of Tables, giving the effects of the ferric sulphate on numerous preparations of cultures of bacilli, as also on urine, acid and alkaline fæces, mixed excreta, and sterilized excreta with the addition of typhoid fever bacillus cultures.

These experiments proved that even in a 2½ per cent. solution ferric sulphate possesses an energetic disinfecting action upon the germs of cholera and typhoid fever, and may be safely relied upon for the destruction of these bacilli in human excreta. It may also be assumed that, while the sulphuric acid has some share in this action, the metallic salts present also play their part; and it was the fact of its being possible to employ these substances in the form of a dry powder which induced the Author to undertake a further series of experiments, in which the powdered ferric sulphate was mixed with dry peat, such as is employed in dry closets. The results are likewise set forth in the form of Tables, and lead to the conclusion that a mixture of two parts by weight of peat-dust with one part of ferric sulphate may safely be depended upon to sterilize cholera and typhoid fever dejections.

G. R. R.

Benzol as an Illuminant. Dr. Krämer.

(Journal für Gasbeleuchtung, vol. l., 1897, p. 369.)

At a meeting in Berlin of the Society for the Promotion of Industries, Dr. Krämer made an interesting communication with reference to the above. Without benzol the whole aniline dye industry and a long list of perfumes and soaps would be unknown. Hofman and Zinin first obtained aniline from benzol, and Hofman showed that it was obtainable from coal-tar. At first benzol was almost exclusively supplied from England. At the commencement of the year 1870 it was estimated that Germany only produced about one-eighth of its requirements, but it now produces three-eighths of the consumption. About 1½ per cent. of benzol may be obtained from good coal-tar; but, with the highly-heated retorts now generally employed, only 1 per cent. of the benzol is obtainable. According to Deville and Bunte, the gas itself retains an average of 92 per cent. of the benzol, and a process was for some time used in France for its extraction, but, as it is the principal carrier of the illuminating power, the value of the gas was depreciated and the process was abandoned. A further source of benzol is found by superheating hydro-carbons, especially paraffin oils and petroleum refuse, but very little has been done in this direction, except by the use of the hydro-carbon by-products obtained by the compression of rich gases for carriage-lighting. Endeavours have also been made to substitute naphthaline for benzol for the production of tar colours, and the present highly-developed industry in naphthaline colours, including the beautiful discovery of recent years by which artificial indigo is obtained, is partly due to this. The recovery of the volatile products from coke ovens now furnishes another source of benzol.

Bunte showed that, when the price of benzol was about 1½*d.* per lb., coal gas of moderate quality could be increased in illuminating power by one candle with 4 ozs. of benzol per 1,000 cubic feet of gas. The direct use of benzol for lighting purposes also suggests itself, but, on account of its high percentage in hydro-carbons, it is unsuitable by itself, or specially constructed lamps are necessary. But as early as 1850 substances rich in carbon, such as turpentine with alcohol and the mixture known as camphene, were used for lighting, and benzol is preferable to any such mixtures as it is soluble in spirit in almost any proportions. Careful experiments made with xylol showed that a mixture of 15 per cent. xylol with commercial spirit effected an economy of 26·8 per cent. provided the xylol does not cost more than the spirit. Ordinary petroleum lamps with round wicks require about 1 oz. of petroleum per candle-hour, while 1½ oz. of the spirit mixture would be needed, so that such a mixture would only compete with petroleum if the latter should rise in price.

C. G.

Noiseless Street-paving Materials. H. Chr. Nussbaum.

(Gesundheits-Ingenieur, 1897, p. 85.)

Attention is directed to a previous article on this same question,[1] in which the Author discussed the various conditions which must be attended to when studying the question of noiseless pavements. In the interval, many opportunities have presented themselves of observing the behaviour of different kinds of wood when employed for this purpose. The paving composed of beechwood blocks did not attain the favourable results which were anticipated. The experiments made with blocks of fir and pitch-pine were more satisfactory, but the best results have been attained by the use of certain Australian hard woods of the various species of eucalyptus, notably blackbutt, mahogany, and tallowood. It is pointed out that all of these woods possess compressive strengths, greatly in excess of the European woods used for street-paving purposes, and that they even exceed granite when tested in compression. Certain blocks used for ten years in Sydney only showed a wear of 3 millimetres. Tallowood is, moreover, extremely rich in turpentine, and thus resists in a high degree the action of the weather, and may be used in places exposed to moisture. This wood has been used in Sydney on 126 kilometres of roads. An account follows of the method of laying the blocks, and keeping the surfaces in a good condition for traffic. On hygienic grounds the use of this wood has much to recommend it, and, in spite of its great cost, in the interior of Germany it has been introduced with success in Leipsic. Some general observations follow on the use of compressed asphalt, and on keeping road-surfaces in a good state for traffic. G. R. R.

Establishment for the Destruction of Town Refuse at Hamburg. F. Andreas Meyer.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. xxix. p. 353.)

The circumstances which have led to the erection of these works for the calcination of ashes and refuse upon a scale largely exceeding anything of the kind in this country, where the plan of employing destructor furnaces originated, are briefly discussed. The chief incentive to undertake the construction of this extensive establishment was the rapid increase in the price demanded by the contractors for the removal of the ashes and domestic refuse, which in 1891 reached a total of over £21,000 a year. The cholera outbreak in 1892 attracted further attention to the insanitary methods in common use and caused great inconvenience, owing to the refusal of farmers at a distance to accept delivery of the infected refuse from Hamburg. An account follows of the negotiations

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[1] Minutes of Proceedings Inst. C.E., vol. cxviii. p. 486.

with various English firms for the erection of trial destructor furnaces, and the subsequent contract with the Horsfall Refuse Company of Leeds to construct an experimental four-cell destructor in 1894. Two other trial cells were erected, and, subsequently, after certain modifications in the process had been introduced, the same firm undertook to erect thirty additional cells on the sub-structure provided by the Hamburg authorities. The entire building, with thirty-six cells in all, was completed at the end of 1895. A detailed account is given of the establishment, illustrated by ten plans, diagrams and photographs.

The total expenditure has amounted to £24,000. The weight of refuse dealt with per cell varied from 4,000 kilograms up to 7,500 kilograms per diem. In 313 working days 78,876,000 kilograms of refuse were disposed of. The working expenses, weights treated, and results obtained for each period of the year are set out in Tables and indicated in a graphic diagram. The total cost of destruction amounted per 1,000 kilograms of refuse to 1·762 mark; the estimated receipts for the by-products and work done as fuel amount to 0·925 mark per 1,000 kilograms of refuse, or 1·762 mark − 0·925 mark = 0·837 mark. Against this must be placed the saving in cost of transport to the depot, which is set down at 1 mark per 1,000 kilograms. The Hamburg destructors have answered every expectation, and will ultimately lead to a small annual saving, as compared with the cost of the system previously in operation. G. R. R.

Government Return of the Completed Structures Erected on the Prussian State Railways in 1894: *Royal Russian Railway Department.*

(Zeitschrift für Bauwesen, 1897, p. 41.)

This is a detailed Table of various works as above, one hundred and twenty-four in number, comprising thirty-one station buildings, eight goods-sheds, seventeen locomotive sheds, nine water-tanks, five engine and boiler houses, eleven workshops, two stores, one railway-servants' barrack, and forty railway-servants' dwellings and watch-houses. There are thirty-five columns in the Table, the first containing the index number of the particular work. The information includes the name and situation, the line of railway, the date and period occupied in carrying out, the designer and constructor, a diagram plan of the work, the area, the cubic contents, the height of structure below and above ground level and of the roof; the cost as originally estimated and of actual construction; the cost of heating, gas and water arrangements; the character of material used in the various portions of the structure, and a column for general remarks.

On the diagram plans the various apartments are noted by abbreviations, of which an explanatory list with their equivalents is given. D. G.

The Auto-Indicator of the Western Railway of France.

BRILLIE.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1897, p. 593.)

In this apparatus the principal instrument is an ordinary indicator, which, however, is mounted in a special manner. The paper drum has a continuous motion, proportional to that of the train. The end of each piston-stroke is marked on the paper by electrical transmission. Diagrams are taken on the same strip of paper, from the cylinder, the valve chest and the exhaust-pipe.

The apparatus is started by means of a cord pulled by the operator, who may be on the driver's platform or in a carriage behind the engine. The cycle of operations in the auto-indicator is as follows: Blowing steam through the indicator cylinder; starting the registering drum; bringing the indicator pencil into contact with the paper; taking a diagram from one end, from the other end, from the valve-chest, from the exhaust pipe; replacing the paper; automatic stoppage of the apparatus. These operations require 160 revolutions of the driving-wheel, but the diagrams are taken while 60 revolutions are being made. At the end of each series, the apparatus is ready to commence another series, on the cord being pulled.

The Paper is accompanied by numerous illustrations of the apparatus and of the diagrams obtained by it.

A. S.

Resistance to Motion in Fast Passenger Trains on Straight Roads.

BARBIER.

(Revue générale des Chemins de fer, April, 1896, p. 272.)

As the result of a series of experiments in 1882 on the Northern Railway of France[1] with trains of ballast wagons loaded with 10 tons of coal, axles lubricated with oil, train weight 406 tons to 609 tons, running on a straight level road at speeds varying from 15 to 35 miles an hour, Mr. de Laboriette found that the following formula held good, viz.:—

$$R = 1 \cdot 45 + 0 \cdot 0008\ V^2.$$

To ascertain if this law also held good in the case of passenger trains at higher speeds, further experiments have been carried out with four-wheeled passenger carriages and eight-wheeled bogie-

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[1] Revue générale des Chemins de fer, April 1883.

carriages on straight sections, both on the level and on inclines, at speeds above 35 miles an hour. The experiments with the four-wheeled vehicles extended over a period of four years (1891–95), and were made with a great number of trains, special and ordinary, at all seasons and under all circumstances. The average train weight (exclusive of engine and tender) was 162½ tons, the speed from 37 miles to 71 miles per hour. The bogie experiments were made in June, 1895, with International Wagon-Lits Company's sleeping-cars of 30 tons each, train weight (excluding engine and tender) about 210 tons.

These recent dynamometrical experiments show that for the four-wheeled carriages of the Northern Railway the following equation holds good—viz., where R = resistance per ton moved, and V the speed per 0·621 miles per hour:—

$$R = 1 \cdot 6 + 0 \cdot 46 \, V \left(\frac{V + 50}{1,000} \right),$$

and for the bogies of the Wagon-Lits Company—

$$R = 1 \cdot 6 + 0 \cdot 456 \, V \left(\frac{V + 10}{1,000} \right)$$

on straight level sections with a speed of 37 miles to 71 miles.

As regards the specific resistance R^1 on inclines, $R^1 = R + 0 \cdot 9\, i$, where R is the corresponding resistance on the level at same speed, i = the inclination of the rails per inch in 100 feet, i being positive, zero, or negative in the case of a rise, level, or fall. The Paper is illustrated by an elaborate diagram with abscissas and ordinates showing the curve in the case of each experiment.

W. A. B.

Electro-mechanical Appliances in use on the Northern Railway of France. E. Sartiaux.

(Revue générale des Chemins de fer, 1897, p. 429.)

This Paper describes (1) Capstans for shunting purposes; (2) Capstans for working turn-tables; (3) A combination of both the above.

The construction is practically the same in all, and consists of an outer basin shaped cast-iron casing, provided with four feet. This is sunk in the ground, and rests on a sleeper bed; the earth is well rammed, and three rings of squared paving are laid round it with space for a cast-iron commutation chamber.

The mechanism consists of a dynamo of eight poles, with induction from the vertical shaft. This shaft carries the capstan-head and acts as an accumulator. It rests on a pivot supported by arms attached to four of the poles.

The capstan, cover, electro, cross-bar, and shaft form a combination which rests on trunnions working in bearings, cast on the outer casing, and is capable of being capsized for the purpose of examination or repair. The diameter of the capstan-head is 15 inches, and the pull exerted can be regulated from 2 lbs. up to 19 cwt. A similar type of machine is used for turn-tables, the capstan-head being replaced by a pinion which engages the chain to work the turn-table. A third variety is adapted to work one, two, or three turn-tables, and also for haulage. The prime cost, including overhead or underground connections, is, for those of the first type, £220; of the second, £260; and of the third, £360.

The working expenses per annum vary from £2 to £6, according to amount of work performed. The Paper is fully illustrated, and two charts are supplied showing the force expended and work performed.

W. A. B.

Velocity Meter on the Peyer-Favarges Company's System.

Ludwig Geiringer.

(Organ für die Fortschritte des Eisenbahnwesens, 1897, p. 58.)

The Author, Chief Engineer of the Kaiser Ferdinands Northern Railway, reports that of all the instruments employed by him for a series of years, the above has given the best results in recording the speed of locomotives.

Its most noticeable features are:—

1st. That it indicates the speed at each moment.

2nd. The clockwork is self-winding and so requires no attention.

3rd. The construction is very simple.

4th. The cost is less than that of any other.

It is capable of registering up to 77·625 miles per hour. In cases where the circumference of the driving-wheel has had to be re-turned in consequence of wear and tear, the instrument can very simply be readjusted to record correctly under these altered circumstances.

Motion is derived from one of the driving-wheels; the whole construction is clearly described and well illustrated by seven drawings to scale. Twenty-two of these meters have been at work on the Kaiser Ferdinands Northern Railway for more than two and a half years without requiring repairs of any kind, and have proved most satisfactory and efficient.

W. A. B.

Stopping a Runaway Goods Train on a Steep Gradient by Means of a Sand Catch-Siding.

(Verein für Eisenbahnkunde, 1896, p. 40.)

This siding was designed and laid down by Mr. Privy Councillor Köpcke of the Saxon Board of Finance, in consequence of a serious accident to a runaway train in 1890, on a falling grade of 1 : 55, near the Dresden Neustadt Railway Station.

It is a simple device and of proved efficacy. Points connect the main line with the siding; there is no crossing, the rails being laid parallel to those of the main line and on the same sleepers; longitudinal sleepers or sheet-iron flanges retain the sand in position; its maximum depth ranges from 2 to 3 inches, its length being determined by circumstances; beyond, the rails are free and rejoin the main line as before.

The points are connected with the signals, and lead into the siding as long as the signal is against a train.

Fears were expressed that the sand would arrest the train so suddenly as to cause serious damage to the rolling-stock. Experiments prove these fears unfounded. Mr. Köpcke reckons that the maximum force of impact occurs when the wheels first enter the sand, and may be expressed thus—$P_{max} = \frac{q f l}{4}$, where—

q = average load per axle (= about 8 tons);
f = sand resistance = 0·0625 by experiment after deduction of 0·005 resistance of rails;
l = length of train in units of average distance between axles.

With a sand siding a times the axle distances, this maximum is considerably reduced provided $a > 2\,l$, and may be expressed thus—
$P_1 = \frac{q f l^2}{8\,a}$.

In April, 1895, such a siding, 547 yards in length, and with 383 yards sanded, was laid down at the spot mentioned above. At 4.30 A.M., December 21st, a goods train of twenty-nine wagons (fifty-nine axles), 417 tons in weight (locomotive 42·2 tons, tender 16·85 tons), 270 yards in length, ran away down the 1 : 55 grade at great speed into the sand siding, and came quietly to a stand 27 yards from the end of the sand, without either shock or damage, although the fifth wagon was empty, and the ninth, tenth, thirteenth, sixteenth, twenty-first and twenty-fourth were very lightly laden. In twenty-four minutes the train continued its journey. These sidings are also laid down at many terminal stations, and have saved many accidents. The Paper is illustrated with plan and elevation to scale.

W. A. B.

The Railway from the Senegal to the Niger. Capt. Calmel.

(Mémoires et Compte rendu des travaux de la Société des Ingénieurs Civils de France, March, 1897, p. 257.)

This railway was first proposed by the French Government in 1879. In 1881 a vote of £340,000 was passed for the portion from Kayes to Bafoulabé, a distance of 82 miles, and by the end of 1884 a total sum of nearly £1,000,000 had been spent, but only 33 miles had been constructed, and it was not till 1888 that the line was completed to Bafoulabé. The mismanagement of the railway during this period appears to have been great; the permanent way was most defective, and the amount of rolling-stock very small. In 1892 a fresh attempt to push on with the line was made, and it has now been put into good order and extended to a point just across the River Bafing at Mahina by a branch which leaves the line to Bafoulabé 5 miles from that place.

The line, as originally made, required, to a large extent, reconstruction and ballasting, while some very considerable deviations were put in. The bridge across the Bafing is one of the principal works on the line: with a total length of 1,312 feet, it consists of 16 spans of 82 feet over all. The site chosen for the bridge gave rock foundations for all the piers and the abutments, while several piers were founded during the dry season on the then exposed bed of the river. For the remainder, barriers were formed on the up-stream side so as to give still water on the site of the foundations, which were then formed of concrete, thrown into the water. At none of these points was the water then deeper than 3 feet 7 inches. The upper portion of all the piers was of masonry set in lime mortar. The main girders were 6 feet 11 inches deep, with verticals and crossed diagonal bracings, and were erected on land, then bolted together, end to end, in sets of three, and hauled into position on the piers. The bridge was completed in June, 1896.

This line, when finished, will have a length of about 250 miles from Bafoulabé on the Senegal to Toulimandio on the Niger; the gauge is 1 metre, the sharpest curve 300 metres (985 feet) radius, and the ruling gradient $2\frac{1}{2}$ per cent. After the crossing of the Bafing, the only serious difficulties are at the following points:—The crossing of the Bakhoy at Toucolo by a bridge 1,181 feet long, but here the foundations will be similar to those at Mahina; crossing the summit of the Manambougou, involving some heavy rock-work; near Kandiaourva, where there will be a long and high bank; and the descent into the valley of the Niger, $3\frac{1}{2}$ miles or $4\frac{1}{2}$ miles of heavy rockwork. The Author considers that the line should be finished in eight or nine years.

He gives a detailed description of the existing rolling-stock and permanent way, and of the construction of the Mahina bridge, as well as his views as to the future construction and working of the railway. There are fifteen illustrations to the Paper, including a small diagram map of the line, the remainder being chiefly photographic views of different portions of the work.

R. B. M.

The Behr Single-Rail Railway.

F. B. BEHR, Assoc. Inst. C.E.

(Engineering, 11, 18 and 25 June, 1897, p. 788 *et seq.*)

This system, which was originally applied to a sand-swept Algerian desert line by Mr. Charles Lartigue, is about to receive an extended trial at the Brussels Exhibition. The line consists of a single rail supported on triangular angle-bar standards, 1 metre apart, and is 4 feet 1½ inches above the level of the sleepers. The single carriage, which has been built by the Gloucester Railway Carriage and Wagon Company, is 58 feet long and 11 feet wide. Its bottom edge is 7 inches above the sleepers, and the floor-level 5 feet. In the intervening space are the electric motors for propulsion. There is a deep recess running longitudinally along the centre, in which are placed the wheels and trucks. All the supporting wheels are in tandem, and consist of two trucks of four wheels each, the two middle wheels of each truck being driven. The carriage holds 100 passengers in four rows, the total weight being 55 tons. The electric current is collected by a sliding contact from an insulated rail laid on the sleepers. The carriage is prevented from leaning over, whether owing to unequal balancing or to centrifugal force in rounding curves, by sixteen pairs of horizontal wheels, which bear upon four rails supported by the triangular track standards. It is hoped that a speed of 90 miles an hour will be attained on the three-mile experimental line.

A. P. H.

The Permanent Way of the Jungfrau Railway. E. STRUB.

(Schweizerische Bauzeitung, 3 April, 1897, p. 97.)

This refers to the two sections, about 2 kilometres each, now in course of construction, between the stations Scheidegg, 6,770 feet, Eigergletscher, 7,613 feet, and Grindelwaldblick, 9,223 feet above the sea. The steepest gradient is 25 in 100, and occurs in 87 per cent. of the second section, but not at all in the first section. The highest portion of the railway, viz., 1·6 kilometres long, is in tunnel with a least radius of 200 metres; the remainder is open with a least radius of 100 metres.

The permanent way is heavier than that of other mountain-railways with a view to greater safety and less cost of maintenance. Accordingly the train is heavier, and consists of the locomotive with thirty seats weighing 17·1 tons, and a carriage with fifty seats weighing 8·9 tons when full. There are two motors of 125 HP., each producing a pressure of 3·3 tons on the teeth of each pinion and a speed of 8·5 kilometres (5·26 miles) per hour. The 4-inch flat-bottomed steel rails, 41·5 lbs. per yard, and generally 10·5 metres long, are laid to the metre-gauge on steel sleepers 1 metre apart. The rack-rail, also of rolled steel, in the middle between the ordinary rails, is 6¾ inches high, and in lengths of 3·5 metres; accordingly every fourth space between the sleepers is 0·5 metre. The rail-head, into which the teeth are cut cold, is 2½ inches broad, decreasing downwards to 1½ inch, thus admitting the use of forceps brakes, which, when not pressed tight, still prevent the lift of the axle. These are the only brakes used, and the fastenings of the rails have been designed with due regard to this circumstance. Horizontal parts are avoided on the railway in order to prevent counter-pressure on the rack, and even the three stations have gradients of 1·5, 7 and 12·5 in 100 respectively. The complete weight of steel is 74 lbs. per foot.

M. A. E.

Rolling Cradles for Light Railways.

C. S. Du Riche Preller, Assoc. M. Inst. C.E.

(Engineering, 19 March, 1897, p. 366.)

This article deals with the question of transfer of goods, etc., from normal gauge to narrow gauge lines, and *vice versâ*; and the Author gives the results of his inspection of several typical cradle installations in South Germany and Switzerland.

The system of rolling cradles, or "transporteurs," referred to is that patented by Langbein, and improved by Close, and is the outcome of the trolley originally designed and patented by Charles Brown, formerly of Winterthur. In Brown's arrangement the trolley was formed by a pair of bogie trucks carrying a rigid girder frame, for the reception of the standard gauge wagons, which trolley, on the narrow gauge line, was run into a loading pit of such depth that the upper face of the girders of the carrying frame, for the standard gauge truck, was brought down to the same level as the standard gauge rail surface. But the fact of the trolley thus formed being unalterable in length, and therefore only adapted for standard gauge wagons of a given wheel base, limited its application. The Langbein rolling cradles, on the other hand, are independent of one another, a separate cradle being used for each axle (or pair of wheels) of the standard gauge truck, so that the length of wheel-base of the latter is immaterial.

The arrangement of the pit and mode of transfer is described, and refers generally to the metre gauge, for which the wheel-base of the cradle trucks is 1 metre. There are nearly 100 pairs of these rolling cradles in operation on different narrow gauge railways throughout Germany. Particulars are given of several narrow gauge lines on which they are used, including that at Geneva; and the article is illustrated by diagrams of Brown's trolley and the cradles in question, together with a plan of the transfer yard at Geneva, and two photogravures of the cradles in use.

D. G.

The Use of Storage Batteries in Railway Work.

WM. BAXTER, JUN.

(Electrical World, vol. xxix., 1897, pp. 62 and 91.)

In these articles the Author first deals briefly with the use of storage batteries in the ordinary manner for electric railway work simply as regulating appliances in the power-house, and also as a means of evening-up the load throughout the day, so that the generating plant may be kept at full output while at work.

The main subject then follows, and is treated at great length both theoretically in respect to methods of arrangement, and practically also from the standpoint of cost. It involves the use of accumulators along the line for the purposes of transmission or transformation of energy in sub-stations. The Author claims that for long transmissions, say on lines 15 miles or 18 miles long, this use of batteries as transformers will be found more economical in first cost than if placed in the power-house, whilst it will also keep the voltage more uniform.

The method more usually adopted is to place the batteries in sub-stations with separate feeders connecting them through distinct volt-raising machines (called "boosters") in the power-house, to the main generator circuit. The Author, however, gives diagrams and estimates as to the cost of such a system compared with one at higher pressure, using batteries for transforming the current at sub-stations, and maintains the latter to be preferable on the ground of economy for long-distance transmissions, although it is very difficult to point out a dividing line between such and the ordinary lines where parallel working with heavy feeders and volt-raising machines is employed.

F. B. L.

Homogeneous Stamped Steel Axle-Boxes.

SÜRTH.

(Verein für Eisenbahnkunde, 1896, p. 63.)

These axle-boxes, manufactured by a process patented by Mr. Ehrhard of Dusseldorf, are in one piece without weld or join. The horn-plate guides are of the best wrought iron tee-bar, riveted in a special manner to the sides of the box; these were submitted to a series of searching tests, described at some length by the Author. The severest of them consisted of a succession of five blows from a 110 lbs. weight falling 3 feet, 6 feet, 10 feet, 13 feet, and 15 feet; no displacement of the rivets resulted, the unriveted arm of the angle-bar alone showing a slight deflection. From the construction of the steel axle-box, a special arrangement for rendering it dirt- and oil-tight was necessary: this is minutely described. Statistics are likewise supplied showing the excessive cost in repairs, and the immense loss in other ways, caused by the constant fractures of the ordinary cast-iron axle-boxes.

In the sixty-one workshops on the Prussian state railways, during the traffic year 1891–92, to replace damaged axle-boxes, 405 tons of raw material were required, representing, when manufactured, a sum equal to £20,315.

The steel axle-box weighs 8 lbs. as against 16 lbs., the weight of the present cast-iron ones, and though the cost cannot be stated exactly, it is estimated that it will be about 20 per cent. greater than for cast-iron.

The Paper is illustrated by a sketch.

W. A. B.

Roller Bearings.

(Engineering, 28 May, 1897, p. 725.)

Thirty years ago the Ipswich express had its carriages equipped with roller-bearings. The great difficulty was to prevent the rollers twisting, and on this account the system has not been generally adopted. The success of ball-bearings in bicycles has led to renewed interest in the matter. Experiments show that the friction in ball-bearings is about equal to that in efficiently lubricated plain journals. The latter, however, are not usually efficiently lubricated, especially at starting, while the former have the advantage of accurate adjustment. In practice ball-bearings are not successful for heavy machinery, but the want has been met by rollers, in which the bearing surface is much greater. The Roller Bearing Company enclose a number of rollers in a live ring or cage, which efficiently prevents twisting. Experiments at Lancaster with tramcars show the starting resistance with roller-bearings to be from one-fourth to one-sixth of that required with plain bearings. Roller-bearings can be applied to continuous shafting, the live ring being made in halves dovetailed together. The bearings are constructed to contain oil, though this is useful rather to prevent rust than for purposes of lubrication.

A. P. H.

Firing with Oil in the Arlberg Tunnel. H. Tichy.

(Organ für die Fortschritte des Eisenbahnwesens, 1897, p. 72.)

The Arlberg Tunnel, $6\frac{1}{2}$ miles in length, has no ventilating shafts; the smoke and gases ascend the tunnel and find an exit at the east end, which is 288 feet above the western entrance. With an easterly wind there is practically no ventilation, and its atmospheric condition such that both the staff and the traffic are seriously inconvenienced, the signals at times becoming quite invisible. The authorities consequently determined to try the Holden system of firing with liquid fuel. The Papers describe the simple and inexpensive addition necessary on an ordinary locomotive. Two orifices are made into the fire-box near the door; through these the distributors are led, pipes connect them with an oil-tank of 264 gallons capacity on the tender. By means of other pipes and taps a combination of oil, air, and steam is forced in the form of fine spray over the fire in the fire-box; this can be regulated by the driver at any moment, so that he can fire with coal or oil at pleasure. Tables of experiments on the atmospheric condition of the tunnel at various times, under all conditions and with different firing material, are given, together with the careful chemical analyses in each instance.

The results proved conclusively that the improvement in the atmosphere of the tunnel, produced by the use of liquid-firing material, was such as to render it perfectly healthy and free from deleterious gases. The oil-firing, moreover, was found cheaper than either coal or coke, and so favourable were the results that the Directors of the Austrian State Railways determined to have twenty-five heavy goods and twelve passenger locomotives fitted up with this arrangement, so that all locomotives passing through this tunnel should use oil-firing.

The Paper is illustrated, and accompanied by Tables of the results of experiments.

W. A. B.

Tramway Tunnel at Boston, U.S.

(The Engineer, 23 April, 1897, p. 410.)

The city of Boston is now building a subway under the congested district of the city for the use of the electric tramways. It is kept as close to the surface of the streets as possible, and will have four tracks for the greater part of its length. At each of the three termini there will an inclined approach connecting it with the surface line of tramways. Where possible it is built as cut-and-cover work, having a concrete invert, with steel columns 24 feet apart, and roof beams. Concrete walls are built enclosing the columns, and brick jack-arches are built between the roof beams. Where the line is in tunnel two side tunnels are driven from shafts at the curb-line of the streets, and in these the concrete walls are built, which are afterwards planked across and the intermediate portion excavated, so that the concrete invert and brick arch can be constructed.

A. W. B.

The Madeleine-Courbevoie Battery Tram-Cars, Paris.

A. Soulier.

(L'Industrie Électrique, 1897, p. 154.)

One line of accumulator or storage battery cars has for some time been in operation between Paris and Romainville; and another system is now at work on the lines extending from the Madeleine to the fortifications north-westerly, and thence branching out in three directions to Puteaux, Courbevoie-Asnières, and Levallois-Perret.

The reason for thus increasing the number of such tramway systems (admittedly of a most expensive type in so far as maintenance and depreciation are concerned) is, of course, the obvious one that Paris, like many other large cities, hesitates before committing itself to the overhead trolley wire, although this method may be cheaper to install and maintain. The improved services only to be obtained by the use of mechanical traction are, however, demanded by the public, and hence the change.

The special feature of the Courbevoie tramway system consists of arrangements made at each terminus to give a rapid charge to the accumulators while the cars wait after finishing each journey. This is effected by running underground feeders from the power-house to the three termini, where they are connected to standards or posts somewhat resembling those used for fire-alarms, but of course considerably larger and more substantial. A short length of flexible twin cable serves for carrying the current thence to the car on its arrival at the terminus. Differently shaped plug contacts, for positive and negative poles respectively, are fitted to the cable terminals for insertion into the car battery terminals; and a double throw switch is provided for connecting the battery mains either to the car motors for discharging, or to the charging standard at the terminus, already mentioned.

It is therefore impossible for the conductor, or "wattman," to make wrong battery connections for recharging, or to couple up so that the car motors might take current from the feeder mains direct. An automatic device is provided for showing the completion of charge.

The car batteries are placed under the side seats or benches in the car, but as they do not require to be frequently taken out for charging, as hitherto the custom with self-contained vehicles, they can be in essence hermetically sealed off from the car interior, thus preventing the annoyance of gas and acid fumes. Two small rotary fans worked by electric motors are set in operation, moreover, when charging, in order to draw out these unpleasant accompaniments of the process. Each car has 200 cells of the Tudor type, weighing about 36 lbs. each, or $3\frac{1}{2}$ tons in all; three negative and two positives comprise the cell, in a box of ebonite.

The cars are double-decked, and each weighs 14 tons when fully loaded and carrying its complement of fifty-two passengers; on emergency they can pull a trail car also, up to a weight of 7 tons. The batteries are always charged and discharged in series, regulation of speed, &c., being obtained by means of controller mechanism and resistances somewhat after the ordinary method; but part of the resistance is liquid.

After every round trip the car batteries are charged up from the terminal standards for about ten or twelve minutes, the average charging current being about 120 amperes.

Very complete details of the routes, power-house, generating plant, car equipment, &c., with diagrams and illustrations, are contained in the article.

F. B. L.

Insulation and bonding of the Third Rail Electric Conductor.

H. K. LANDIS.

(The Electrical Engineer, New York, vol. xxiii., 1897, p. 611.)

The Author describes a method of insulating and bonding the third rail-conductor of the railway at Nantasket Junction, near Boston, where electric trains are now running. The use of the trolley construction in this case would have necessitated a double line of poles or the spreading of the parallel tracks in place. The first cost of the third-rail system is said to be less than one-half of the trolley construction used on the adjacent seven miles of track. The third rail is of a wide V section inverted, and supported on blocks of pitch pine creosoted and then boiled in tar. The rail is of steel, and has a sectional area of about 9 square inches. It weighs 93 lbs. to the yard. The upper surface of the conductor rail is arranged to be 1 inch higher than the surface of the two service rails. At crossings the conductor ends in two bare cables, each of which runs through a creosoted pine conduit 4 inches square with a bore of $2\frac{1}{2}$ inches. The space between the conductor and the conduit is filled in with an insulating compound of petroleum residue and asphalt. The two service rails are bonded in the ordinary way. The third rail is bonded by copper plates 12 inches long by $3\frac{3}{4}$ inches by $\frac{1}{16}$ inch placed between the fish-plates and the rail. Four cables leave the power-house, two of which are insulated and are connected to the conductor rail. The other two cables are uninsulated and are used as return, being connected to the service-rails. The electricity is supplied to the rails at 600 volts, and no trouble from short circuiting has been experienced up to the present. A number of workmen have received shocks from the system, but no permanent ill effects have been felt. On a dry summer's evening the leakage current between the third rail and earth was found to be $\frac{1}{2}$ ampere. After a heavy rain storm, a leakage current of 2·6 amperes was observed. A severe test of the system when some 2 miles of the track were flooded by water showed that the regular service could be maintained.

R. W. W.

Safety Appliances on Electric Railway Generators.

GEORGE MOFFAT.

(The Electrical Engineer, New York, vol. xxiii., 1897, p. 450.)

The Author refers to the numerous fires which have lately occurred in electric supply stations for light and power, and to the need for investigating the real cause of the outbreaks. He proceeds to describe the arrangements in the Mount Vernon Station in Philadelphia, which was recently burnt down. The first generator installed was a 400-kilowatt dynamo, and the circuit breaker for this machine was fixed on the negative side, as is usual. The new machines of 1,100 kilowatts capacity were erected in the autumn of 1894. As these machines sparked very badly, the makers thought it advisable to break the positive side so as to cut off the excitation in case of short circuit. The connections used are shown in the diagram. As trouble arose from this combination, fuses were tried, but were found to be quite unreliable owing to the uncertainty of the fusing current. The Author states that it was decided to shift the circuit breakers on to the negative side; but, as the dynamos had been condemned and new ones ordered, the change was deferred.

The fire was caused on the 3rd March, 1897, by a dangling crane chain short-circuiting the positive to earth through the fly-wheel. The short circuit occurred on the machine side of the circuit-breaker. Hence, although it was opened by the current from other machines it still left the dynamo in question unprotected. The station had a wooden floor which was greasy. This floor was ignited by the molten metal thrown over it and the station was destroyed. The Author details the obvious method of avoiding a similar occurrence, and some other precautions which should be taken.

R. W. W.

Motor-Cars for Public Transport. Ch. Kuss.

(Annales des Ponts et Chaussées, December, 1896, p. 732.)

This is a short Paper describing some experiments with a steam road-car for public traffic in the department of the Meuse. The want of improved communication was felt between the towns around Woëvre, which had no railway connection; and while the military authorities refused to consent to the construction of branch lines, an attempt to establish a horse-car service proved unsuccessful. Under these circumstances the authorities determined to try what could be done with a steam motor-car, and in July 1896, a trial locomotive and trial car, on the "Scott" system, were hired from the Société des Chaudières et Voitures à Vapeur. The locomotive weighed about 4 tons empty, and 6 tons with coal and water on board. On the locomotive, and behind the engine and vertical boiler, was a compartment capable of carrying eight seated passengers, and six standing on the rear platform. The trial car weighed $1\frac{1}{2}$ ton, and carried twelve inside seated passengers, with standing-room on the platforms for twelve others. The locomotive was fitted with variable gear for different speeds.

The conclusions come to after thirteen days' trial on the various roads of the department were that the train could easily traverse all the main roads in the department; that after the first few days its running was very regular, and punctual to the programme laid out beforehand; horses were seldom frightened by it; that it was easily stopped and steered; and the cars were comfortable, and suited to the requirements of the traffic. The average speed was about $7\frac{1}{2}$ miles per hour, and varied from 3 miles to 4 miles up-hill, to from 11 miles to 12 miles down-hill. The Paper is illustrated by a perspective view, and details of the locomotive and car, and sections along some of the worst gradients climbed by the train, the steepest being one of 14 per cent. for a length of nearly 100 yards.

The whole cost of the experiments amounted to about £66, of which about £41 was for hire of the train and its transport by rail to the department. The total distance run by the train was 390 miles.

R. B. M.

The Working of Single-Cylinder Steam-Engines. E. Lefer.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1897, p. 88 *et seq.*)

During the last twenty years the Author has taken indicator diagrams from engines working under widely different conditions, and has noticed the persistent occurrence of certain undulations, which have been hastily attributed by most experimenters to imperfections in the indicator. These undulations, being produced in the diagrams taken by different indicators, were carefully investigated, and the Author concludes that they represent real phenomena undergone by the steam in its passage through the cylinder. The Paper is devoted mainly to their discussion.

Action of the Cylinder Walls.—The Author's observations seem to show that the extent of the temperature change is independent of the point of cut-off, and that consequently the initial condensation in the cylinder is also independent of the cut-off.

Compression.—At the beginning of the compression period the cylinder walls are at a higher temperature than the steam, which is consequently superheated; as the compression proceeds the temperature of the steam becomes equal to, and ultimately higher than, that of the walls, and condensation occurs. From examination of a large number of indicator diagrams, it is seen that the steam pressure rises regularly until it reaches a certain value, when it remains nearly constant, indicating a partial condensation on the cylinder walls. The inflection of the diagram curve is not to be attributed to faulty working of the indicator spring. If the point of cut-off be varied while the number of revolutions of the engine remains constant, the point of inflection of the compression curve is higher the later the cut-off, while with a very late cut-off the point of inflection may disappear.

Expansion.—The water condensed on the cylinder walls during admission is re-evaporated during expansion. This re-evaporation does not take place continuously, but in a great number of cases a sudden re-evaporation, indicated by the expansion line becoming horizontal, takes place after cut-off. The earlier the cut-off the earlier also is the sudden re-evaporation. In some cases a series of undulations, not due to imperfections of the indicator, are shown on the expansion curve.

Consumption of Steam.—The Author divides the steam actually used in any engine into five parts: the theoretical consumption due to the working fluid acting as a perfect gas, that due to the action of the cylinder walls, the consumption in the jackets, that due to external radiation, and that due to leakage. The steam consumption due to internal condensation is independent of the ratio of expansion. Leaving the last three portions out of account, the Author calculates the steam consumption for an engine in which the length of stroke is twice the diameter of cylinder, for different steam pressures and ratios of cut-off, and gives the results in tabular form. For condensing engines the most economical cut-off ratio varies from $\frac{1}{8}$ for a pressure of 2 atmospheres to $\frac{1}{12}$ for a pressure of 12 atmospheres. For non-condensing engines the best cut-off ratios at 2 atmospheres and 12 atmospheres are $\frac{1}{2}$ and $\frac{1}{6}$ respectively. The influence of length of stroke (compared with diameter of piston) is also shown by a table of steam consumptions.

A. S.

The Peugeot Petroleum Motor.

(Engineering, 21 May, 1897, p. 676.)

Carriages driven by this motor won the second prize in the Marseilles and Monte Carlo competition. In one case the total weight was 1,378 lbs., which, with an engine of 6 HP., was equivalent to 238 lbs. per HP.

The motor is of the horizontal two-cylinder type, efficiently enclosed in a dust-proof case underneath the carriage. The crank-shaft is provided with a fly-wheel and with a cone for the friction clutch. The vaporized petroleum is drawn in by a valve at the upper part of each cylinder and the exhaust underneath. Ignition is by tubes maintained at a sufficient temperature by two oil-burners. The valves are actuated by a rocking-shaft, which receives its motion from a cam on the main shaft. It runs longitudinally to a point beneath the cylinders, where it alternately works the valves of the two cylinders. The two cranks are at the same angle, and as each cylinder alternately gives an impulse every two revolutions, the result is an impulse every revolution. The governing is on the hit-or-miss principle.

A. P. H.

Horizontal-Axis Turbines for Driving Dynamos Direct.

A. Butin.

(Le Génie Civil, 13 March, 1897, p. 296.)

This is a short article describing some types of turbines with horizontal axis, suitable for coupling direct to dynamos. The Author points out that when the fall of water available is less than 13 feet, direct coupling to the dynamo shaft generally becomes impracticable owing to the low speed of the turbine. The first two machines described have an inward flow of water, the waste escaping at one or both ends of the turbine. In the first case the turbine is rated at 40 HP. to 45 HP., with a fall of 41 feet 8 inches and a speed of 630 revolutions per minute. The second one is for a fall of 95 feet, and a speed of 400 revolutions per minute. This machine has two turbine wheels, and the waste escapes at the two ends, the end pressures being thus balanced, and the maximum power being 450 HP. The efficiency of these turbines ranges from 80 per cent. to 87 per cent.

The second type of turbine has an outward flow; one machine described being of from 50 HP. to 60 HP., suitable for a fall of 328 feet, and running at 700 revolutions per minute. The other machine, with only partial distribution, is designed to give 40 HP., with a fall of 164 feet and a speed of 400 revolutions per minute.

The Author concludes with a short description of a turbine of only about $\frac{1}{6}$ HP. for a fall of 164 feet, and to run at a speed of 1,375 revolutions per minute, the flow being outward, and the supply-pipe only $1\frac{1}{2}$ inch in diameter. The article is illustrated by a single-page plate, and eight small cuts in the body of the Paper.

R. B. M.

Tests of a 38-Inch and 26-Inch Cascade Water-Wheel at Ohio State University, U.S.A. JOHN H. COOPER.

(Journal of the Franklin Institute, 1897, p. 376. 2 Figs.)

The type of wheel tested is one made by Messrs. James Leffel & Co., of Springfield, Ohio, and is known as the "Cascade." It will be remembered that the double bucket of the well-known Pelton wheel is so formed that the jet of water is divided by the midrib of the bucket into two equal parts. The Cascade type consists of a wheel with a thin rim having a cutting-edge, on each side of which is a series of buckets, those on one side alternating with those on the other. With this arrangement it is claimed that a more constant torque is obtained. One, two, or three nozzles may be used, and each jet is shut off separately. The buckets are not held on by bolts, but the wheel is cast solid with the buckets. The tips of the nozzles are made separate so that they are capable of adjustment for position and for size of orifice.

A Table of the results of the tests is given, from which it appears that the 38-inch wheel was tested under a head of water varying from 147·7 feet to 165·7 feet, and gave an output varying from 12·25 HP. to 15·05 HP., at a speed varying from 273·6 revolutions to 337 revolutions per minute, and an efficiency varying from 87·06 per cent. to 91·02 per cent.

The 26-inch wheel was tested with a head of water varying from 160·0 feet to 166·2 feet, and gave an output varying from 8·8 HP. to 14·9 HP., at a speed varying from 377·4 revolutions to 482·8 revolutions per minute, and an efficiency varying from 87·23 per cent to 91·85 per cent.

E. R. D.

The Power Plant, Pipe Line and Dam of the Pioneer Electric Power Company. H. GOLDMARK, M. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, May, 1897, p. 264.)

The city of Ogden, Utah, near which these works have been recently built, is situated in the basin of the Great Salt Lake, 35 miles north of Salt Lake City, and 4,300 feet above sea-level. The object of the scheme is to utilize the waters of the Ogden River watershed for the development of power for distribution in the city of Ogden and the surrounding district, and for irrigation. It includes:—a masonry dam across the cañon near its upper end, 60 feet high above the river bed, to produce a large storage reservoir with a capacity of nearly 12,500 million gallons; the pipe conduit, 6 feet in diameter, and 6 miles long, 5 miles of which is wooden stave pipe, and the remaining mile, at the lower end, riveted steel; the power-house, containing water-wheels and electrical generators; and electric transmission lines and sub-stations for its distribution.

The pipe-line is calculated to deliver 250 cubic feet of water per second, with a full reservoir, which corresponds to a velocity of 9 feet per second in the 6-foot pipe. The maximum hydrostatic pressure in the wooden pipe is 117 feet, and in the steel pipe 516 feet. The prime-movers are water-wheels of the impulse type, directly connected to the electrical generators. The complete plant will consist of ten water-wheels, of 58 inches diameter, and 1,200 HP., at 300 revolutions per minute, of which five are erected. The dynamos are three-phase alternate-current generators, with an output of 750 kilowatts at 300 revolutions per minute, and a potential of 2,300 volts, with two continuous current exciters. After leaving the building, the water is returned to the river. Step-up transformers raise the voltage to 16,100, at which pressure the current passes into the transmission lines, the longest of which is at present 38 miles. Step-down transformers reduce the pressure again before distribution. A small crib dam has been built temporarily a short distance above the site of the permanent dam, so that the plant can be brought into use prior to the completion of the concrete dam.

A. W. B.

The New Holyoke Water-Power Dam.

D. E. THOMPSON, Assoc. M. Am. Soc. C.E.

(Engineering News, 13 May, 1897, p. 292.)

The water-power plant at Holyoke, Massachusetts, is the largest in New England. The drainage area of the Connecticut River above Holyoke is 8,000 square miles. The first dam across the river at Holyoke was completed in 1848, but, before the water rose to its crest, the dam toppled over. In the following year a second dam, 1,020 feet long and 30 feet high, was built of timber, but the maintenance of the apron protecting the river-bed below the dam gave a good deal of trouble, and the dam itself required attention from time to time. A contract for building a new stone dam, about 120 feet lower down the river than the old one, was let in 1895. The overflow takes place over the top of the dam, and its down-stream profile, built of cut granite blocks set in Portland cement, is made with a reverse curve, so that the water flows off it tangentially to the river bed. The upper part of the curve is a parabola, being the curve of freely falling water flowing 4 feet in depth over the crest of the dam; the lower part is a cycloid. The up-stream profile is equivalent to a batter of 1 in 5. The dam is about 60 feet in height above its foundations, its core is built of rubble masonry set in cement, and it backs up the water into a canal, which supplies the mill water-wheels. These develop 30,000 HP.

A. W. B.

Subterranean Temperatures at Wheeling and Pittsburg.

W. Hallock.

(School of Mines Quarterly, New York, 1897, p. 148.)

The Author gives the results of observations on underground temperature at great depths at Wheeling, West Virginia, and at Pittsburg, Pennsylvania. The original temperatures obtained at different depths in the Wheeling oil-well were published by the Author in the *American Journal of Science*, vol. xviii. p. 234. The observations there recorded were completed in 1891, and the hole was protected by driving an oak plug into the top of the casing. In 1893 the hole was opened, and it was found to be full of water to within 40 feet of the top, the water having probably entered at the lower end of the inner casing, 1,570 feet below the surface. Observations of the temperature made in 1893 showed results differing not more than 0·2° F. from those obtained in 1891. It is thus evident that no appreciable circulation of water goes on in a hole of 5 inches diameter.

A well now being bored at Pittsburg had in February, 1897, attained a depth of 5,386 feet. The well is dry and has an inlet of gas at a depth of 2,285 feet. Observations at a depth of 2,350 feet showed a temperature of 78° F., or about the same as that of the Wheeling well. At a depth of 5,000 feet a temperature of 120·9° was observed. This represents a temperature of 127° at the bottom, 5,386 feet below the surface of the earth.

B. H. B.

Hotchkiss Automatic Machine-Gun Trial.

(The Engineer, 16 April, 1897, p. 389.)

This new arm has been made so far only for the service rifle bullet, and was exhibited near Erith on the 12th April; it fired single shots and repetition firing for $1\frac{1}{2}$ minute, at the rate of about 300 rounds per minute. The same barrel will stand about 12,000 rounds of cordite. The gun consists of thirty-one parts, its weight without the tripod is 43 lbs., and with it 66 lbs., the muzzle velocity with cordite is 2,000 feet per second. The barrel is made of thick steel, and provided with a radiator surrounding the chamber portion to keep it cool. Beneath the barrel is a steel cylinder in which works a long piston of small diameter, which is normally kept thrust forward by a spiral spring. The rear end of the piston is cut into various cams which actuate the whole breech and firing mechanism. At a short distance from the muzzle, there is, under the barrel, a small hole which communicates with the front end of the lower cylinder. As the bullet passes this port a puff of the powder gases enters the working cylinder and drives the piston back about 6 inches. The piston, acting on the various elements, ejects the fired cartridge, replaces it by a fresh one, and, if the trigger has been pulled back for continuous firing, fires it. In its travel backwards the piston uncovers two exhaust ports which allow the powder gases to escape and permits the return of the piston to its forward position in readiness for the next round. The cartridges are carried in light stamped brass trays, each of which holds thirty rounds; the trays are fed into the gun by hand.

A. W. B.

The Carvés Coke-Ovens of the Vizcaya Company of Billbao.

MANUEL B. DE HEREDIA.

(Revista Tecnologico Industrial, 1897, p. 5. 2 Figs.)

The Author opens by contradicting the statement that good coke cannot be produced by a process which also permits the by-products to be obtained, as this has been shown to be possible in many countries. He gives a Table showing the annual production of pitch distilled annually in different countries. Not every class of coal can be used in such ovens, and the ordinary Belgian type is better for certain kinds, the essential difference between the Carvés type and the usual form is that in the latter case all the gas formed by distillation of the coal passes mixed with air direct to the chambers surrounding the ovens and is there burnt, whereas in the Carvés ovens distillation takes place apart from the air, as there is no direct communication between the interior of the ovens and the surrounding chambers, and the gas reaches them after depositing its pitch, benzol and ammoniacal salts. The installation of these ovens of the Vizcaya Company occupies an area of

21,000 square yards and consists of 144 ovens in four batteries of 36 each in one line. Two batteries were set to work on the 9th of November, 1888, and the other two in May 1890. The dimensions of each oven are: length, 23 feet; width, 1 foot $7\frac{3}{4}$ inches; height, 6 feet $6\frac{3}{4}$ inches; each holds 5 tons of coal and produces 75 per cent. of coke or 3·75 tons. The average time required for coking is forty-eight hours. The Author then describes the process in detail. The composition of the gas after being washed is by volume, hydrogen 52 per cent., CH_4 35 per cent., carbonic oxide 6·5 per cent., the rest consisting of C_2 H_4, carbonic acid, water, sulphuric acid, benzol, &c.

The temperatures are as follows: in furnace 2,000° C., and in the passages from 1,310° C. to 1,401° C. After being burnt in the ovens the gases pass below eight boilers, reaching them at 700° C. and passing to the chimneys at 300° C. The auxiliary apparatus for treating the benzol and ammoniacal liquors are also described. The average output per ton of coal treated is pitch, 55 lbs. to 59·7 lbs.; benzol, 4·4 lbs.; sulphate of ammonia, 15·4 lbs. to 17·6 lbs. As to whether the Carvés or the ordinary type of oven should be preferred will depend upon the quality of the coal and the possibility of disposing of the by-products.

E. R. D.

The Handling of Material at the Blast-Furnace. AXEL SAHLIN.

(Advance proof. Transactions of the American Institute of Mining Engineers, February, 1897.)

This Paper deals with the numerous mechanical appliances required in charging, and for disposing of the metal and slag, in modern blast-furnace practice, especially in America. Among the contrivances noticed with more or less of detail are the bunker system for filling barrows at the Dowlais-Cardiff Works, and the transfer-car system, combined with an electric trolley line of the Maryland Steel Company at Sparrow's Point, Baltimore, where the ore is brought to the lift scales from points up to 900 feet distant. One weigher with two assistants, and two motor boys for the electric line per turn of twelve hours, are enabled to handle the materials necessary for the supply of a furnace making up to 392 tons per day. For lifting the material to the furnace top, vertical direct-acting hoists of the Gjers type were introduced at Bethlehem by Mr. John Fritz in 1860, and are still at work, but these, although efficient and giving little trouble in working, are deficient in reserve capacity when compared with steam hoists. The later developments of the blast-furnace in the direction of large outputs have, however, brought back the inclined hoist into favour, and, combined with methods of automatic emptying of the charging barrows into the furnace, have been adopted at Pittsburgh, Lebanon, Pennsylvania, and at Thomas, Alabama. In the latter instance 30-inch gauge drop-bottom cars are pushed up the furnace incline by a long bar running on a central line of 22-inch gauge moved by $\frac{3}{4}$-inch wire hauling ropes. The bottom doors of the car are kept closed by a weight at the end of a balance lever, which is lifted by a fixed guide bar at the furnace top, and allows the contents of the car to fall into the bell without any manual assistance. The capacity of the machine is about 5,500 tons per week, but a very much larger automatic charging plant, combined with a double bell-closing gastight cover, has been adopted at the Duquesne furnaces, Pittsburgh.

At works situated on navigable waters in America, the Brown hoisting and conveying apparatus is universally adopted for unloading ore from ships, and conveying it to the storage place. This may be built as a gantry crane spanning the stock yard, as well as in the cantilever form, either travelling or revolving. Examples of the former are to be found at the Illinois South Steel Company's Chicago Works, where there are sixteen in one parallel series, and at the Duquesne furnaces, while the latter is illustrated by an example, ranging over a space of 320 feet in diameter, giving a storage capacity of 63,500 tons, when piled to a height of about 48 feet. The ropeway is frequently used for carrying ore and cinder about blast furnaces in Europe, notably at the Gutehoffnungshütte, at Oberhausen, and at Seraing. In the United States it is in use at the Buffalo furnaces, where from 2,500 tons to 3,000 tons of ore are unloaded and distributed daily, over a distance of about 2,000 feet. The Author considers that a combination of the Brown conveyor, with travelling steam shovels for reloading the ore, hopper storage for coke and flux, electric transfer and good inclined skip hoists of large capacity per trip, would represent the most effective arrangement that the present state of the art will permit.

The contrivances noticed for the disposal of the cast are the Dowlais pig-breaker of Messrs. Martin & James, and the Uehling casting machine, the latter consisting of two endless chains, about 90 feet long, between the centre of the sprocket wheels, carrying a series of cast-iron chill moulds, overlapping at their edges so as to form a continuous band. These are moved at the rate of 15 feet per minute, the filling being done from a casting-ladle at one end, supplied either from the blast furnace or a mixer. The time required for the mould to travel to the other end, six minutes, is sufficient to allow the metal to solidify when the pig is transferred to a second carrier and cooled by passing it through a trough of water, so that it can be delivered directly into the railway wagon. The casting machine includes two chains of moulds working side by side, and can dispose of about 1 ton of iron per minute. The largest cast in a single day has been 729 tons for two furnaces at the Lucy Works, Pittsburgh. In general character this machine is very similar to the Hawden slag conveyor, which has also been introduced into America by the Cambria Iron-ore Company, for use in the conversion of slag into road ballast.

Two other labour-saving contrivances are the Baker furnace-tapping machine, in which the tapping-bar is worked by a rock drill, and Vaughan's tap-hole closing machine, in which the clay plug is forced into the tap-hole by a similar arrangement driven by air pressure. These are used by the Maryland Steel Company, and allow a cast to be made without taking the blast off the furnace.

H. B.

The Salt Mines of Transylvania. R. Lamprecht.

(Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien, 1897, p. 48.)

The important deposits of rock salt in Transylvania are of recent tertiary age. The rock salt forms irregular masses consisting chiefly of pure salt of granular texture. The colour is usually white or grey. In Torda, however, yellowish white salt is met with in considerable quantities, and in Parajd a red variety occasionally occurs, and a blue fibrous variety as a great rarity. Gypsum and marl are frequently found enclosed in the salt.

The Maros-Ujvar salt-mine is situated on the left bank of the river Maros. The deposit has in plan the shape of an egg, with a length of 900 yards and a width of 500 yards. It has been explored to a depth of 160 yards. The mine was worked in ancient times. The modern workings began in 1791, when three shafts were sunk. These are 50 to 60 yards in depth. In 1867 the mine was drained by an adit level driven round the deposit, and by the sinking of the Stefania shaft a new field was opened. This new shaft is equipped with a 30-horsepower engine, and has reached a depth of 86 yards.

A deep exploratory shaft has been sunk to a depth of 230 yards, with the object of ascertaining the thickness of the deposit. Altogether there are seven steam-engines at work with an aggregate horsepower of 186. The chambers of the old and new mines are lit by electricity. The salt is under-cut and blasted down; the product consisting of shaped blocks weighing 100 lbs. is carried in trucks to the shaft, and thence raised to the surface. The small salt is pulverised in mills and packed in 100-lb. sacks. In 1895 the production amounted to 51,841 tons, 500 men being employed.

The Author also describes the following mines:—

——	Output in 1895.	Men employed.
	Tons.	
The Deésakna mines . . .	17,122	160
The Parajd mines	4,679	100
The Vizakna mines	3,693	75
The Torda mines	1,606	34

With a view to utilise the earthy salt and brine accumulating at the bottom of the shafts, the first Hungarian alkali works were started last year.

B. H. B.

New Method of Casting Pig-Iron. E. A. Uehling.

(Engineering News, New York, 29 April, 1897, p. 269.)

This article describes an apparatus designed by the Author for casting and transporting pig-iron at blast furnaces, and in operation at the Lucy furnaces of the Carnegie Steel Co.

It is claimed for this invention that it saves waste and reduces greatly the cost of labour in the following particulars:—

(1) In the method of casting pig-iron in sand-mould, sand adheres to the pig, and is weighed with it to the detriment of the purchaser, and entails the use of additional fuel to melt it and limestone to flux it.

(2) It saves cost of labour in moulding, in breaking the pigs from the sows while they are hot, and in transporting the pigs from the moulding-house to the railway.

By Mr. Uehling's method, the pig-metal is run from the blast furnace into a ladle mould holding from 15 to 20 tons. From the ladle it is poured into a pouring-pot with two nozzles, which discharge two streams into two sets of continually travelling moulds.

These moulds are attached to an endless chain of links and rollers which pass over sprocket-wheels at each end; these wheels are actuated by power applied at a point about 90 feet from the casting-ladle. The chain travels at the rate of about 15 feet per minute; and by the time a mould reaches the outer sprockets the metal is sufficiently solid to be ejected, as the mould passes over the sprockets.

On the return journey, the moulds, being upside down, pass over jets which sprinkle them with milk of lime, contained in a tank below, and prevented from settling by a set of paddles on a revolving shaft. The lime forms a coating on the inside of the mould which prevents the fluid metal from adhering to them.

The invention also includes a pig-iron cooler and transporter. It consists of travelling chains similar to those used in carrying the moulds; but in place of them there is a continuous series of flat steel plates. This conveyor is set at right angles to the line of mould carriers, just under the outer end of the latter, and may be of any length (at the Lucy furnaces, 308 feet).

After travelling horizontally for most of the length (through a long iron trough filled with water) it mounts a grade, and as the flat plates pass over the sprocket-wheels, they drop the pigs into shoots, from which they slide into the trucks.

Another advantage claimed for this system is the very small amount of scrap made—less than 400 lbs. of scrap in a cast of 75 tons. The casting-machine has a capacity of 800 tons of raw material in each twenty-four hours. And the value of the iron cast by this method for basic or Bessemer purposes is said to be worth from 25 to 75 cents (1*s.* to 3*s.*) per ton more than sand or chill-cast pig.

Eleven minutes from the time the iron leaves the lip of the ladle it is cooled and on the trucks ready for transportation.

The Paper is illustrated by a series of photographs affording a general idea of the arrangement, and also by dimension-drawings of the details.

W. A. B.

Recent Progress in the Metallurgy of Iron.

E. DE BILLY and E. JULHIET.

(Bulletin de la Société de l'Encouragement pour l'Industrie Nationale, 1895, p. 47.)

This Paper, giving a summary of the improvements effected during the previous eighteen months in the various operations occurring in the preparation of iron, is divided into the following sections: preliminary treatment of ores, the blast furnace, puddling, Bessemer process, open-hearth steel, Stockman process, the forge, the rolling mill, wire manufacture, armour plates, moulding, special steels, tin-plate manufacture, uses of electricity. References are given to all the Papers which have been consulted, and numerous illustrations are interspersed throughout the text.

A. S.

The Ailments of those Employed in Zinc Works, and Hygienic Preventive Measures. Dr. SEIFFERT.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1897, p. 419.)

The Author gives the results of his twelve years' experience while employed as the medical officer of a zinc manufactory, during which time 1,300 workpeople came under his observation. Of these 1,000 were males and 300 females. The relative numbers of the sexes engaged at one time were 641 males and 145 females, the latter being thus in the proportion of 22·6 per cent. of the whole. Reference is made to the investigations of previous writers on this subject and to the opinions expressed by them. An account follows of the career of the operatives from the beginning of their working life, formerly at 12 but now at 16 years of age, to their retirement from active labour, after an average length of service of about 29 years.

The most noticeable attack is the rapid advent of anæmic symptoms, loss of appetite, disturbance of the digestion, muscular and nerve pains, failure of the extremities, severe diarrhœa, and the fatal blue line in the gums, all pointing to lead-poisoning. At 40 years of age the workpeople have, as a rule, lost all interest in labour, and it is only the dire necessity to earn a living which enables them to continue in their occupations. There can be no doubt that slow and subtle lead-poisoning is the chief factor in these chronic ailments, but there is still a possibility that other metallic poisons, notably zinc, may lead to certain of these injuries to health, chiefly in attacking the muscles and nerves. Both the blende and the calamine, employed as ores, contain from 1 to 2 per cent. of lead, and since even the minutest traces of this metal when once introduced accumulate in the system, there is here sufficient evidence of the probable origin of the grave symptoms mentioned. It is quite possible, however, that the sublimed zinc, if inhaled, may cause similar injuries to those which arise from the lead fumes, and it is known that sulphate of zinc, chloride of zinc, and even acetate of zinc may give rise to poisonous action in the system. Many other metals are present in the fumes and dust of the zinc works, such as cadmium, antimony, and arsenic, which are all most dangerous poisons. Even the sulphurous acid, carbonic oxide, and carbonic acid gas, constantly breathed as they must be in small quantities, may prove highly injurious. Some reports of the chemical investigations of Mr. Brandhorst indicate the existence, in different parts of the bodies and in the secretions of the zinc-workers, of antimony and zinc. It is shown that these substances must enter the system mainly through the lungs along with the dust and fumes, and various remedial and sanitary precautions, based upon the experience gained during these investigations, are embodied in a series of recommendations.

G. R. R.

The Effect of Great Current Strength on the Conductivity of Electrolytes. THEODORE WILLIAM RICHARDS and JOHN TROWBRIDGE.

(American Journal of Science, 1897, p. 391.)

Using the method referred to in the preceding Abstract, the Authors have studied the effect of discharging a large condenser through an electrolyte. Two copper plates of 16 square centimetres area, fixed 3 centimetres apart, in a saturated solution of copper sulphate, gave a resistance of about 3·8 ohms with the discharge of one, two, or three Leyden jars. By Kohlrausch's method the resistance was found to be 4 ohms.

Experiments with zinc sulphate and with cadmium sulphate gave similar results. The conductivity of electrolytes, unlike that of gases, appears, therefore, to be practically independent of the current strength, the explanation offered being that the great mass and specific heat of the material prevents the temperature from rising sufficiently.

G. J. B.

Aluminium for Electrical Conductors. C. C. Burr.

(The Electrical Engineer, New York, vol. xxiii., 1897, p. 144.)

The Author gives particulars of some electrical conductors erected between the power-house of The Niagara Falls Hydraulic Power and Manufacturing Company to their pot-room building. The power-house is situated at the bottom of the Niagara gorge, some 250 feet below the building, where the current is used. The conductors, hence, were practically vertical and had to have sufficient section to carry 10,000 amperes. It was estimated that about 24 tons of copper would be required, while the weight of aluminium for the same capacity and loss would be $11\frac{1}{2}$ tons. The details of the line are as follows: Each conductor is made up of 250 $\frac{3}{8}$-inch rods 350 feet long. The rods in this conductor being in one piece, all intermediate joints are dispensed with. The rods are supported in the wire tower at intervals of 25 feet. The supports are of wood, so arranged that each rod is supported independently of the others. An S-shaped bend is made in each rod just above each support to provide for expansion and contraction. The conductors to the furnaces inside the pot-house are also aluminium. It is claimed by the Author that the first cost of this line was not more than it would have been if copper had been used, and that the supports required were cheaper because of the lightness of the aluminium. The aluminium is also less affected by the atmosphere than copper.

R. W. W.

Recent Determinations of the Electrical Conductivity of Aluminium. Joseph W. Richards and John A. Thomson.

(Journal of the Franklin Institute, 1897, p. 195.)

The Authors state that there has been considerable uncertainty as to the actual value of the electrical conductivity of this metal. This has arisen from several causes: the impurity of the metal itself; reference to conductivity of copper and silver, when the exact degree of purity of the standards was not known; lack of a standard of resistance; and imperfect methods of measurement. They used the Standard International Ohm, and experimented with wire in 50 feet lengths, using a delicate galvanometer. The samples were supplied by the Pittsburgh Reduction Company, and were all analyzed by Mr. Handy of the Pittsburgh Testing Laboratory. The Authors refer to the experiments of Mr. C. F. Scott, electrician of the Westinghouse Electric Company, Pittsburgh; those of Lord Kelvin, Charpentier-Page, Dewar and Fleming, and C. R. McGee, and they quote the values obtained and compare them with those found by themselves. Allowing for the lack of careful analyses of the aluminium used by some of the experimenters, the results obtained agree with those found by the Authors. These are given in a Table, and serve to show the great change in conductivity resulting from even small percentages of impurity.

Taking the conductivity of pure copper at 100, then that of—

98·5 per cent. pure aluminium is				. . . .	55·0
99·0	,,	,,	,,	. . . .	59·0
99·5	,,	,,	,,	. . . .	61·0
99·75	,,	,,	,,	. . . .	63·0 to 64·0
100·0	,,	,,	,,	probably .	66·0 ,, 67·0

Annealed wire has a conductivity 1 per cent. greater than unannealed.

E. R. D.

The Electrical Conductivity of the Ether. John Trowbridge.

(American Journal of Science, 1897, p. 387.)

The Author's experiments lead to the conclusion that the chief resistance to the passage of a current through a highly rarified gas is encountered at the surface of the electrodes, and that when this is overcome the ether offers very little resistance. The method employed has been already described.[1] The electrical circuit is provided with two spark-gaps, one of which is placed in the gas to be examined, while the other is photographed with a revolving mirror, the resistances being estimated by comparing the damping of the electrical oscillations. As source of current a battery having an electromotive force of 20,000 volts, with a resistance of ¼ ohm per cell, was used. By combining this with a modification of the Planté rheostatic machine the electromotive force could be raised to 500,000 volts. It was found that at least 100,000 volts were necessary to produce the Röntgen rays, and each discharge appeared to consist of at least ten oscillations, with a period of about one ten-millionth of a second. The resistance of the rarified medium was less than 5 ohms, and it appeared to be independent of the distance between anode and kathode. Experiments were made with sparks in air, and also under a pressure of four atmospheres. A somewhat greater length of spark could be obtained in hydrogen than in air, but there was no appreciable difference in the resist-

[1] *Philosophical Magazine*, December, 1891; also *American Journal of Science*, April, 1897.

ance. Neither the material nor the form of the electrodes was found to have any effect in this respect. The Author considers that under very high electrical stress the ether breaks down and becomes a good conductor.

G. J. B.

A Method of Demonstrating and Studying the Time-relations of Variable Currents. FERDINAND BRAUN.

(Annalen der Physik und Chemie, vol. lx., 1897, p. 552.)

This method is based upon the deflection of the kathode rays in a magnetic field. The Author uses preferably a vacuum tube of special design. It has a cylindrical body 26 centimetres long, with an aluminium kathode at one end, an anode in a side tube 10 centimetres from the kathode, and an aluminium diaphragm with a central aperture 2 millimetres in diameter at the other end. Beyond the diaphragm the tube expands into a pear-shaped portion 19 centimetres long, and 8 centimetres diameter at the widest part. In this is placed a mica screen covered with a phosphorescent material, on which the pencil of kathode rays passing through the diaphragm produces a luminous spot visible through the end of the bulb. The tube is excited either by an induction coil or a 20-plate Toepler machine. A small coil, traversed by the current which it is proposed to study, is brought close to the diaphragm, causing the kathode rays to be deflected more or less according to the momentary value of the current strength. In order to render these movements visible to the eye, the phosphorescent spot is observed by means of a revolving mirror.

The Author points out that owing to the use of the kathode rays as an indicator, the instrument is perfectly aperiodic, and may therefore find an application in many branches of research. As examples of the kind of work for which it may be used, he gives the curves of the town supply (50 alternations per second), which very much resemble those of a tuning-fork. Another series of figures shows the current-curves of the primary and of the secondary of an induction coil, both with and without a condenser.

By a slight modification of the arrangement, he is able to show the difference of phase between the primary and the secondary, and the effect of electrolytic polarization in producing a change of phase. He has also studied by the same method the rate of propagation of magnetism in iron, which he finds to be about 86 metres per second, with a rod 9 millimetres thick, and a current of 50 alternations per second, a result which agrees fairly well with the rate of 88·7 metres per second observed by Oberdeck[1] in a rod 8·7 millimetres in diameter, with 133 alternations per second.

G. J. B.

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[1] Annalen der Physik und Chemie, vol. xxii., 1884, p. 81.

On the Electrical Resistance of Saline Solutions in Movement.

ITALO BOSI.

(Il Nuovo Cimento, 1897, p. 249.)

According to Hittorff's hypothesis[1] no change of resistance should result from the flow in either direction of an electrolyte from one pole to the other, whereas the contrary may be expected if the views of Arrhenius[2] are accepted. The Author has therefore investigated the subject by a method free from some of the objections which may be brought against Edlund's[3] experiments.

He measured the difference of potential between two fixed points in a tube filled with the liquid under observation and traversed by a current, all the connections being made by means of non-polarizable electrodes. A zero method was employed, the capillary electrometer being used as an indicator. The experiments show that in those solutions in which electrolysis produces greater concentration at the positive pole, the resistance increases when the liquid moves against the current, and diminishes when it flows with the current. But in solutions which become more concentrated at the negative pole, the increase of resistance occurs when the liquid moves in the same direction as the current. Finally, there is no variation of resistance in either case in those liquids in which electrolysis produces no alteration of concentration at either electrode.

G. J. B.

Tests of a Gülcher Accumulator. Professor W. PEUKERT.

(Elektrotechnische Zeitschrift, 1897, p. 156.)

The Author obtained from the Gülcher Accumulatoren Fabrik of Berlin a set of their new cells to test. This type of cell has already been referred to.[4] The plates consist of a fabric woven of lead wire and glass fibre, these electrodes are placed between plates of hard rubber and bound round with glass fibre.

The accumulator tested was of type A_3, and had three positive and four negative plates, each 3·94 inches by 5·8 inches by 0·12 inch thick. The outside dimensions of the glass cell were 3·72 inches by 6·1 inches by 8·5 inches, the total weight in working order was 13·8 lbs. According to data given by the makers, the maximum charge and discharge current was 7·5 amperes, and the capacity 37 ampere-hours for a six hours'

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[1] Annalen der Physik und Chemie, vol. xcviii., 1856, p. 1.
[2] Journal de Physique, series 2, vol. v. p. 433.
[3] Annalen der Physik und Chemie, vol. clvi. p. 251.
[4] Minutes of Proceedings Inst. C.E., vol. cxxviii. p. 419.

discharge, 40 ampere-hours for eight hours' discharge, and 45 ampere-hours for twelve hours' discharge. The Author charged and discharged the battery nineteen times, some of the charge and discharge currents being six times that given already as the maximum; but even with this excessive current no injury was done, no active material fell, nor were the plates buckled, and the normal capacity was obtained on reverting to ordinary use. In one case, when charged at the normal rate, 38·18 ampere-hours were put in and 33·41 ampere-hours got out, representing 87·5 per cent. efficiency.

The Author considers that the use of glass fibre does not increase the internal resistance of a cell. He draws a comparison between this type of cell and other types, obtaining the data respecting the other cells from a work by C. Heim entitled, "Accumulators for Stationary Electric Plants," second edition, 1897. Data for eight types in all are given, and it appears that the output per lb. weight of cell is higher in the Gülcher-type than in any of the others.

E. R. D.

Equalizing Connections for Compound-wound Dynamos.

E. R. Keller.

(Journal of the Franklin Institute, 1897, p. 200. 7 Figs.)

The Author alludes to the necessity for using equalizing connections for compound-wound dynamos which are coupled in parallel. So soon as one of the machines generates a potential higher than the other there would be a tendency for the machine at lower potential to have its polarity reversed and for it to be driven as a motor. In order to avoid this, an equalizing connection is necessary. The Author attempts to make this plain by a hydraulic analogy, and proceeds to discuss several methods of arranging the connection. Where only two machines are used, and both are of exactly the same design, the current of one armature may be carried round the series coils of the other machine, and *vice versâ*, but where the machines differ it is useless. The arrangement most commonly used is to connect the series coil of each machine to a common bar or equalizer, and to provide a single pole switch in the connection for each machine. This method was first suggested by Gramme for series machines and by Mordey for compound. The Author then calculates the current which might pass in the equalizer and cites examples. Finally he proposes a new arrangement, for which he claims that the drop of potential is divided equally among all the machines, in consequence of which the currents in the series windings of all the machines are equal under all conditions. This is accomplished by connecting the beginnings of all of the series coils to an extra bus bar, to which is connected also one brush of each machine, instead of connecting the series windings direct to the brushes and the junctions of these to the equalizing bus bar. The system does not equalize the currents in the armatures and it necessitates an additional conductor from the dynamo to the switchboard, and, moreover, the whole current passes through the conductors which here replace the equalizer. The Author considers these disadvantages insignificant for small installations; but they might need consideration in very large stations.

E. R. D.

The Verification of Thomson Electric Energy Meters.

E. O'Keenan.

(L'Industrie Électrique, 1897, p. 184.)

The Thomson electricity-meter is used throughout one of the largest electric lighting "secteurs," or divisions, of Paris for recording the amounts taken by each consumer; and it therefore becomes important that the instruments thus employed should be accurately calibrated from time to time, in the interests of both supplier and consumer.

In this article the Author (who is chief inspector and head of the laboratory belonging to the electric light company) deals first with the methods followed for ascertaining the curves for the various types of meter, and states that the characteristic is—speaking generally—a straight line passing through the abscissa, or base line, slightly above the origin; that is, in comparing the watts indicated with the true watts passed. This may be represented by an equation of the form $Y = A + Bx$; where Y stands for the watts indicated, A is the constant of point of origin, positive or negative; B the angular co-efficient or characteristic, and x the exact watts, acting in the series coil. A has a positive or negative value, according as the mean moment of friction per revolution is smaller or greater than the moment of the couple due to the reaction of the compound winding upon the moving ring. This is regulated by means of the brushes. B is smaller or greater than unity (tan 45°), according as the magnets are too strong or too weak. It is also influenced by the surrounding temperature, which may increase or diminish the Foucault currents making effect on the disk; but this is not a serious matter.

In practical testing, it is enough to take two readings as carefully as possible, in order to arrive at the elements of a meter characteristic. If A is negative, the brushes are too tight, or other causes for excessive friction may exist; or else the ampere turns in the compound winding are insufficient; and conversely if it is positive, the brushes are loose, or the compounding too strong. If B is less than 1, either the magnets are too near the spindle or the temperature is too high; and conversely.

In general, the characteristic does not pass exactly through the origin, but cuts the base line of ordinates between the origin and a point representing one-hundredth of the meter's capacity. This means that a slight starting current is required to make the meter begin to register, and therefore is on the consumer's side, as well as the fact that a slight lagging tendency is also purposely given to each meter. The majority of the meters give a mean reading of from 95 per cent. to 105 per cent.; two-thirds of them, at least, recording less than 100 per cent.

The Author also gives an approximate co-efficient formula, by means of which consumers' accounts may be rectified from the meter readings according to the mean readings; that is, if the meter reads 102 per cent., then the indicated consumption is divided by the mean reading, thereby reducing the amount to be paid for; and conversely, if the meter reads too low, the amount is proportionately increased. He then shows how these meters are verified and arranged for use on the 5 wire circuits; practically the same process being gone through and equivalent results obtained.

F. B. L.

Impedance and Drop of Voltage in Alternating Circuits of Large Size. R. V. Picou.

(L'Industrie Électrique, 1897, pp. 105, 153.)

In the first of these two communications the Author states that the effects of reactance are generally negligeable when the conductors are short and the currents circulating of a feeble nature, also when fairly large currents are produced under a small difference of potential. It is, however, very different in the case of transformer secondary circuits, or with the use of powerful currents, as, for instance, in the manufacture of calcium carbide. Recent experiments showed cases where the reactance was practically equal to the useful potential difference, thereby causing a lag, or phase difference, of $\frac{\pi}{4}$, due simply to a defective arrangement of conductors.

The Table compiled by Mr. Kennelly, showing the factor of impedance with conductors a given distance apart (up to 50 centimetres or 20 inches), only includes wires up to 10 millimetres diameter. The Author, therefore, in view of the extensive applications latterly introduced for alternating currents, gives a diagram showing the results for larger sections, at the most usual frequencies. From this diagram is deduced the fall in voltage per 100 metres of double conductor consequent on the effect of impedance for a current of 100 amperes, with conductors spaced 30 centimetres or 12 inches apart. A Table of values for the factors of impedance, corresponding to the different sections and frequencies (40, 50 and 83), is also appended.

In his second article, the Author refers to the above-mentioned subject and statements in order to explain their possible misuse or misunderstanding. He points out that the curves given to show the drop in voltage are only accurate when there is no other self-induction but that of the line, and when there is also no appliance at the end of the line using the current. These are conditions obviously not realized in practice. He therefore, after working out theoretical examples, comes to the conclusion that the best plan is to calculate the values of the inductance of the lines for the given frequencies, and to use these figures for numerical applications. A Table of these values is given, in C.G.S. units, and from this is deduced another Table to show the drop in volts.

F. B. L.

Long-distance Electrical Transmission between Folsom and Sacramento, California.

(The Engineer, 11 June, 1897, p. 590.)

The Folsom-Sacramento power-transmission scheme comprises the construction of a dam, 89 feet high at the middle, across the American River above Folsom, the conveyance of the water along a canal 2 miles long, the transformation of its power at Folsom into electric current, and its transmission to Sacramento. The hydraulic plant consists of four pairs of 30-inch McCormick turbines of 1,260 HP. capacity at 300 revolutions. Each shaft is coupled to a 750-kilowatt three-phase generator. From the generator the current passes to the transformers, each of 250-kilowatt capacity, of the air-blast type, in which the pressure is raised from 800 volts to 11,000 volts, and the current passes to the high-tension transmission lines, 24 miles in length; a separate line being provided for each generator. The current is delivered to step-down transformers, and among the uses it is put to are its utilization for lighting purposes in the town, for the electric tramways, railway shops, &c.

A. W. B.

Malta Electricity Supply.

(The Engineer, 2 April, 1897, p. 343.)

This work was undertaken by the Government of Malta, and commenced supplying current in December 1896. Gas-lighting in the streets is dispensed with, arc- and glow-lamps being used for the purpose. The machinery is capable of dealing with 375 kilowatts, of which the public lighting requires 124 kilowatts. Steam is supplied to the first instalment from three Babcock and Wilcox water-tube boilers, each capable of evaporating 6,000 lbs. of water per hour at a working pressure of 150 lbs. per square inch. There are five main engines, three of 166 HP., one of 84 HP., and one of 40 HP. The engines are coupled direct to their respective alternators of the Mordey-Victoria type, by Raworth flexible couplings. Three of the alternators have an output of 100 kilowatts, and the other two 50 kilowatts and 25 kilowatts respectively. They generate current at the pressure of 2,000 volts and work in parallel with each other, irrespective of size. There are four exciters, each capable of exciting all the alternators running at the same time, and two small exciters coupled directly to the two smaller alternator shafts. The current is carried from the generating station to Valetta, Floriana and Three Cities by means of concentric high-tension feeders, insulated with specially-treated paper, covered with lead and armoured, and laid direct in the ground. There are forty-six transformers in use at present, varying from 18 kilowatts to 2 kilowatts, of the Mordey-Victoria type. They transform the current from 2,000 volts to 210 volts or 105 volts. The arc-lamps for public lighting are of the Brush-Vienne, 15 ampere, alternate-current type, arranged to burn sixteen hours without attention; they are worked on a separate main connected to small transformers which reduce the current from 2,000 volts to 35 volts.

A. W. B.

A Rail-Earth for Railway Telegraph Stations. P. Höfer.

(Elektrotechnische Zeitschrift, 1897, p. 168. 1 Fig.)

The Author points out that the large section of the rails permits of a low resistance being obtained in the return, say 0·4 ohm to 0·5 ohm instead of 20 ohms, where good wet earth returns are used. But in frosty weather the resistance of the rail return increases until it may become greater than the wet earth return, and for this reason both should be used. The connection to the rails requires attention, and the Author has designed a method which he describes. It consists of a flat plate held by two of the fish-plate bolts; the end of the plate is in the form of a pin. The earth wire is wound round this pin and well sweated on, it is then carried down in the form of a spiral of several coils into a covered wooden box. The spiral portion takes up the vibration.

E. R. D.

Telephone Installations without Call-Batteries at the Subscriber's End. G. Ritter.

(Elektrotechnische Zeitschrift, 1897, p. 97.)

This is a long article continued through three issues of the journal. The Author points out the desirability of simplifying telephone working, and describes an improvement whereby the magneto or battery is abolished at the subscriber's end and calling up and off takes place automatically.[1] Either single or double leads can be used. Practical experience has only been had, however, on lines with metallic returns.

In the diagrams connections are shown for both single and double lines, and both are so arranged that the act of lifting off the receiver gives the signal for attention at the station, and the act of hanging it up gives the signal for switching off.

The current causing these movements is produced by a battery or its equivalent at the exchange, and either direct or alternating current may be used.

Diagrams of the connections are given, and from these it appears that in the case of a line with metallic return, when the subscriber lifts his receiver off the hook, the hook makes a momentary earth contact, thus closing the circuit of a battery at the exchange, and the current from this battery actuates the magnet and allows the drop in the exchange to fall. The hook is brought to rest in the usual manner against a contact closing the line. A similar arrangement at the exchange causes the call-bell to ring at the instrument of a subscriber with whom it is desired to hold a conversation. The various means of coupling up at the exchange are shown.

Having described by the aid of diagrams the special arrangements required in double leads, the Author proceeds to deal with single leads. In this case the drop at the exchange is held up by a magnet constantly excited. The act of lifting the receiver at the subscriber's end causes the hook to momentarily break the magnet circuit and so allow the drop to fall. The arrangements of the jacks and contacts is described fully by the aid of diagrams.

E. R. D.

The Flow of Gas or Steam through Pipes. Arthur J. Martin.

(Engineering, 19 March, 1897, p. 361.)

The sub-heading of this article is "A comprehensive Table of the flow of gas or steam through pipes, with an examination of some of the formulæ now in use."

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[1] This is the system introduced in 1883 in the British Post Office by Mr. Preece and now in use all over that system.—Sec. Inst. C.E.

This question has not been so fully investigated as that of the flow of water through pipes, and in preparing a Table for gases, there are difficulties which do not arise in the case of water, owing to the variation which takes place in pressure or temperature; and the Author's first step in the preparation of these Tables was the selection of a formula. The experimental data on which such a formula can be based are scanty, and the results which have hitherto been arrived at by different observers somewhat conflicting.

Various formulas for the flow of a fluid (whether liquid or gaseous) through a pipe are given, including those of Prof. Unwin, Hawksley, Hurst, Beardmore, Babcock and Wilcox, and others. The results vary very considerably, that of Prof. Unwin giving much higher velocities under the same conditions than those of almost all the other authorities quoted (in one instance nearly twice the amount). Prof. Unwin's formula is corroborated to a great extent by the result of Prof. Rudler's experiments in the compressed air mains of Paris, and this, together with other reasons stated, led the Author to adopt, with slight modification, Prof. Unwin's formula as the basis for his Tables. The article is illustrated by three diagrams, one being a graphic comparison of the velocities arrived at by the different formulas above referred to, another of the loss of pressure with high densities, and the third, the loss of pressure with low densities. There are also three Tables of the flow of gases under different conditions.

D. G.

The Production and Uses of Ozone. Otto.

(Mémoires et Compte rendu des travaux de la Société des Ingénieurs Civils de France, March, 1897, p. 310.)

The Author first shortly refers to the existing machines of Siemens and Halske, and of Andréoli, for producing ozone, and points out that the theoretical efficiency in output of these machines is rather less than 2 per cent. This low result is greatly due to the heating of the machines, which, in his opinion, is caused (i) by the employment of too high potential, and (ii) by a bad choice of dielectric. The Author gives the results of a series of experiments which he carried out in order to ascertain, with a given thickness of dielectric and distance apart of conductors, at what voltages the discharge between the conductors took the form of an electric glow and of a shower of sparks. In the first set of these experiments, he employed two plates of dielectric (glass) between the two conductors, and, in the other, one dielectric between the conductors and the other outside, the glass in both cases being on the face of the conducting plate.

He then describes the apparatus he used in carrying out these experiments, and also the ozone machines, which he designed from the results obtained. These machines were of four types, but the general arrangement in all was one of plate conductors protected either on one or both sides with dielectric, arranged alternately of opposite sign, with an air space between, through which air space the gas to be ozoned was passed, and across which the electric discharge took place. In some cases the gas was drawn in at the edges of the plates, and delivered through a central aperture on one side, and in others was drawn in and delivered at central apertures, one on one side and the other on the other. With this type of machine, he obtained, at a periodicity of 80 per second, a theoretical efficiency of 15 per cent.; and he found, as he explains in his theory of the machine, that the output increased as the periodicity of the working current increased, and also as the velocity of the current of gas through the machine was increased.

He concludes by detailing the various commercial and other uses to which ozone can be put, chiefly by superseding oxygen as an oxydising agent. There are fourteen illustrations and diagrams in the Paper explaining the text.

R. B. M.

A Method of Preparing Phosphorescent Strontium Sulphide.

José Rodriquez Mourelo.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxiv., 1897, p. 1024.)

The Author uses a modification of the process described by Verneuil[1] for the preparation of the phosphorescent sulphide of calcium. A mixture of 285 grams of commercial carbonate of strontium, 65 grams of flowers of sulphur, 4 grams of crystallized carbonate of sodium, 2·5 grams of chloride of sodium, and 0·4 grams of sub-nitrate of bismuth, is packed tightly in a clay crucible and covered with a layer of starch. It is then kept at a bright red heat for five hours and allowed to cool slowly. The resulting sulphide, which is granular and friable and almost white, is highly phosphorescent, shining brightly in the dark after exposure to the diffused light of the laboratory. The Author finds that these sulphides, however prepared, generally lose, when they are powdered, the power of phosphorescing after exposure to light, but acquire it again after being mixed with starch and heated to redness for five hours.

G. J. B.

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[1] Comptes Rendus de l'Académie des Sciences, vol. cii. p. 600, and civ. p. 501.

A Reaction of Carbon-Monoxide. A. MERMET.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxiv., 1897, p. 621.)

The Author has made a long series of experiments on the best means of detecting traces of carbonic oxide in the air of mines, and rooms heated by furnaces. He uses the following test solutions. (A). A solution of 2 or 3 grams of nitrate of silver in 1 litre of distilled water. (B). A litre of distilled water is boiled with a few drops of nitric acid perfectly free from chlorides. A solution of potassium permanganate is then added drop by drop until a permanent pink colouration is produced, the object being to destroy any organic matter that may be present. After cooling, 1 gram of crystallized permanganate of potash is dissolved in the purified water, and 50 cubic centimetres of pure nitric acid added. This liquid must be kept from the light and protected from dust.

A sample of the air to be tested is procured by taking a stoppered bottle full of water into the suspected place, and emptying it there. A similar bottle is filled with air of known purity in like manner. Into each bottle is poured 25 cubic centimetres of a mixture containing 20 cubic centimetres of the solution A, 1 cubic centimetre of solution B, and 1 cubic centimetre of pure nitric acid, made up to 50 cubic centimetres with distilled water. This mixture, which is of a pale rose colour, is decolourized by carbon-monoxide, in a time varying from one hour to twenty-four hours according to the quantity present.

In this way two parts of carbon-monoxide in 10,000 parts of air can be easily detected by the decolorization of the test liquid. Some other gases have the same reducing effect upon the test solution, but their presence or absence can be determined in other ways.

The liquid in the comparison bottle of pure air should retain its pink colour for several days.

G. J. B.

A Thermometer for Very Low Temperatures. F. KOHLRAUSCH.

(Annalen der Physik und Chemie, vol. lx., 1897, p. 463.)

The mixture of hydrocarbons known as petroleum-ether has been found by Holborn and Wien to remain sufficiently soft at the temperature of liquid air to enable it to be used as a thermometric liquid. The Author gives the results of a series of measurements made in order to further investigate its suitability for this purpose.

The petroleum-ether used had a specific gravity of 0·6515 at 17° C., and boiled at 33° C. It had a very high coefficient of expansion, the volume at − 188° C. being only $\frac{4}{5}$ of the volume at

0° C. and $\frac{3}{4}$ of the volume at 30° C. With the exception of gases and some liquids near the critical point, the Author has not found any substance in which there is so great an alteration of volume without solidification. Certain precautions are necessary in using the petroleum-ether, as it becomes very viscous at − 190° C., and if rapidly cooled is apt to separate in the stem of the thermometer, leaving an "air-bubble" which does not close up again.

The mean coefficient of expansion referred to the volume at zero was found to be as follows:—Between − 188° and − 80° C. = 0·00104; between − 80° and − 50° C. = 0·00112; between − 50° and 0° C. = 0·00125; between 0° and + 22·7° C. = 0·00145; between + 22·7° and + 30·0° C. = 0·00158.

G. J. B.

The New Polarizing Photo-Chronograph at the United States Artillery School, Fort Monroe, Va., and some experiments with it. A. C. Crehore and G. O. Squier.

(Journal of the United States Artillery, 1896, p. 271.)

The polarizing photo-chronograph, invented by the Authors, is the instrument that first proved directly that the velocity of a projectile increases for some time after passing the muzzle of a gun. The value of the instrument lies in the fact that the record is made by an imponderable index—a beam of light—so that the inertia of the moving parts is done away with. The record is written photographically. The shutter consists of two Nicol's prisms and a tube containing bi-sulphide of carbon, the latter being surrounded by coils of insulated wire, through which an electric current can pass. A heavy fly-wheel is caused to rotate rapidly by an electric motor, and carries on its face a highly sensitive photographic plate, protected from the light by a shallow box, in which are two opposite radial slots closed by drop-shutters, which can be released electrically so as to expose the plate. In a line with the one slot is a condensing lens, then follow in order the analyzer, the tube containing bi-sulphide of carbon, surrounded by four coils of wire coupled in parallel, and the polarizer, on which the light of an arc-lamp is concentrated by a lens. The polarized light, after passing through the bi-sulphide of carbon, can only pass through the analyzer when it is twisted by the passage of the electric current in the encircling coils. A measuring scale is imprinted on the sensitive plate by placing opposite the other slot one prong of a tuning-fork, of which the number of vibrations is known by the note. Through a small hole in a piece of foil attached to the prong of the fork, a beam of light is reflected from the arc-lamp by a mirror, and focussed on the sensitive plate, making a wavy line of known period of undulation, to which the dark and light patches are referred. It is arranged that the movement of one key starts the fork vibrating, fires the gun, completes the electric circuit, and opens the camera-shutter. The shot breaks the circuit by rupturing wire-screens, the circuit being remade in each case by the shot in passing another wire.

A. W. B.

The Storage of Acetylene.

(Journal für Gasbeleuchtung, vol. l., 1897, p. 317.)

The continued attempts to develop the carbide industry and the use of acetylene for lighting purposes have recently been considerably discouraged by frequent explosions which have occurred, and the prospects of the use of this undoubtedly important gas for illuminating purposes have been much prejudiced by undue fear and by the strict regulations imposed for the erection of acetylene apparatus and the sale of carbide and acetylene. Mr. M. G. Claude and A. Hess have devised what they claim to be a perfectly safe method of storage, which was explained at the meeting of the Académie des Sciences, Paris, on the 22nd March, 1897, by Mr. d'Arsonval.

It is proposed to avoid the danger of compressed acetylene by making use of its great solubility under pressure in certain fluids. It is fairly soluble in acetal, methylal, and acetic ether, but more particularly in ordinary acetone (C_3H_6O), and this body is easily produced and is obtainable at a relatively low price. At ordinary pressures and at a temperature of 59° F., acetone takes up twenty-five times its volume of acetylene, and its solubility increases nearly in proportion to the pressure; so that, with a pressure of twelve atmospheres, one volume of acetone will absorb about three hundred volumes of the gas. By this means the use of acetylene becomes very simple, as, by gradually opening a cock at the top of a receiver containing the dissolved gas under pressure, the gas passes out until the receiver is at ordinary atmospheric pressure, and the exhausted fluid can then be again charged with acetylene. The volume of the fluid increases by absorbing the gas, and under a pressure of twelve atmospheres it would be one and a half times that of the original acetone. The solubility decreases with increased temperature, from 59° F. to 122° F., by about one-half, and the pressure is doubled by an increase of 86° F. Comparatively low pressures may be employed, so that only light metal receivers are necessary, which are less dangerous in the event of an explosion, and, in consequence of their lightness, more acetylene can be stored per unit of weight. The coefficient of expansion of acetylene solution is not nearly so great as that of liquid acetylene, so that the receivers can be nearly filled without risk of bursting.

The general knowledge of the relations of explosive mixtures justifies the opinion that the explosive properties of acetylene, on account of its endothermic formation, will be greatly decreased, if not entirely destroyed, by its solution in a neutral fluid. It was shown that, with a solution of acetylene in acetone at a pressure of three atmospheres, a platinum wire could be raised by electricity to a bright red heat without an explosion occurring.

C. G.

On the Use of Naphtha Oil as Fuel in the Russian Navy.

Lieut. M. G. DE LA DROITIÈRE.

(Revue Maritime, tome cxxxiii., May 1897, p. 385.)

Mazout, the combustible employed, is the residue obtained after extracting from naphtha oil the petroleum, benzine and other hydrocarbons inflammable at low temperature. Its use is unattended with danger. It cannot be ignited by flame, or by shells bursting in it. Before it will burn it is necessary to raise it to a very high temperature, and it is in fact less dangerous than coal. Its evaporative duty is nearly twice that of coal and it is smokeless. The radius of action of a vessel is estimated to be increased 60 per cent. by the substitution of naphtha oil for coal.

The oil is injected into the furnace in the form of spray by means of a steam-jet. Experiments have been satisfactorily carried out on board the torpedo-boat "Viborg." The steam for spraying the oil is supplied by an evaporator which also makes fresh water for the boilers.

S. W. B.

Launching of H.M.S. "Niobe."

(Engineering, 5 March, 1897, p. 309.)

The cruiser "Niobe" was built at the Naval Construction and Armament Works at Barrow-in-Furness, and was launched on the 20th February last.

The article is illustrated by four photogravure views of the bow and stern, and of the broadside amidship and aft before launching. These views show the great care required in the preparations for the process of launching, owing to the exceptionally fine lines on which she is constructed, and her great weight in proportion to the length, and it may be said that, owing to the accentuation of these conditions, increased precautions are called for in each successive launch of vessels of this description.

Her length is 435 feet, her beam 69 feet, and her displacement at 25 feet 3 inches draught will be 11,070 tons. Her engines are to be 16,500 I.HP., and her speed will probably be 21 knots.

Her launching weight was 6,300 tons, or probably nearly twice as much as a merchant vessel of the same length; consequently the ways had to be exceptionally broad, viz., 5 feet, to reduce as far as practicable the pressure upon the sliding surface (1·84 tons per square foot in this instance). At the instant when the stern became water-borne, when the latter was about 300 feet off the ways, the pressure in this case amounted to about 1,500 tons on the far end of the ways.

The cambered inclination of the ways is given, and detailed descriptions of the form of cradles used, the amount of deflection in the hull after becoming water-borne, and some particulars of her engines, armament, etc.

D. G.

The Stern-wheel Steamers "Empress" and "Liberty."

(Engineering, 12 March, 1897, p. 340.)

These steamers have been recently constructed by Messrs. Easton, Anderson and Goolden for the Royal Niger Company. The article is illustrated by three full-page drawings and smaller diagrams in the text.

The length is 137 feet, beam 27 feet, and the depth at the sides 6 feet. The draught, with steam up and 15 tons of coal on board, is 26 inches. The hull is of mild steel, the shell being of $\frac{3}{16}$ inch plates, and all the metal up to the level of the main deck is galvanized. The vessel is divided into eight watertight compartments by five athwartship bulkheads, and two longitudinal bulkheads in the engine space.

Instead of having the paddle-wheel projecting beyond the stern of the ship, as has usually been the case heretofore, in the instance of these vessels there are two paddle-wheels, one on either side of the stern, and the ship is cut away or indented so that the outer edge of the wheel does not project beyond the profile of the hull. The pair of engines are so arranged as to work the two wheels either simultaneously in one direction, or may be worked independently in opposite directions, an important point in the navigation of the narrow and tortuous channels of some of the West African waterways.

The engines are of the compound type, with cylinders of 10 inch and 22 inch diameter and 36 inch stroke.

Full details of these are given, and of the consumption of coal, &c. The mean speed is 7·38 knots.

D. G.

Contract Trial of the "Gresham." C. A. McAllister, U.S.R.C.S.

(Journal of the American Society of Naval Engineers, May, 1897, p. 253.)

The "Gresham" is a single-screw steel revenue-cutter of about 900 tons displacement, intended for service on the Great Lakes.

Length between perpendiculars	188 feet.
Beam	32 ,,
Draught	10 ,, 10 inches.
Prismoidal coefficient of fineness	0·606
Block ,, ,,	0·48
I.HP. (total)	2431
Displacement on trial	820 tons.
Speed	17·53 knots.

The machinery consists of a set of triple expansion-engines having cylinders 25, 37½, and 56¼ inches diameter respectively, and having a stroke of 30 inches.

The steam-pressure is 160 lbs. per square inch, and the revolutions 165 per minute. There are four single-ended Scotch boilers, having a total heating-surface of 5,185 square feet and a total grate-surface of 168 square feet.

Full particulars of hull and machinery, with scantlings and dimensions of parts, are given.

S. W. B.

The Contract trials of the United States Gunboats "Helena" and "Wilmington." W. S. Smith, U.S.N.

(Journal of the American Society of Naval Engineers, May, 1897, p. 360.)

These two steel twin-screw sister vessels were built at Newport News, Virginia, from designs furnished by the navy department. The contract price for each vessel complete, except armament, was £70,000. They have high freeboard forward extending for three-fourths of the vessels' length. They are designed for service in rivers and estuaries. Machine and rapid-fire guns are placed in fighting-tops to command the banks of a river.

The main battery consists of eight 4-inch quick-firing guns, two on the forecastle, four in sponsons on the main deck under the forecastle deck, and two aft. The secondary battery is composed of four 6-pounder quick-firing guns, four 1-pounder and four gatlings. A belt of 1-inch nickel steel at the water-line protects the machinery.

The dimensions are—

Length on load-water line	250 feet 9 inches.
Beam	40 feet 1 inch.
Draught	9 feet.
Displacement	1,397 tons.

There are two sets of triple-expansion engines, having cylinders 14½ inches, 22 inches and 33¼ inches in diameter respectively, and a stroke of 18 inches. Steam is supplied by six single-ended return-tube boilers working under forced draught, and having a total heating surface of 4,800 square feet and a total grate surface of 126 square feet. The speed of the "Helena" on trial was 15·49 knots, and of the "Wilmington" 15·07 knots. The I.HP. was 1,988 and 1,894 respectively.

Very full particulars will be found in the article.

S. W. B.

A Boat Constructed of Cement.

(Cosmos, 5 June, 1897, p. 718.)

Small boats are being constructed of cement by Mr. Gabellino in Italy. The frames are made of round iron and upon them is stretched wire netting. A coating of cement is applied inside and outside. The thickness is not stated. The outer surface takes a bright polish like marble.

Boats can be built of cement at a less cost than if constructed of wood or steel. Experiments are being made with a view of producing armour plates of cement stiffened with several layers of wire netting.

S. W. B.

Ship-Lift at Henrichenburg.

OFFERMANN, Government Engineer, Dortmund.

(Zeitschrift für Binnenschiffs-fahrt, 1897, Heft 5, p. 150.)

The water-level of the branch from Dortmund is from 46 feet to 52½ feet above that of the main Herne-Münster Canal at their junction near Meckinghoven. To connect the two, a lift has been constructed capable of raising at one operation ships of 600 tons burden (220 feet long by 26 feet beam), drawing 5¾ feet to 6½ feet of water. A water-tank, 230 feet long, 30 feet wide and 8 feet deep, is supported by five clusters of four iron lattice-work piers, resting on five huge wrought-iron air-tight cylinders, which float in five wells sunk below the bottom of the lower chamber for the reception of the tank. This chamber is kept free of water; the tank, therefore, is always in the dry.

A suitable water-tight connection between the canals and the inside of the tank provides for the entry of ships. Water is kept constantly in the tank, the weight of which, together with the tank (3,000 tons), is kept in perfect equilibrium by the buoyancy of the five atmospheric air-cylinders floating in the wells. This is in no wise disturbed by the entry of a ship, as it displaces merely its own weight of water. Motion up or down is effected by adding to or withdrawing water from the tank. It is kept in a true vertical plane by guide piers on each side, braced together overhead by girders carrying a platform for the various mechanisms, and supporting the horizontal shaft and cog-wheels which turn the vertical screw-shafts which pass through four massive screw-heads attached to the four lower corners of the tank, and regulate and control its movements. These are forged from one piece of steel, 71 feet long and 11 inches exterior diameter, bored throughout and capable of supporting the whole weight in case of accident. Power is supplied by a 150-H.P. electromotor. Forty ships can be passed in both directions in a day, the passage lasting thirty minutes. The cost was about £12,255.

Map, plan and sections illustrate the Paper. Readers are further referred to an article by Fr. Jebeus, "Ship-lift with screw-lifts," in the Zeitschrift for 1895–96.

W. A. B.

The Measurement of Grain Pressure in Silos. Prante.

(Zeitschrift des Vereines deutscher Ingenieure, 1896, p. 1122.)

The Author records in this Paper the results of investigations carried out at Bernburg (following up the suggestions of Mr. Janssen)[1] for determining the lateral pressure in silos from grain in various conditions of storage. The apparatus by which the pressure was transmitted and gauged is briefly described. The experiments were carried out on circular silos, respectively 12 feet 6 inches and 5 feet in diameter: first, with the grain in a state of rest; then with the outlet valve open and the grain being drawn off; and, lastly, with the grain being drawn off and more grain being simultaneously filled in above. The records of the experiments are included in four tabular statements from which the subjoined extracts indicate the general results:—

Table I.—Grain at Rest.

A silo, 12 feet 6 inches diameter.

Height of Column of Grain above Testing-Point, in Feet.	Lateral Pressure in Lbs. per Square Foot.	
	Dry Californian Wheat.	Dry Russian Rye.
6·6	16·4	24·6
16·4	44·0	81·9
32·8	139·3	204·8
49·2	243·7	358·4

[1] Minutes of Proceedings Inst. C.E., vol. cxxiv. p. 553.

TABLE II.—GRAIN AT REST AND IN MOVEMENT (OUTLET OPEN), DRY RUSSIAN WHEAT.

Height of Column of Grain above Testing-Point, in Feet.	Lateral Pressure in Lbs. per Square Foot.	
	(i) At Rest.	(ii) Drawn-off at Rate of 0·06 Foot per Minute.
6·6	30·7	..
16·4	75·8	..
32·8	143·4	661·5
39·4	170·0	819·2
42·6	186·4	917·5
49·2	219·1	1,146·9

TABLE III.—GRAIN AT REST (DRY WHEAT).
B silo, 5 feet diameter.

Height of Column of Grain above Testing-Point, in Feet.	Lateral Pressure in Lbs. per Square Foot.
8·2	106·5 to 114·7
18·0	196·6 ,, 213·0
32·8	249·8 ,, 262·1
50·8	278·5 ,, 286·7

TABLE IV.—GRAIN (I) AT REST; (II) DRAWING OFF; AND (III) DRAWING OFF AND REFILLING SIMULTANEOUSLY.

Height of Column of Grain above Testing-Point, in Feet.	Lateral Pressure in Lbs. per Square Foot.		
	(i) At Rest.	(ii) Drawing-off.[1]	(iii) Drawing-off and Refilling.[1]
18·0	90·1 to 114·7	196·6 to 262·1	..
9·8	106·5 ,, 131·1	237·6	..
4·3	..	41·0 to 61·4	..
3·3	..	..	65·5 to 81·9
5·2	..	..	90·1 ,, 106·5
9·2	..	..	196·6
11·5	..	..	245·8
14·8	..	..	573·4

The chief point clearly shown by these records is the great immediate increase of pressure when the grain is in movement and the conditions of cohesive stability are altered.

P. W. B.

[1] Drawing-off in first experiment at rate of 0·097 foot per minute; in all other cases at 0·197 foot per minute.

The Ludwigshafen Flour-Roller Mills. R. Geissler.

(Zeitschrift des Vereines deutscher Ingenieure, 1896, p. 1069.)

The works described in this Paper are the extension and remodelling of a 300-sack plant, to adapt it for turning out 1,000 sacks (100 tons) per diem; and the substitution of the most recent types of rolling and cleaning appliances for the machinery previously in use. The buildings comprise the mills, a large open-floor warehouse, and a silo-granary. The wharf equipment includes a ship-elevator of a capacity of 40 tons per hour. From this the grain is delivered by a travelling belt and spouting to the silos and to the series of dust-extracting, cleaning-, weighing-, rolling-, and mixing-machines, which are described in some detail. The silos are twenty-four in number, and have a capacity of 190 tons each, or a total storage of 4,560 tons.

P. W. B.

Pneumatic Grain Elevators.

(Le Génie Civil, 10 April, 1897, p. 362.)

This is a description of two pneumatic methods of elevating and conveying grain. The first system is by suction; a fan in a suitable position, at the upper end of the pipe-line, forming the elevator and conveyor, creates a partial vacuum in the pipe. The lower end of the pipe dips into a receiving hopper, and at the point where the grain is required to be deposited, a separating chamber is fitted on the pipe, with a short vertical length of pipe on the under side, having at its lower end a balanced valve which allows the separated grain to pass through, while preventing air from entering when the vertical pipe contains no grain. The dust is carried off by the current of air.

In the other system the fan is situated at the lower end of the pipe-line, and forces air at the required pressure through the pipes. The grain is admitted to the pipes by a sort of revolving hopper, driven by a small jet of air from the main pipe. This hopper allows the grain to enter at the proper rate to permit of its being carried off by the current of air, and discharged by it at the upper end of the pipe. The article is accompanied by several illustrations. A plant of the first type installed at Vouziers elevates the grain to a height of 72 feet with an expenditure of 15 HP., a vacuum of $23\frac{1}{2}$ inches of water and an output of 15 tons of grain elevated per hour; while a plant of the pressure type at Armentières with a HP. of 30, and a pressure of $31\frac{1}{2}$ inches of water, delivers 18 tons per hour. Another installation of this type at Marseilles conveys the grain a distance of 230 feet and then raises it 46 feet. The conveying-pipe in this case is about 14 inches in diameter, and the pressure of air $17\frac{3}{4}$ inches of water, the capacity being about 4 tons per hour.

R. B. M.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1896–97.—Part III.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)." Abstracted Papers are not so indicated.

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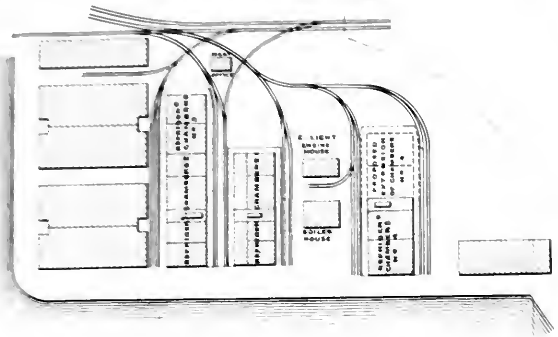
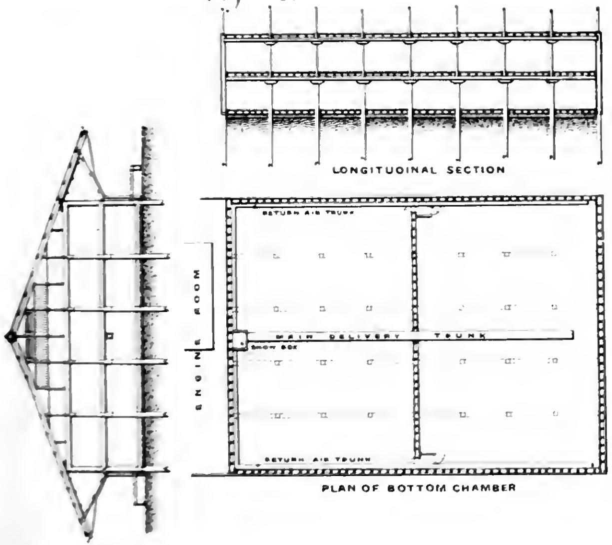
COLD STORAGE

AT THE LONDON AND INDIA DOCKS

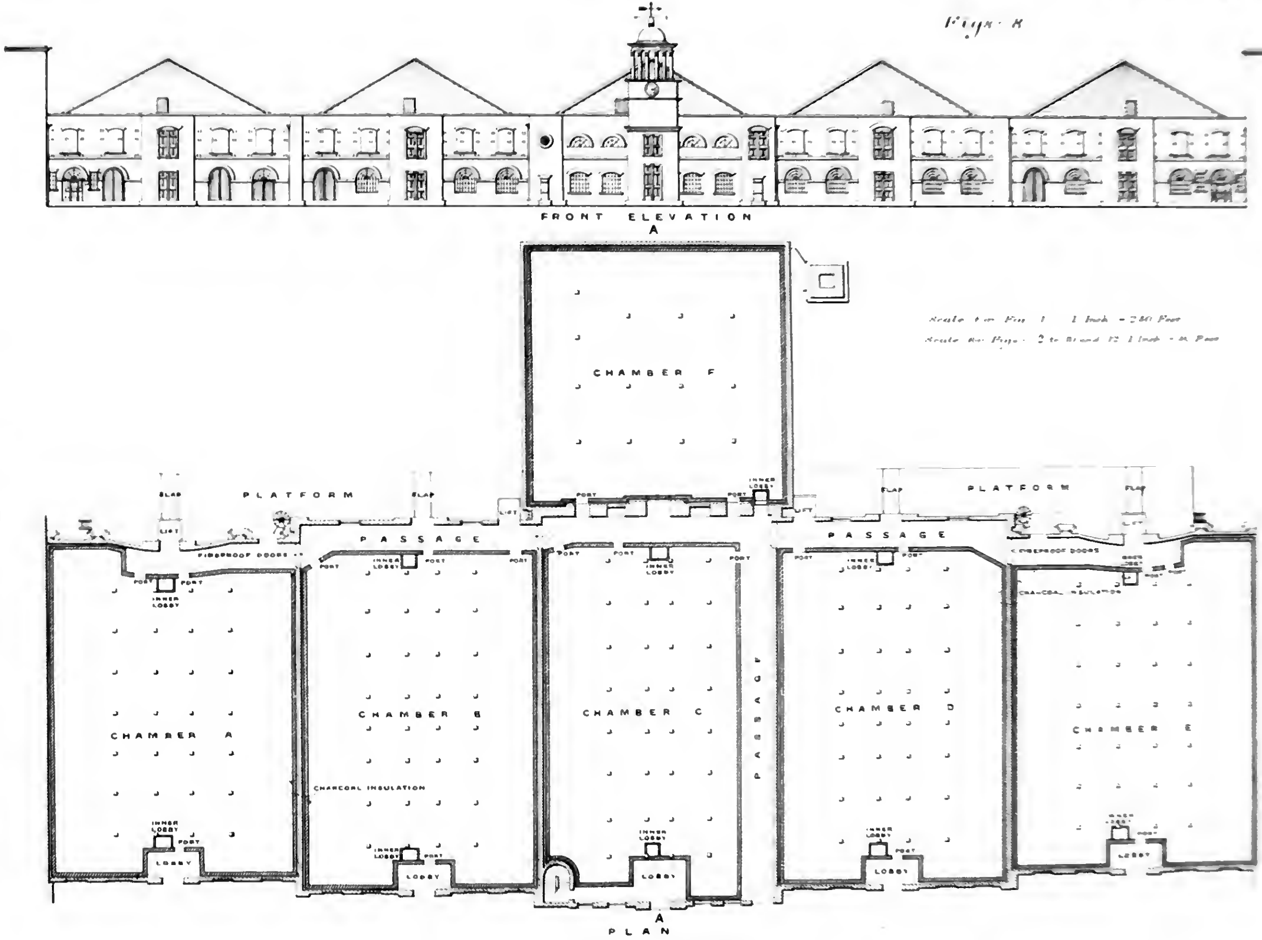
Fig. 1



Figs. 2.

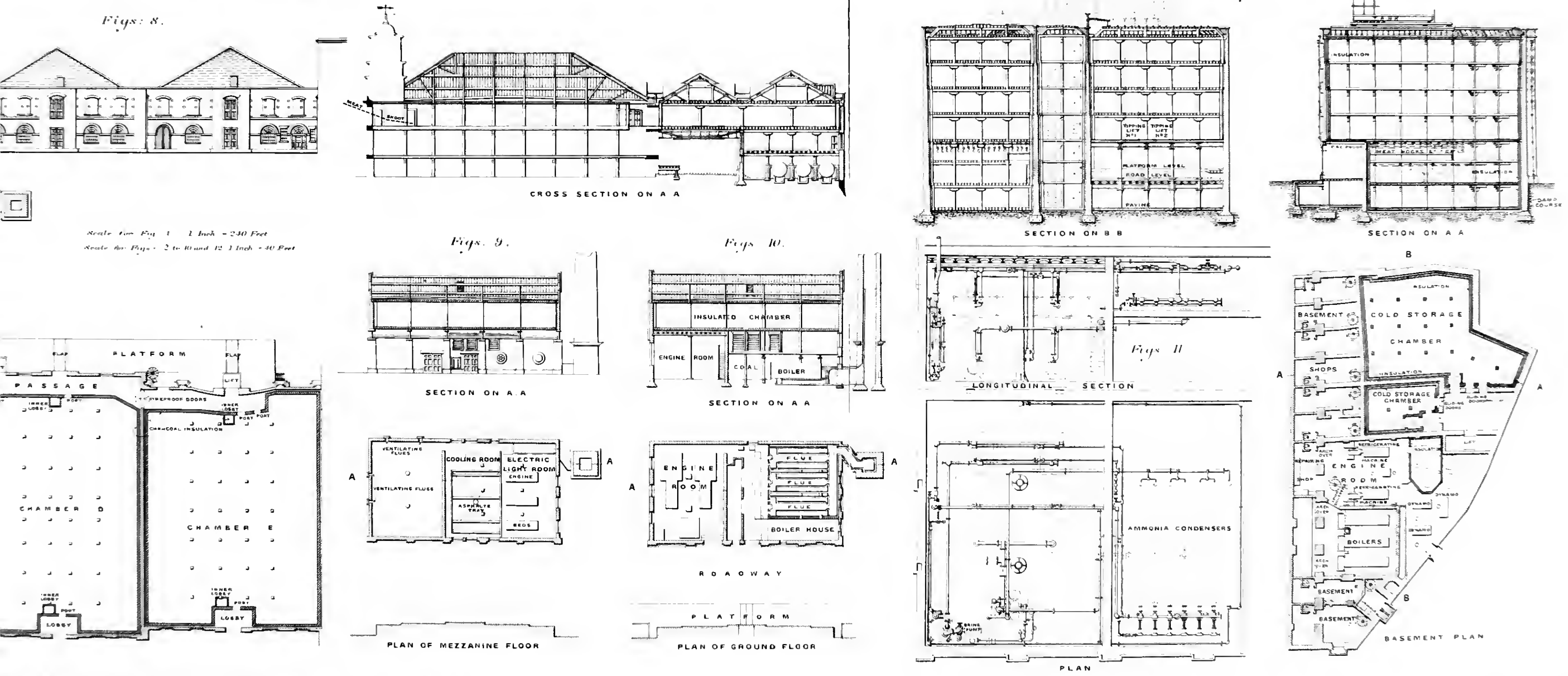


Figs. 8



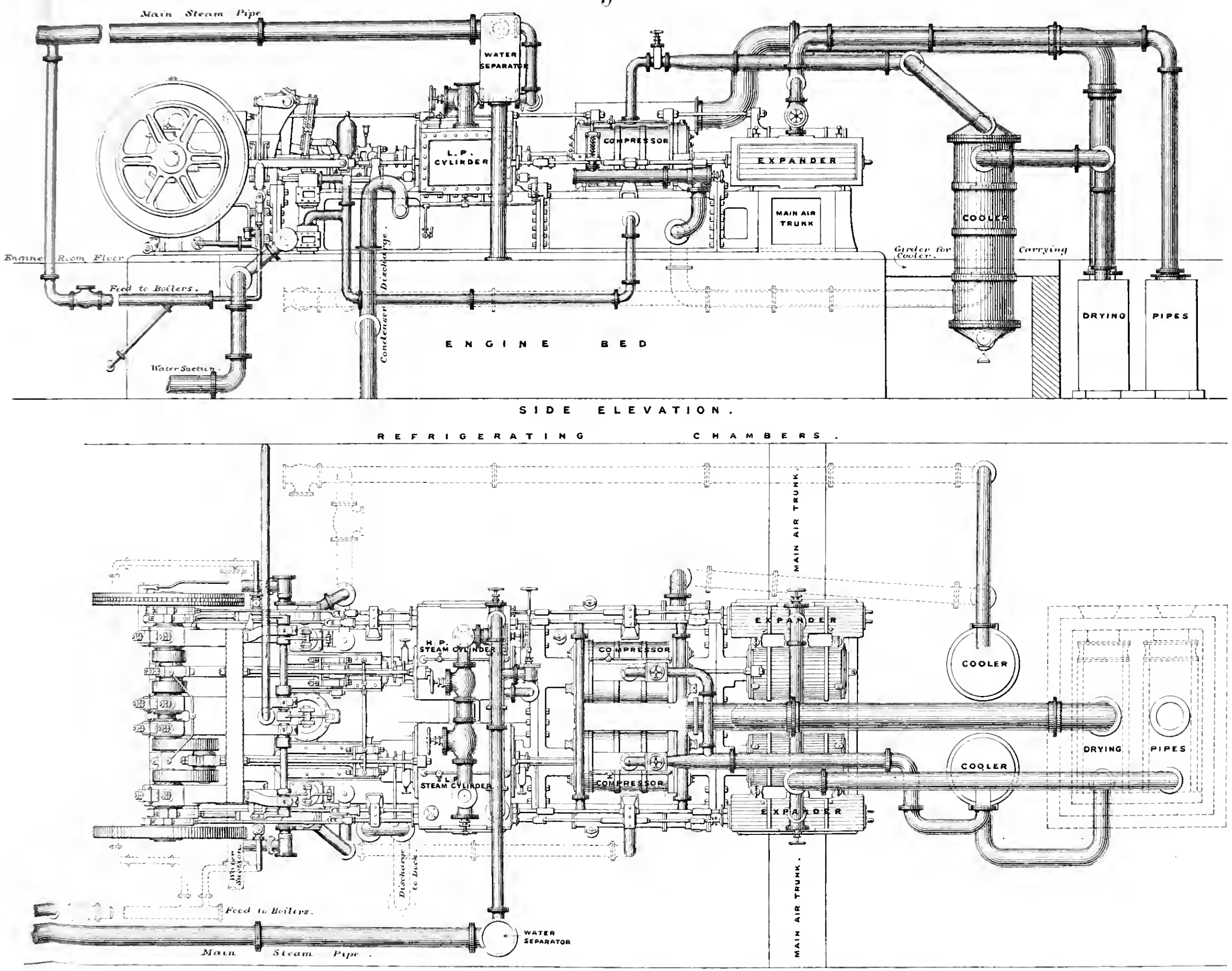
Scale for Fig. 1 1 Inch = 240 Feet

COLD STORAGE
AT THE LONDON AND INDIA DOCKS



COLD STORAGE
AT THE LONDON AND INDIA DOCKS.

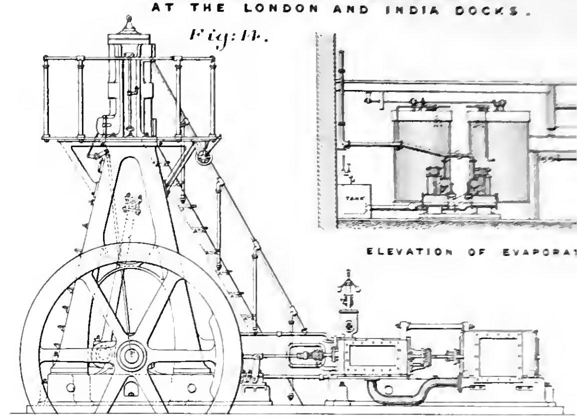
Figs. 13.



SIDE ELEVATION.

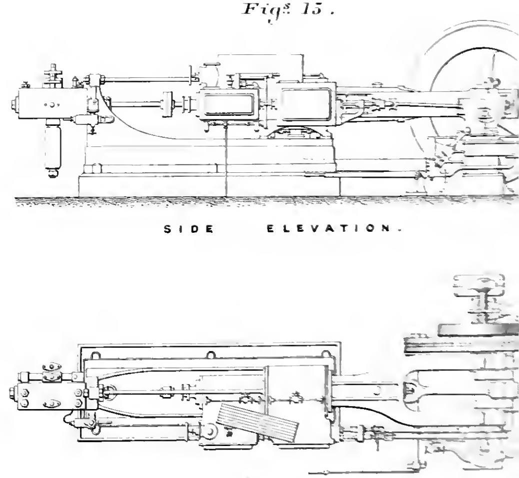
PLAN.

Fig: 14.



ELEVATION OF EVAPORAT…

Figs. 15.



SIDE ELEVATION.

PLAN.

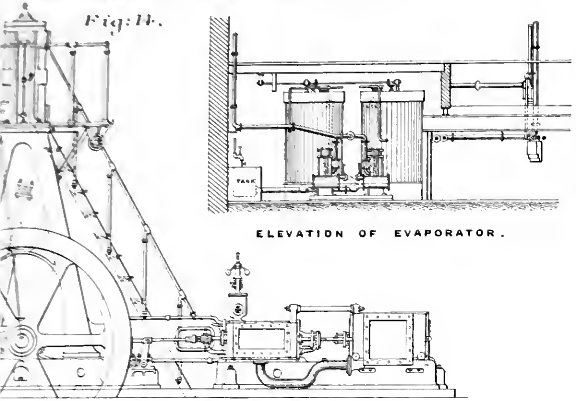
H. F. DONALDSON.

Scale for Figs. 13–15 3/16ths Inch = 1 Foot. Feet 5 4 3 2 1 0 5 10 Feet.

Scale for Figs. 16, 1/16th Inch = 1 Foot. Feet 10 5 0 10 20 30 Feet.

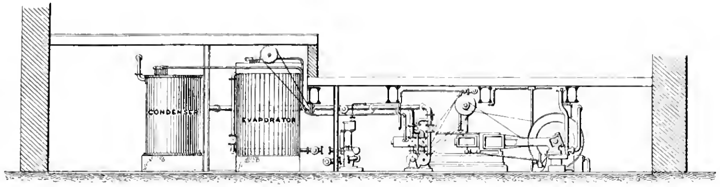
COLD STORAGE
AT THE LONDON AND INDIA DOCKS.

Fig: 14.



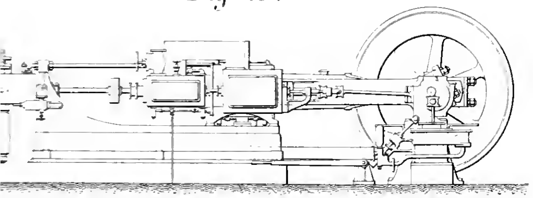
ELEVATION OF EVAPORATOR.

Figs 16.



SIDE ELEVATION.

Figs 15.



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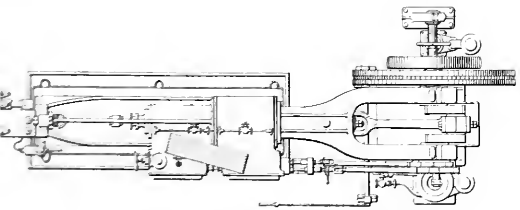

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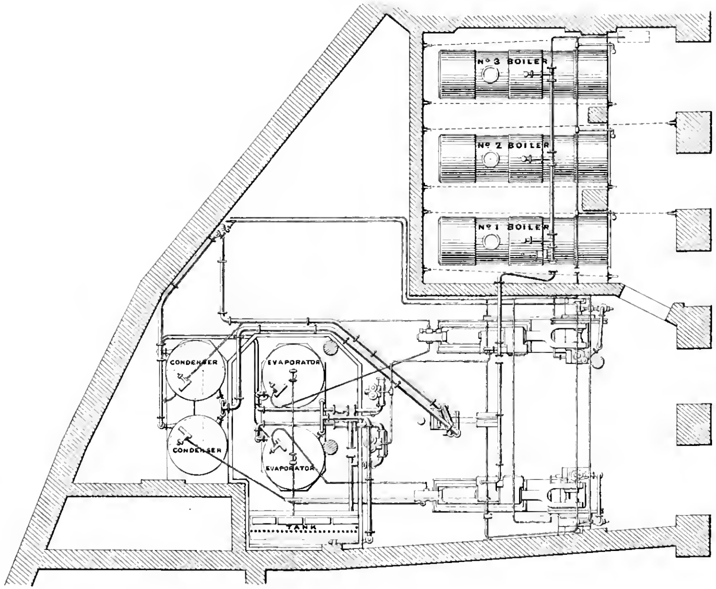
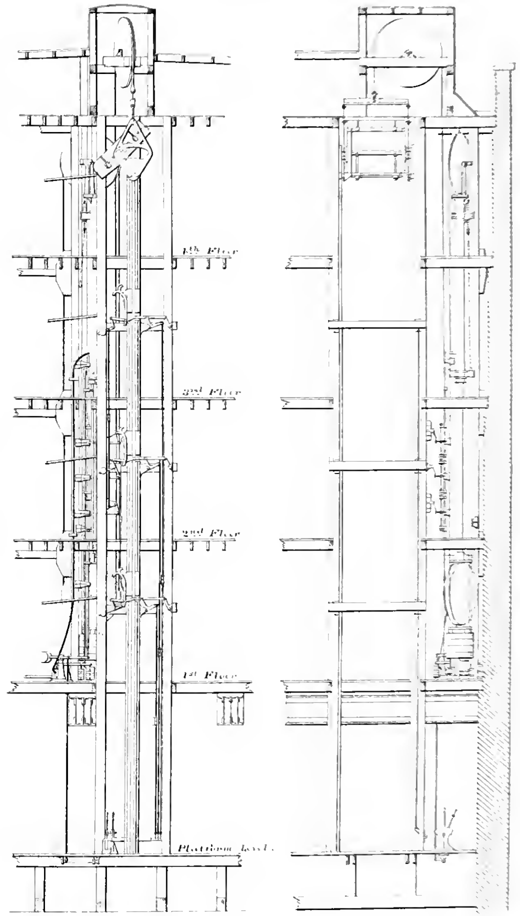


PLAN.

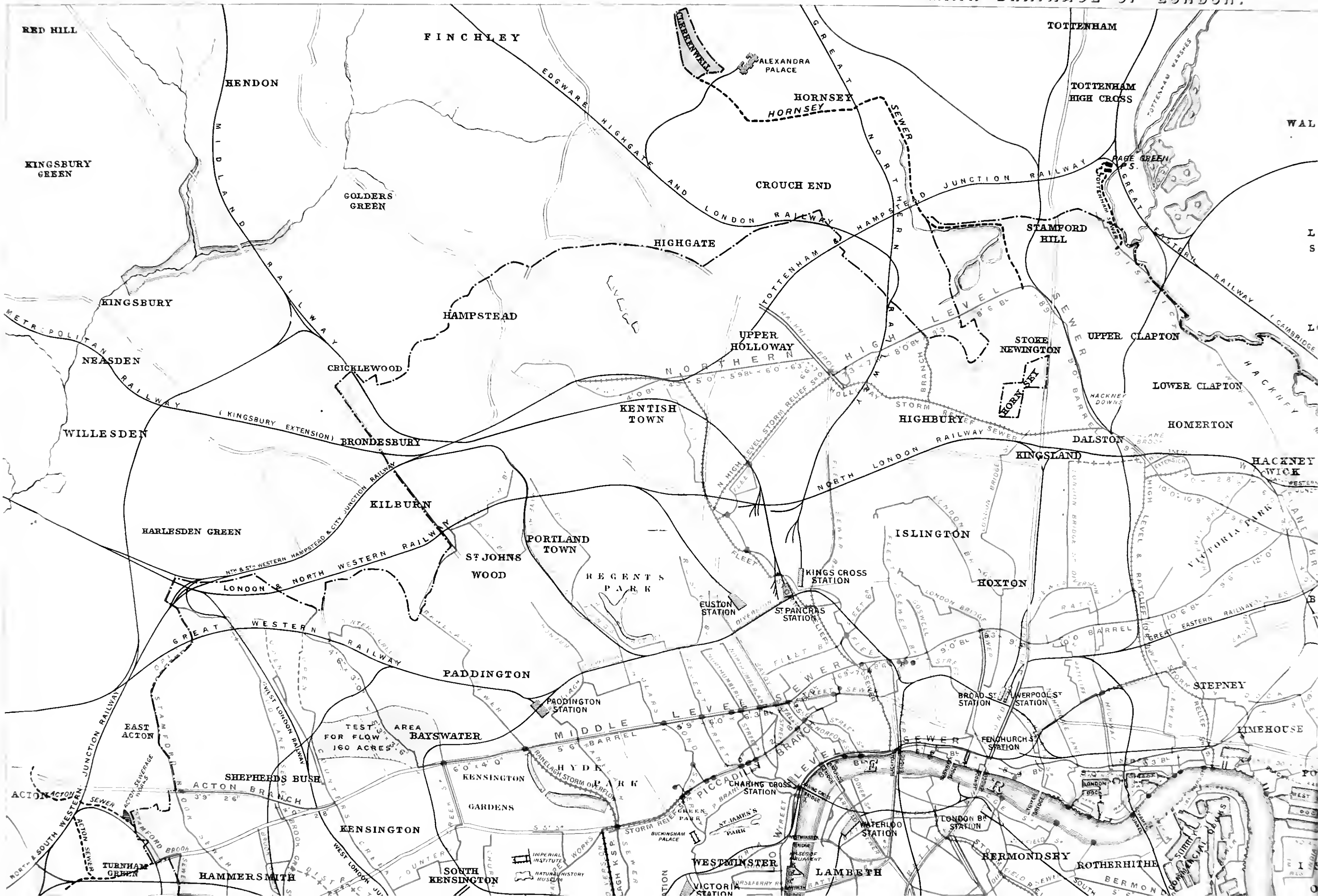
Figs 17.

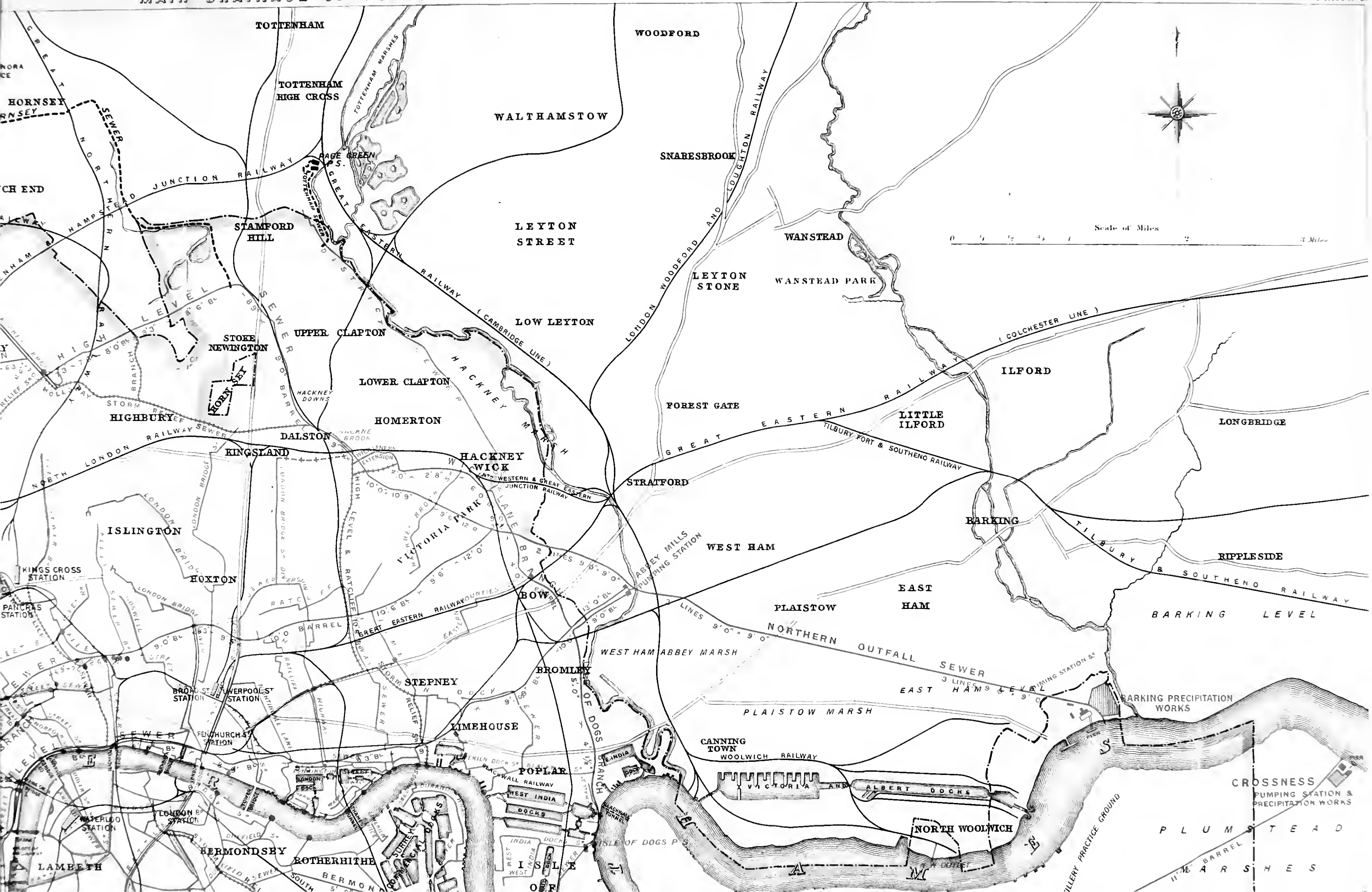


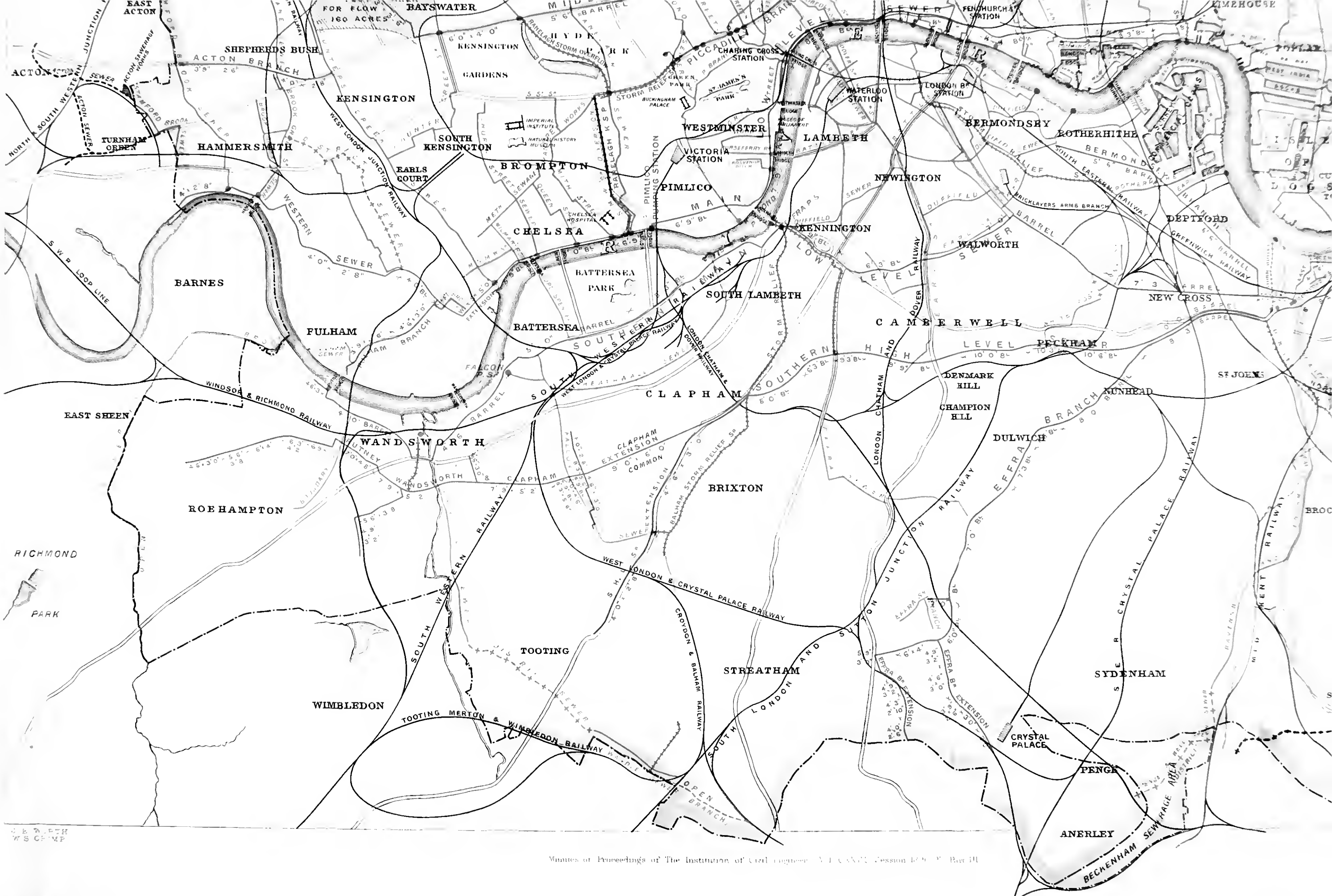
Scale for Figs 17, 3/32nds Inch = 1 Foot.

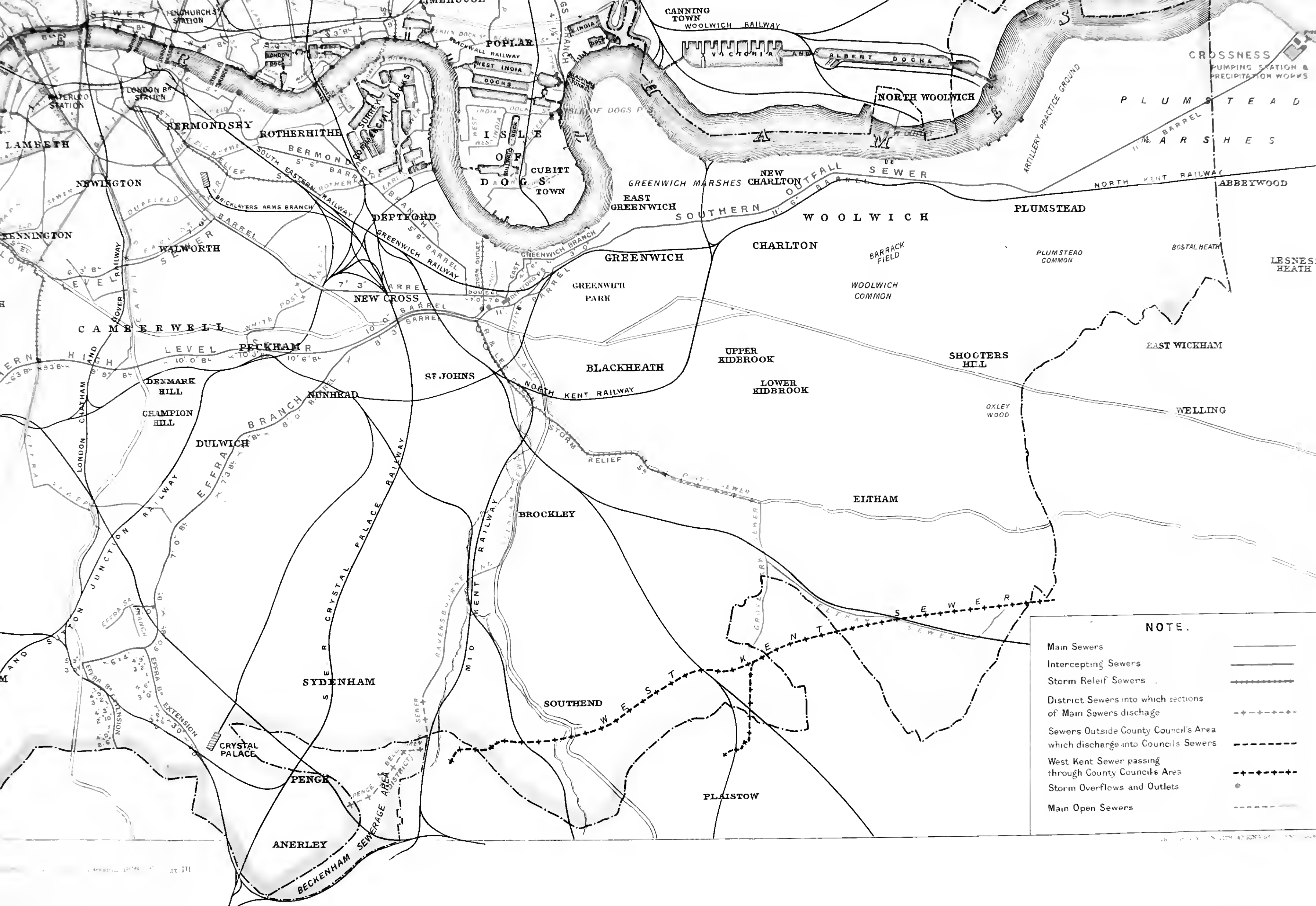
Feet 10 5 0 10 20 30 Feet.

MAIN DRAINAGE OF LONDON.



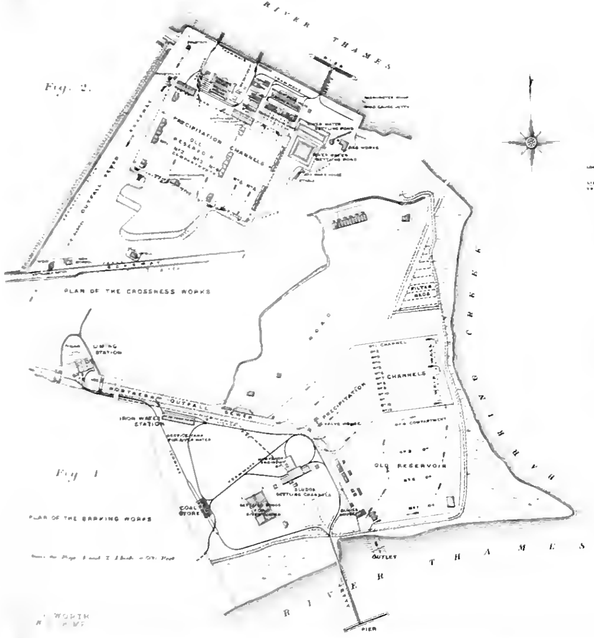

TOTTENHAM
WOODFORD
HORNSEY
TOTTENHAM HIGH CROSS
WALTHAMSTOW
SNARESBROOK
PAGE GREEN P.S.
STAMFORD HILL
LEYTON STREET
WANSTEAD
Scale of Miles
LEYTON STONE
WANSTEAD PARK
UPPER CLAPTON
STOKE NEWINGTON
LOW LEYTON
ILFORD
LOWER CLAPTON
HOMERTON
FOREST GATE
LITTLE ILFORD
LONGBRIDGE
HIGHBURY
DALSTON
KINGSLAND
HACKNEY WICK
STRATFORD
ISLINGTON
VICTORIA PARK
BARKING
WEST HAM
RIPPLESIDE
KINGS CROSS STATION
HOXTON
ABBEY MILLS PUMPING STATION
EAST HAM
BOW
PLAISTOW
BARKING LEVEL
NORTHERN OUTFALL SEWER
WEST HAM ABBEY MARSH
BROMLEY
STEPNEY
EAST HAM LEVEL
BROAD ST STATION
LIVERPOOL ST STATION
BARKING PRECIPITATION WORKS
PLAISTOW MARSH
LIMEHOUSE
FENCHURCH ST STATION
CANNING TOWN
WOOLWICH RAILWAY
POPLAR
VICTORIA AND ALBERT DOCKS
CROSSNESS PUMPING STATION & PRECIPITATION WORKS
WEST INDIA DOCKS
NORTH WOOLWICH
WATERLOO STATION
LONDON STATION
ISLE OF DOGS P.S.
PLUMSTEAD MARSHES
BERMONDSEY
ROTHERHITHE
LAMBETH
ISLE OF DOGS
GREAT EASTERN RAILWAY
TILBURY & SOUTHEND RAILWAY
NORTH LONDON RAILWAY
HIGH LEVEL SEWER

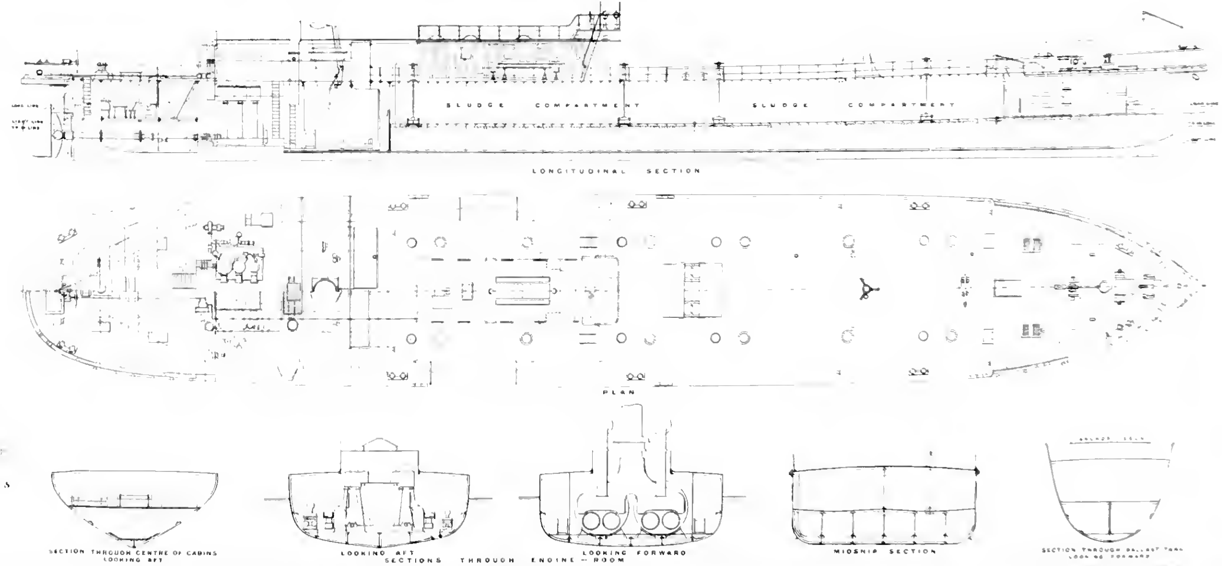

EAST ACTON
BAYSWATER
HYDE PARK
KENSINGTON GARDENS
SHEPHERDS BUSH
ACTON BRANCH
ACTON
KENSINGTON
TURNHAM GREEN
HAMMERSMITH
SOUTH KENSINGTON
EARLS COURT
BROMPTON
IMPERIAL INSTITUTE
NATURAL HISTORY MUSEUM
PICCADILLY
CHARING CROSS STATION
GREEN PARK
ST. JAMES'S PARK
BUCKINGHAM PALACE
WESTMINSTER
VICTORIA STATION
PIMLICO
PIMLICO PUMPING STATION
LAMBETH
WATERLOO STATION
LONDON BR. STATION
FENCHURCH STATION
LIMEHOUSE
POPLAR
BERMONDSEY
ROTHERHITHE
NEWINGTON
KENNINGTON
WALWORTH
DEPTFORD
NEW CROSS
CHELSEA
CHELSEA HOSPITAL
BATTERSEA PARK
BATTERSEA
BARNES
FULHAM
SOUTH LAMBETH
CAMBERWELL
PECKHAM
DENMARK HILL
CHAMPION HILL
NUNHEAD
ST. JOHNS
CLAPHAM
DULWICH
EAST SHEEN
WANDSWORTH
CLAPHAM COMMON
BRIXTON
ROEHAMPTON
RICHMOND PARK
TOOTING
STREATHAM
SYDENHAM
WIMBLEDON
CRYSTAL PALACE
PENGE
ANERLEY
BECKENHAM SEWAGE AREA
WINDSOR & RICHMOND RAILWAY
S.W.R. LOOP LINE
NORTH & SOUTH WESTERN JUNCTION
WEST LONDON JUNCTION RAILWAY
SOUTH WESTERN RAILWAY
WEST LONDON & CRYSTAL PALACE RAILWAY
LONDON CHATHAM & DOVER RAILWAY
CROYDON & BALHAM RAILWAY
TOOTING MERTON & WIMBLEDON RAILWAY
WEST END & CRYSTAL PALACE RAILWAY
LONDON AND SUTTON JUNCTION RAILWAY
SOUTH LONDON AND SUTTON RAILWAY
SOUTHERN HIGH LEVEL
SOUTHERN LOW LEVEL
EFFRA BRANCH
BRICKLAYERS ARMS BRANCH
GREENWICH RAILWAY
SOUTH EASTERN RAILWAY
CLAPHAM EXTENSION
WANDSWORTH & CLAPHAM
BALHAM STORM RELIEF
EFFRA BR. EXTENSION
C. E. WORTH
W. S. CHAMP



FENCHURCH S^T STATION
POPLAR
CANNING TOWN
WOOLWICH RAILWAY
VICTORIA AND ALBERT DOCKS
CROSSNESS PUMPING STATION & PRECIPITATION WORKS
BLACKWALL RAILWAY
WEST INDIA DOCKS
NORTH WOOLWICH
ARTILLERY PRACTICE GROUND
PLUMSTEAD MARSHES
WATERLOO STATION
LONDON B^E STATION
BERMONDSEY
ROTHERHITHE
SURREY COMMERCIAL DOCKS
ISLE OF DOGS
CUBITT TOWN
LAMBETH
NEWINGTON
BRICKLAYERS ARMS BRANCH
SOUTH EASTERN RAILWAY
DEPTFORD
GREENWICH RAILWAY
GREENWICH MARSHES
NEW CHARLTON
EAST GREENWICH
SOUTHERN OUTFALL SEWER
NORTH KENT RAILWAY
ABBEYWOOD
WOOLWICH
PLUMSTEAD
KENNINGTON
WALWORTH
GREENWICH
CHARLTON
BARRACK FIELD
PLUMSTEAD COMMON
BOSTAL HEATH
LESNESS HEATH
WOOLWICH COMMON
GREENWICH PARK
NEW CROSS
CAMBERWELL
PECKHAM
HIGH LEVEL
BLACKHEATH
UPPER KIDBROOK
LOWER KIDBROOK
SHOOTERS HILL
EAST WICKHAM
ST JOHNS
DENMARK HILL
CHAMPION HILL
NUNHEAD
DULWICH
OXLEY WOOD
WELLING
STORM RELIEF SEWER
EFFRA BRANCH
LONDON CHATHAM AND DOVER RAILWAY
BROCKLEY
ELTHAM
CRYSTAL PALACE RAILWAY
MID KENT RAILWAY
RAVENSBOURNE
WEST KENT SEWER
SYDENHAM
SOUTHEND
EFFRA B^R EXTENSION
CRYSTAL PALACE
PENGE
PLAISTOW
ANERLEY
BECKENHAM SEWERAGE AREA
NOTE.
Main Sewers
Intercepting Sewers
Storm Relief Sewers
District Sewers into which sections of Main Sewers dischage
Sewers Outside County Council's Area which discharge into Councils Sewers
West Kent Sewer passing through County Councils Area
Storm Overflows and Outlets
Main Open Sewers

MAIN DRAINAGE OF LONDON.





MOND GAS PRODUCER.

Fig: 6.

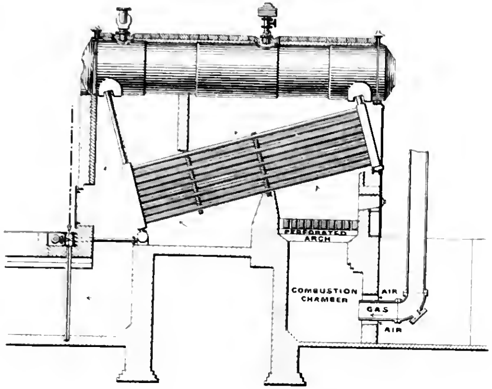
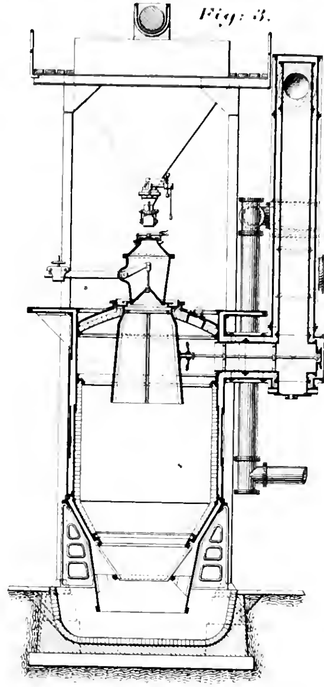


Fig: 3.



Figs: 7.

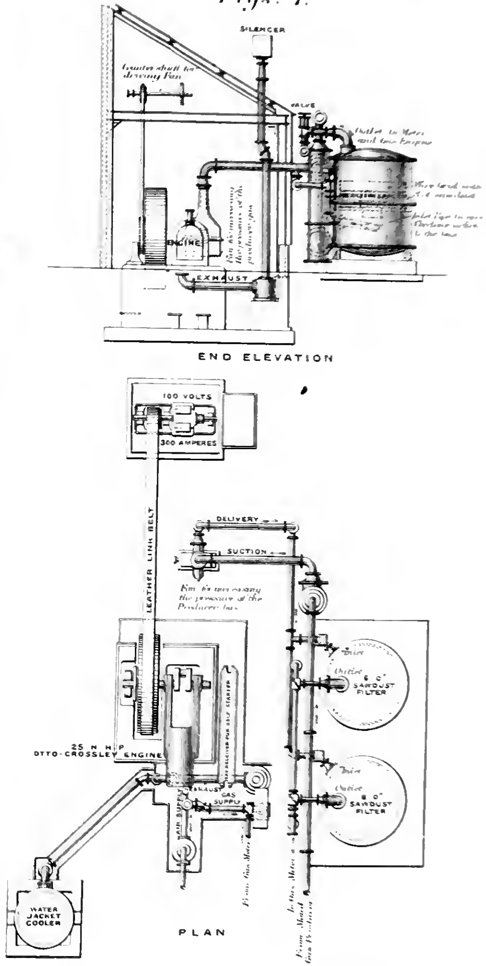


Fig: 2.

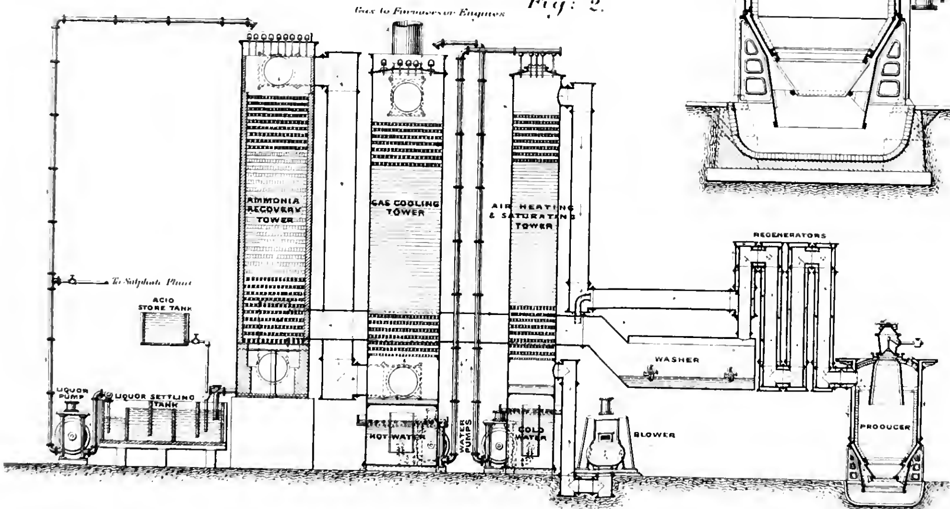
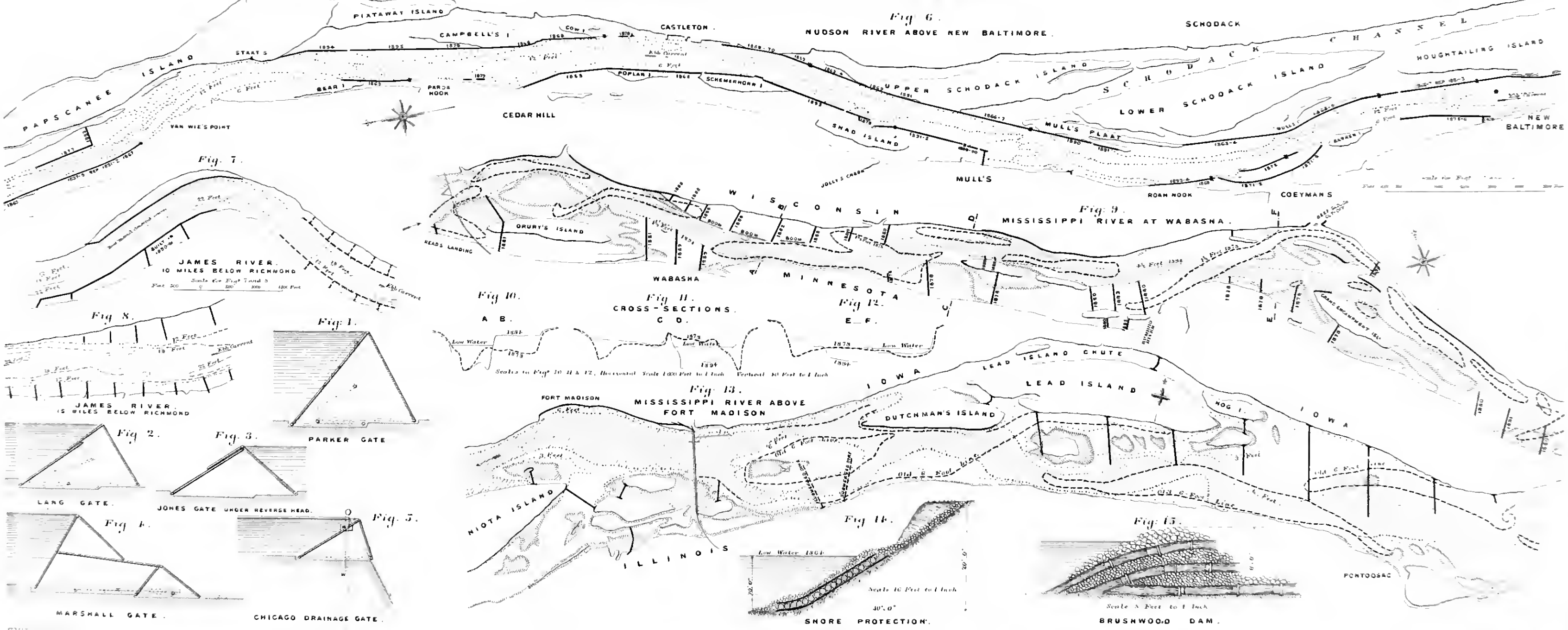


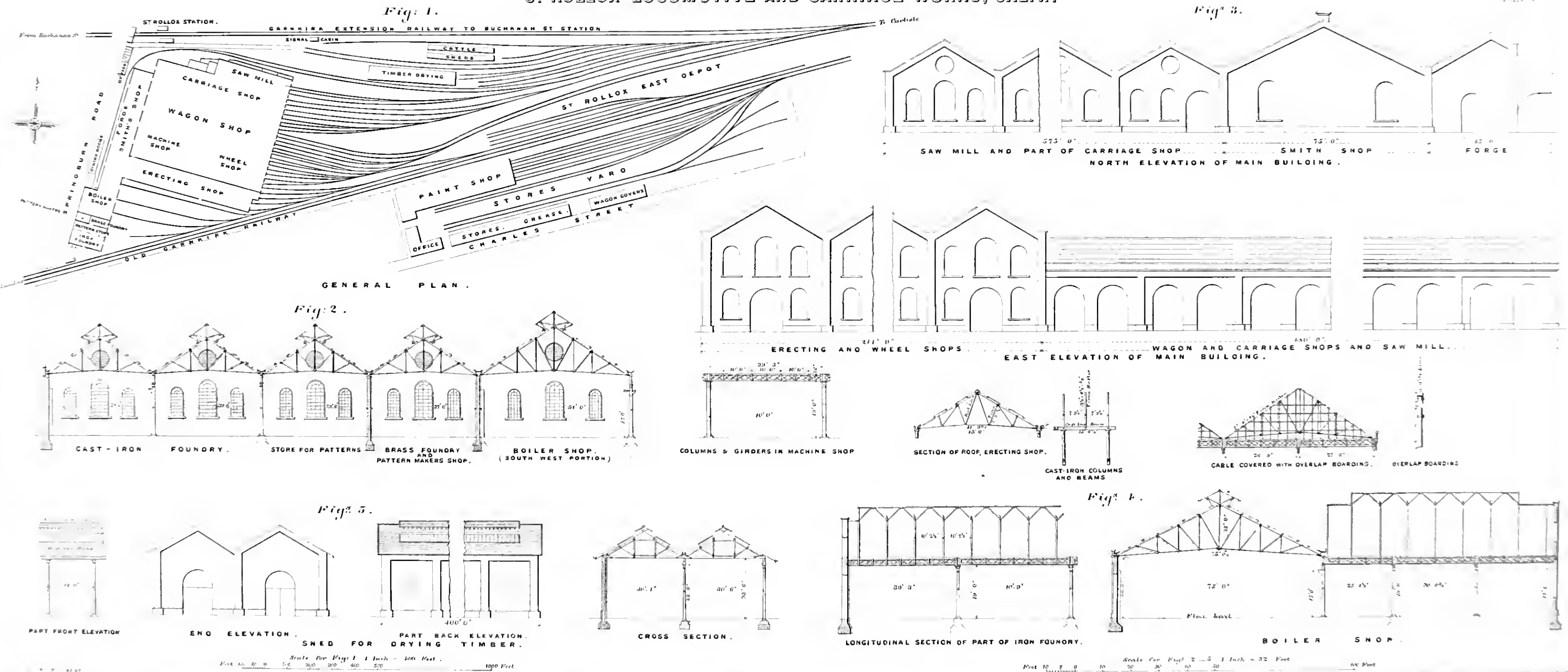
DIAGRAM OF PLANT

Scale of Figs 3.6 and 7

INLAND NAVIGATION IN THE UNITED STATES.



ST ROLLOX LOCOMOTIVE AND CARRIAGE WORKS, CAL. RY



HORWICH LOCOMOTIVE WORKS, L. & Y. R.Y