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ALFRED GILES, President,  
in the Chair.

(*Paper No. 2720.*)

### “Hydraulic-Power Supply in London.”

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THE distribution of hydraulic power has made considerable progress since 1887, when the Author gave to the Institution an account of the works<sup>1</sup> then existing in London. The advance that has been made in those works during the past six years is shown by the following summary:—

	December 1887.	December 1893.
Miles of mains laid . . . .	27	67
Number of pumping-stations .	1	3
Horse-power provided . . . .	800	2,600
Power-water pumped in one week	2,062,000 gallons.	7,540,000 gallons.
Number of machines at work .	609	1,925
Capital expended . . . .	£150,000	£421,000 <sup>2</sup>

In 1887 Hull was the only town besides London in which there was a public distribution of hydraulic power at high pressure. Supplies are now given also in Liverpool, Birmingham, Melbourne and Sydney, while works are being constructed in Manchester, Glasgow and Antwerp. The public distribution of hydraulic power on the accumulator system has thus become well established as a development of industrial enterprise.

<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. xciv. p. 1.

<sup>2</sup> This sum includes an expenditure of £30,000 upon the new pumping-station at City Road in course of construction.

## FALCON WHARF AND MILLBANK PUMPING-STATIONS.

The first station at Falcon Wharf, Blackfriars, was described by the Author in the Paper alluded to. In 1887, a second station situated at Millbank, not far from the Houses of Parliament, was in course of construction. The arrangements at Millbank differ somewhat from those at Falcon Wharf. The engines and boilers are of the same type, but the steam-pressure is increased to 100 lbs. per inch. The water delivered from this station, instead of being taken direct from the river, is pumped into tanks from a well sunk to the level of the London clay, 18 feet below Ordnance datum. Overlying the clay is a gravel bed 9 feet 6 inches thick. Headings were driven from the well in the gravel bed for a distance of 300 feet, 150 feet of the heading being under the river. The water pumped from the well is perfectly clear and bright as it runs from the gravel, but rapidly changes its character on exposure to the air, turning to a muddy reddish yellow and precipitating a deposit of iron oxide. The average yield of the well is 300,000 gallons in twenty-four hours, which is sufficient for the present requirements of this station. The water is pumped from the well by hydraulic pumps into tanks over the engine-house. As at Falcon Wharf, filtered-water tanks are placed over the boiler-house at a lower level, the difference of head being utilized to overcome the resistance of the filters to the passage of the water through them. The total capacity of the filtered and unfiltered water-tanks is 300,000 gallons, equal to one day's supply from the station. Hydraulic power is not supplied during the night from this station, but pumping from the well and the filtering-process go on continuously during the twenty-four hours. The hydraulic pumps are not only economical machines but afford great facilities for this class of duty. Their working is quite independent of the running of any particular station so long as the pressure in the general system of power-mains is kept up. Hydraulic pumps (Figs. 1, Plate 6) have now superseded the steam-pumps formerly used at the Falcon Wharf Station.

The methods at first adopted at Falcon Wharf for getting water from the river were not altogether satisfactory. At lowest spring-tides there was a considerable interval during which no water could be obtained from the river, and the storage-tanks on one or two occasions proved to be of insufficient capacity to tide over the interval. It was determined therefore to reclaim a portion of the

foreshore and to sink wells and drive headings under the river in the gravel-bed, as had successfully been done at Millbank. The result was somewhat disappointing. Not more than 10,000 gallons per hour could be obtained, though 280 feet of headings were driven in the gravel on the top of the London clay, and at the termination of the headings there was only about 3 feet of gravel between the top of the heading and the level of the foreshore. The gravel was choked by the river mud. The principal portion of the water used at Falcon Wharf has therefore still to be taken direct from the river. The wells and headings have, however, insured a sufficient quantity of water being obtained at all states of the tide. The reclamation of the foreshore has also given increased area for storage of pipes, which was much wanted, and the use of the hydraulic pumps has effected a considerable economy in the steam-consumption of the station. At the Wapping Station, described hereafter, a well has been sunk to the London clay where the yield is much larger—18,000 gallons per hour—and this without any headings being driven. The gravel-bed at this point is about 12 feet thick.

The arrangements for filtering the water at Millbank are shown in Figs. 2 and 3, the process being that known as the Porter-Clark, but the usual details are somewhat altered to suit the special circumstances. The plant was constructed by Messrs. Gimson & Co., of Leicester, and is capable of treating and filtering 15,000 gallons per hour. The results have been most satisfactory. The preliminary aëration of the water is obtained by allowing the water from the rising-main of the hydraulic pumps to fall over fountains, and most of the iron oxide is precipitated during the time the water remains in the upper tanks. A saturated solution of lime is formed in the lime tank, which contains sufficient for twenty-four hours' supply. The lime is pumped at a regular speed into the softening-vessel, where it meets the unfiltered water coming from the upper tanks. The softening-vessel contains 7,500 gallons of water which passed through it in half-an-hour. This is sufficient time to allow the chemical reactions to take place, and for the excess of lime in the water to be precipitated. The primary object of the process is not to soften the water, so that only sufficient lime is used to carry down the remaining iron oxide, and to form a sufficient filtering medium on the filter-cloths. The water from the softening vessel flows by gravity to the filter-presses (Fig. 3), and the filtered water rises from them into the filtered-water tanks, the difference of level between the clear- and unfiltered-water tanks

being 11 feet. The water, after leaving the presses, passes through a charcoal bed, which strains out any lime that may accidentally pass through them. No lime or deposit has ever, so far as the Author is aware, appeared in the filtered-water tanks. The iron oxide has been very destructive to the cloths. Jute cloths have proved the most durable, but even these require renewing every month. Five filters are in use, and each filter is cleaned every twenty-four hours. The quantity of lime used is  $1\frac{1}{4}$  lb. per 1,000 gallons, which is sufficient to obtain good results from the filters. Incidentally the water is reduced from  $24^{\circ}$  of hardness to  $18^{\circ}$  (Clark's scale). The lime-mixer, pump, and the stirrers of the softening-vessel, are driven by a Brotherhood hydraulic engine. A washer is provided for cleaning the cloths, also driven by a small hydraulic engine. Two men are required to look after the plant. These men work during the day only. When they leave work at night all the filters have been cleaned. The hydraulic pumps and the hydraulic engine are left acting, and the whole process proceeds automatically during the night. The night-watchman stops the pumps and engine when all the reservoirs are full. The cost of working the process is, per 1,000 gallons :—

	d.
Lime . . . . .	0·13
Cloths . . . . .	0·31
Labour . . . . .	0·46
Power . . . . .	0·15
Total . . . . .	<u>1·05</u>

The output is on the average about 1,500,000 gallons per week.

#### WAPPING PUMPING-STATION.

It soon became evident that the power distributed from Millbank would be rapidly taken up, and a third station has been erected at Wapping, on a site adjoining the Shadwell Tidal Basin of the London Docks. This station is of much greater capacity than either of those at Falcon Wharf or Millbank, being built to accommodate six sets of engines of 200 I.H.P. each. The engines were constructed on the Author's system by the Hydraulic Engineering Company at Chester, and are of similar construction to those used at the other stations, but are made triple expansion with a steam-pressure of 150 lbs. per square inch. The cylinders are 15 inches, 22 inches and 36 inches in diameter severally, each having a 2-foot stroke.

The arrangements in regard to the water-supply are as follows. From the well already referred to, hydraulic pumps deliver the water into two compartments of the tanks covering the boiler-house. The additional water required beyond that yielded by the well is taken by a siphon-pipe from the London Dock. The capacity of the unfiltered-water compartments is 150,000 gallons, and each hydraulic pump can deliver 30,000 gallons per hour. On the level of the stoke-hole floor is a filter-house, in which there are eight filters, hereafter described. A certain amount of settlement takes place in the tanks, from which the water is collected in floating pipes and is conveyed to the filters, and after passing through them is collected in an underground clear-water reservoir in two sections.

The main-engine circulating-pumps draw their supply from the reservoir, and, after passing through the tubes of the surface-condensers, the water is delivered into the remaining two compartments of the tank over the boilers. From these compartments the main engines draw their supply for delivery into the power-mains. It will be understood that it is important to have a head on the suction side of the hydraulic-power pumps. The total capacity of the tanks and reservoirs is 800,000 gallons, equal to about twenty-four hours' delivery from the station. The side-walls and bottom of the reservoirs are of concrete, founded on a bed of stiff clay about 4 feet thick, which overlies the gravel. The reservoirs are covered by brick arches carried on iron stanchions and girders. The spandrels of the arches are filled with concrete, and the whole area is covered by a 6-inch layer of fine concrete.

The top of the reservoir is used for the storage of pipes, &c., and a travelling hydraulic crane is here provided.

The boilers are of the Fairbairn-Beeley type (Figs. 4, Plate 6). Vicars mechanical stokers are fitted to all the boilers. For feeding the stokers, the following arrangement is adopted. The attendant fills a hopper trolley from the coal store, and runs it on the platform of a hydraulic lift, which raises it well above the stoker-hoppers. From the lift it is run along rails above the stoke-hole and is tipped into a hopper, from which creepers distribute the coal to the different boilers. The coal used at the station is discharged from the dock direct into the coal store by a hydraulic crane.

The filters (Fig. 5) were made by the Pulsometer Engineering Company. Their chief feature consists in the method of cleaning adopted. The filtering medium is a bed of animal charcoal. When being cleaned, the filter is open to the drain and the flow of water is

reversed whilst a jet of steam is employed to send a current of air into the filters with the washing-water. The effect of the air is to cause violent ebullition in the midst of the charcoal bed, insuring the thorough cleansing of every particle of charcoal. A screen is provided to prevent the charcoal from being washed away. Very good results have been obtained with this filter. It was not intended to use any chemicals, but the water was not so colourless as that obtained from the Porter-Clark plant at Millbank, though the results were superior to those obtained with the sponge filters as fitted at Falcon Wharf, described by the Author in his former Paper. At Falcon Wharf and Wapping, "alumino-ferrie"<sup>1</sup> has been successfully employed to assist the clarification. The quantity used is  $\frac{1}{4}$  lb. per 1,000 gallons, and the cost is 0·083d. per 1,000 gallons. Each filter at Wapping, with water in ordinary condition, will effectually filter from 4,000 to 5,000 gallons per hour. As at Millbank, pumping from the well and filtration proceed day and night, irrespective of the running of the main engines. As a rule these engines do not run more than twelve hours out of the twenty-four. Variations in the demand for power are met as far as possible at the central-station at Falcon Wharf. This is accomplished by the simple expedient of delivering the water into the mains at the out-stations at a somewhat higher pressure than at the central station. The central station is the only one which runs continuously day and night, Sundays and holidays. It results from this that the output per unit of plant is approximately the same at all stations. At the central-station the work is spread over twenty-four hours: at the out-stations it is accumulated into twelve hours. As regards consumption of coal there does not appear to be much difference from this cause. What is gained at the out-stations during the day through more continuous running is lost during the night with banked fires and steam kept up.

In the Author's former Paper<sup>2</sup> reference was made to a pumping-station at Kensington Court. At the present time this station is only used for accumulators, as the mains have been laid from Piccadilly to Kensington, and the supply there now forms part of the general system. The pressure in the mains laid in Ken-

<sup>1</sup> The following analysis of this substance is supplied by Messrs. Spence & Sons, the manufacturers:—

Al <sub>2</sub> O <sub>3</sub> . . .	14·0 per cent.	H <sub>2</sub> SO <sub>4</sub> (free) .	traces.
H <sub>2</sub> SO <sub>4</sub> (in com- bination) }	34·0 "	Water . . .	51·4 per cent.
		Fe <sub>2</sub> O <sub>3</sub> . . .	0·6 "

<sup>2</sup> Minutes of Proceedings Inst. C.E., vol. xciv. p. 18.

sington Court, formerly charged from that station, is 450 lbs. per square inch; a pressure that was adopted because it was the most suitable for the lifts that were put into the houses on the estate. It is interesting to note, as showing the comparatively great cost of running a small plant when compared with that of working a more extensive system, that it has proved to be more economical to charge the Kensington Court accumulator, loaded to 450 lbs., from the 700 lbs. pressure-mains (thus losing 250 lbs. in pressure), than to work the small station at Kensington Court.

#### CITY ROAD STATION.

A fourth pumping-station is in progress at a site on the Regent's Canal, in Wharf Road, City Road, which will have a capacity equal to that at Wapping. The water will be obtained from the canal, and "Torrent" filters will be used, as at Wapping. It is expected that this station will be in running order during the summer of 1894.

#### ACCUMULATORS.

The following accumulators are used in connection with the supply, omitting that at Kensington Court as having no influence on the general system:—

Two at Falcon Wharf . . .	20 inches in diameter,	rams 23 feet stroke.	
One at Millbank . . .	18	" "	20 "
One at Philip Lane, E.C.	18	" "	20 "
Two at Wapping . . .	20	" "	23 "

The total capacity of these accumulators is about 1,600 gallons. The pumping-capacity of the plant is about 3,500 gallons per minute. These figures show that the accumulators act almost entirely as regulators of pressure, and have a very small influence in respect of storage.

#### ENGINE- AND BOILER-TESTS.

A carefully conducted series of experiments has been made to ascertain the efficiency of the triple-expansion engines and the Fairbairn-Beeley boilers at Wapping. These experiments were made under the supervision of Mr. Bryan Donkin, jun. The duty of both engines and boilers was high, nearly 130,000,000 foot-lbs. being obtained from 112 lbs. of Nixon's coal. The steam-consumption in the engines was 14.1 lbs. per I.H.P. per hour, and the boiler and economizer evaporation-test gave 11.1 lbs. of water evaporated per pound of Nixon's coal. The combined

results under the most favourable conditions, *i.e.*, with engine and boiler working up to their full capacity, would give, say, 1·3 lb. of coal per I.H.P. per hour (Appendix).

Similar tests were made about the same time with the Millbank engines, when the consumption of steam was found to be 17·71 lbs. per I.H.P. per hour, and the evaporation of the Lancashire boilers and economisers to be 9·58 lbs. per pound of Nixon's coal.

The best results for purposes of comparison are stated in the following Table:—

—	Steam Pressure.	Lbs. of Steam per I.H.P. Engine.	Calorific Value of Nixon's Coal.	Evaporation Boiler and Economiser, Lbs. Water per Lb. Coal.	From and at 212° Fahrenheit.	Thermal Efficiency per Cent.	
						Engine.	Boiler and Economiser.
1. Millbank. (Compound) . }	93·8	17·71	14·45	9·58	11·28 <sup>1</sup>	12·24	78·7
2. Wapping. (Triple) . . . }	143·0	14·1	15·65	10·22	12·19	15·25	78·2

By the salt test there was no priming either at Wapping or at Millbank. If the amount of water pumped per cwt. of coal at the three stations is compared, the economy of the Wapping plant is very striking. The figures are as follows:—

—	Calorific Value of Coal.	Gallons Pumped per Cwt. Ordinary Small Coal.	Pressure per Square Inch.	Gallons Pumped per Cwt. on basis of equal quality of Coal and equal Accumulator Pressures (732 lbs. per Square Inch).
Falcon Wharf . . . .	..	4,558 <sup>2</sup>	750	(a). 4,048 <sup>4</sup>
Millbank . . . . .	12·30	4,130 <sup>3</sup>	732	4,130
Wapping . . . . .	11·76	4,920 <sup>3</sup>	728	5,118

These are the results of the tests on trial-runs of eight and nine hours with the speed of the engines practically constant. When,

<sup>1</sup> Equivalent to 12·21 with coal of same calorific value as at Wapping.

<sup>2</sup> Durham coal.

<sup>3</sup> Midland coal.

<sup>4</sup> The Author had not the calorific value of the coal used here. The figure 4,048 was obtained by using the evaporative result of 10·59 lbs. of water per lb. of coal as given in his former Paper.

however, the results obtained during long periods are compared, the variation is remarkable. The figures are then as follows:—

	Gallons pumped per Cwt. of Coal reduced to Pressure of 732 lbs. per Square Inch.	Per cent. of Maximum Efficiency $\frac{b \times 100}{a}$ .
Falcon Wharf (2 years) . . . . .	(b). 2,425	59·90
Millbank (2 years) . . . . .	2,663	64·48
Wapping (15 months) . . . . .	2,885	56·37

This great discrepancy is not to be attributed to any variation in the condition of the engines or boilers. The main cause is in the large amount of heat wasted owing to the intermittent nature of the supply. At each station a small amount of steam is used for purposes other than that of driving the main engines, but this is not sufficient to materially influence the figures. The average efficiency in the case of the Wapping station is less in relation to the maximum efficiency than at the other stations, owing to the fact that the output has, up to the present time, been considerably below the capacity of the plant. As the delivery of power from this station increases the efficiency will increase.<sup>1</sup>

In 1887, the Author gave the result of observations made at Falcon Wharf with engines running at full speed constantly, and under the ordinary variable conditions, which showed that there was an increased coal-consumption of one-third from this cause. That experiment was made under conditions which do not apply to the figures now given; as, though the output of the engines and boilers was constantly varying during the experiment, there was no complete cessation of work. From the records of a consumption of nearly 11,000 tons of coal at the several stations, the Author has been able to obtain the following fairly approximate analysis of the total coal-consumption:—

	Per Cent. of Total Coal.
Coal utilized at efficiency of trials, calculated on total output	60
Coal wasted through intermittent running, based on the experiment at Falcon Wharf referred to . . . . .	20
Coal used in keeping steam up in boilers and engine-jackets when stopped during nights and Sundays and changing over boilers . . . . .	12
Steam used for other purposes, variation in quality of coal, defective stoking, &c. . . . .	8
	100

<sup>1</sup> The efficiency is at the present time (Nov. 1893) the same as at Falcon Wharf.

Notwithstanding that the total delivery of power has more than trebled since 1887, no diminution of these losses has resulted. Mr. R. E. B. Crompton, in a Paper on "The Cost of the Generation and Distribution of Electrical Energy,"<sup>1</sup> dealt very fully with this question, and showed the overpowering influence of intermittent running upon the economy of production of electrical energy. It is possibly, as pointed out by the late Mr. P. W. Willans, of less importance in hydraulic than in electric transmission, but extended experience in connection with hydraulic-power supply proves it to be the cause of a serious loss of efficiency.

#### COST OF PRODUCTION AND LOAD-FACTORS.

It is commonly believed that the cost varies inversely with the scale of production, but in the Author's view this belief will not stand the test of experience and careful analysis. For each industry there probably is a certain size of undertaking at which the cost per unit of output is practically a minimum; and it is by no means a universal law that with equal efficiency in the conditions of production, the cost is diminished by an increase of the scale of output. The fact is that the economy to be thus obtained is of a decremental nature; and while at first great economy is obtained by an increased scale of output, the advantage soon tends towards a vanishing-point. The Author has given much attention to these questions as affecting the distribution of hydraulic power, and the very interesting and suggestive Paper of Mr. Crompton, already referred to, has led him to think that a publication of the results of the distribution of hydraulic-power supply in London during the past eight years, may be of service in connection with other undertakings involving the supply of energy from central sources.

It has been already shown how large is the amount of waste that arises from the intermittent character of the supply, and it is a matter of the greatest importance, in order to determine the probable limit of the cost of production, to ascertain in what way the load-factor is influenced by increased use of the power. Below are given the London hydraulic power load-factors for the heaviest day's work in each year, 1887-1892 inclusive, and the corresponding load-factors for each year.

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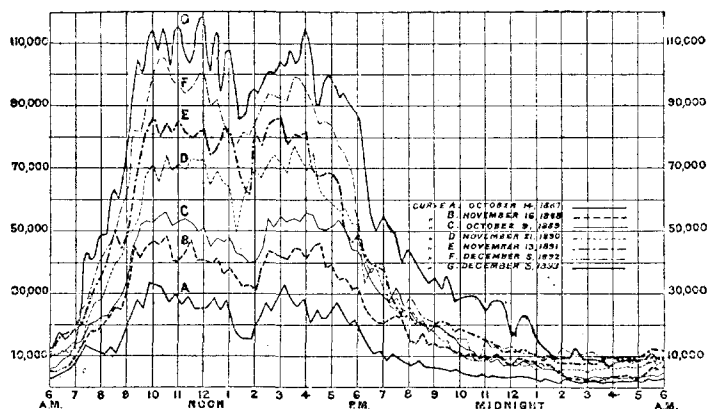
<sup>1</sup> Minutes of Proceedings Inst. C.E., vol. cvi. p. 2.

Year.	Quantity pumped during Year.	Maximum Output.	Annual Load-Factor.	Heaviest Day Load-Factor.
	Gallons.	Gallons per Hour.		
1887	84,647,000	35,000	0.275	0.407
1888	123,055,000	49,000	0.286	0.458
1889	163,883,000	57,000	0.328	0.524
1890	206,421,000	77,000	0.306	0.474
1891	267,671,000	90,000	0.339	0.462
1892	303,032,000	106,000	0.326	0.432
1893	336,636,000	119,000	0.323	0.458

The load-factor is in all cases the ratio of the average output per hour to the maximum output in any one hour during the year.

*Fig. 6* gives the separate maximum curves for the different days, which show clearly the great increase in the total power

*Fig. 6.*



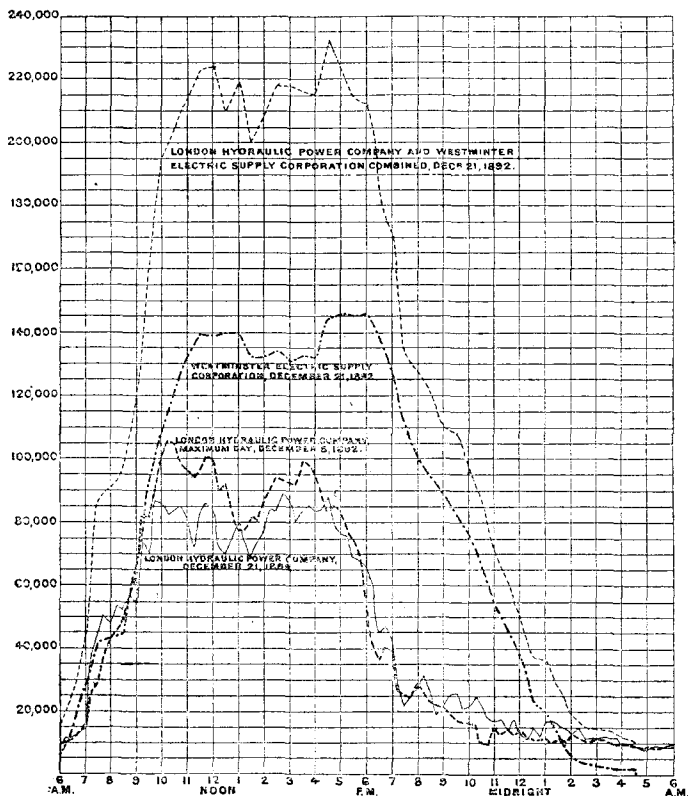
supplied, notwithstanding which the load-factors have not been materially affected. So far, therefore, as regards the influence of load-factors on the cost of production, the experience of hydraulic-power supply does not warrant the supposition that cost is likely to be reduced by the load-factors improving. The increase in the annual load-factors in 1889-93 over 1887-8 is due to the extended area of supply embracing new districts, and not to increase of quantity; the periods of maximum demand for power vary in the different districts and so tend to increase the load-factors. It does not appear possible to make any material improvement in the load-factor by merely increasing the output. It might be supposed, looking at the large amount of plant lying

idle during the night, that, by developing night consumption, say for running dynamos for electric lighting, a much better result would be obtained. Some electric-lighting companies are thus endeavouring to improve their load-factors by supplying power during the day, but the Author's experience is that consumers will not consent to take power exclusively during certain specified hours in the twenty-four, even when a considerable advantage in price is offered; and if they were to do so, no sufficient means exist of keeping them to their bargain. Under these circumstances, at some time or other during the year, it is certain to happen that the time of demand for the power by the class usually served at night, will synchronise with the time of demand of the class served during the ordinary working-hours of the day. The effect of such a conjunction will be to reduce the load-factor of one or other of the two classes of consumption considered separately. For all practical purposes, the only two classes of work open are power during the day and lighting during the night. This is true, irrespective of the particular system employed. It applies with equal force to gas, electricity and compressed-air, as well as to hydraulic power apart from the question of storage. The principal use of the hydraulic system is, at the present time at any rate, for intermittent power, while electric supply is given mainly for lighting.

In order to see the effect of a conjunction of the two, the Author has prepared the diagram, *Fig. 7*, which he has been able to do through the courtesy of Prof. Kennedy, F.R.S. The load-curve of the maximum day's supply of the Westminster Electric Supply Company has been super-imposed upon the hydraulic load-curve of the same day (21 December, 1892), the curves being reduced to the same scale and developed into one. The load-factor of the combined curve is 0.522, whereas the two separate load-factors are,—hydraulic 0.495, and lighting 0.533. The maximum day's output of the hydraulic supply was not on the same day as that of the electric supply, but occurred a few days earlier in the year, on the 5th December. The load-factor for the hydraulic power maximum day was only 0.432. It is noticeable that in the diagram the whole of the supply of the Hydraulic Power Company is assumed to be distributed within the district of the single electric-supply company. The Author has no means of giving the curve of supply of hydraulic power for this district alone, or of ascertaining in any exact manner what the load-factors for the district are, but it is possible to make an estimate with sufficient accuracy. The total quantity

of hydraulic power supplied in the Westminster electric district is about 8 per cent. of the whole. The maximum rate of supply of the total amount of hydraulic power distributed, is only about 73 per cent. of the electric maximum in the Westminster district alone. If the load-factor for hydraulic supply in Westminster were the same as for the whole area, an increase of 5·8 per

Fig. 7.



cent. upon the maximum rate of the present electric supply would furnish all the energy of the hydraulic supply in the district. It is however certain that the load-factor of any single district is less than the load-factor of the whole area supplied. In the Kensington district where hydraulic power is used in private houses and flats, and in some of the large shops, the load-factor for the year was only 0·118 as against 0·326 for

the whole area of supply. Westminster would give a much better load-factor than Kensington, but it is not likely to exceed 0·250, or about the same as the annual electric-lighting load-factor of the St. James' district. A hydraulic load-factor of 0·250 would render necessary an addition of about 7 per cent. to the electric current, to give the equivalent of the hydraulic energy supplied in the district. The load-factor for the Westminster electric supply for the year 1892 was 0·175. If, therefore, all the hydraulic power now supplied were given electrically, the load-factor for the electric supply would only be increased from 0·175 to 0·180. Neither on the maximum day nor on the annual basis is any material effect produced on the load-factors by the combination. The best practicable load-factor is limited in each district by the usual hours of work in regard to power-supply, and by the hours of darkness in regard to lighting. In the absence of storage, owing to the fact that during winter darkness occurs in business hours, conjunction of demand cannot be avoided. In the West End, the maximum period of demand per power is usually during the evening. In many buildings in the West End 30 per cent. to 40 per cent. of the total supply of hydraulic power is used between 6 P.M. and 6 A.M.; and of the total quantity of the London Hydraulic output in 1892, 20 per cent. was pumped between 6 P.M. and 6 A.M.

When dealing with this question of load-factors, it must not be forgotten that they are highly variable in terms and influence, and unless great care is exercised, give misleading results. In cases where a demand for energy, such as for lighting, exists principally during the winter months, there may be for several months a high load-factor whilst for the whole year the load-factor is low. A more uniform output of the same total amount of energy would give a higher load-factor for the year, but would not, therefore, be necessarily supplied on more favourable conditions as regards the cost of production at the station. In the first case, a considerable portion of the plant required to produce the maximum rate of delivery could be thrown entirely out of use during several months of the year, and in this way a high load-factor could be maintained for the plant in use during the whole year. As illustrating this point, it is instructive to compare the fuel-consumption at the Falcon Wharf and Millbank pumping-stations. The load-factor for the former for 1892 was 0·330 and for the latter 0·258. Falcon Wharf works day and night all the year round, while Millbank only runs seventy-two hours a-week. At Millbank, notwithstanding the lower annual

load-factor and the apparently unfavourable conditions, the efficiency in fuel-consumption is 64·48 per cent. against 59·90 per cent. at Falcon Wharf, the efficiency being calculated on the maximum results obtained at each station during the trial. The annual load-factor has, in fact, a far greater influence upon the amount of capital outlay per unit of output than it has upon the cost of fuel and the station-expenses. By breaking up the central-station plant into many sections, it is possible to ensure that machinery actually at work is running usually at as nearly full load as is consistent with the maintenance of an effective and reliable service. Even under the most favourable conditions, a supply approaching the maximum cannot be given for more than 280 days out of 365, and of the 280 (without storage of some kind) it is impossible to get in London from all sources more than twelve hours' work out of twenty-four; so that an annual load-factor of say 0·38 may be regarded as an ideal to which the hydraulic-power load-factor of 0·325 is a fair approximation. Notwithstanding this relatively good load-factor, however, there exists the great discrepancy between the test-run consumption and the actual weekly use of fuel.

This waste can be reduced by sub-division of plant, but it will always be considerable, and the constant running of plant at its maximum capacity, though economical in fuel, may be the cause of increased expenditure on repairs and attendance which will convert apparent economy into extravagance. The supply, moreover, cannot be maintained without reserve plant ready for instant use.

A low load-factor is likely, therefore, to be a permanent cause of low efficiency in all methods of supplying energy which do not admit of a large amount of storage.

It remains to notice the effect of an increasing output in reducing the cost of supply. The experience of the Hydraulic Power Company is shown by *Fig. 8*. The various curves represent the expenditure in pence per 1,000 gallons under the following heads:—

*Station and Distribution Expenses—*

Wages, coal, water, gas, engine-room expenses and stores. (The coal is assumed to have been purchased at the same price throughout.)

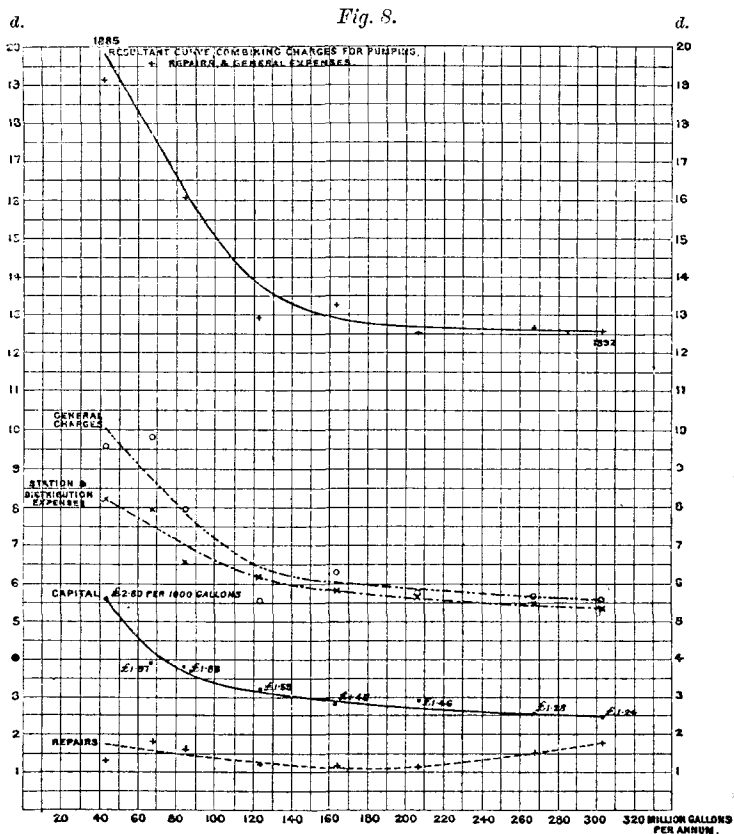
*Repairs*

to buildings, plant, mains and meters.

*General Charges—*

Rates and taxes, insurance, office expenses, stationery, incidental expenses, directors, auditors and salaries.

It should be observed that the curves of the station and distribution expenses, and of the general charges, are nearly the same, both in form and in numerical value. The principal reason why the curve for general charges has not fallen below that for the station and distribution expenses, has been the overpowering influence of the increase in amount of rates. The



rates paid in 1892 were eleven times the amount paid in 1885, whereas no other single item of expenditure under the head of general charges has increased more than five times, and on the average the increase of the other items has been four times. The total increase in the quantity of water pumped per annum has been nearly eight times during the same period, while the station and distribution expenses have increased about four-and-a-half times.

The curve for repairs is quite normal. At first the plant is by no means fully occupied, and the cost of repairs estimated per unit of output is therefore relatively high. As the quantity of power delivered increases, the cost of repairs per unit is for a time reduced; but as the plant becomes older, the cost increases until the normal cost of maintenance and renewals over a long term of years is reached, when the curve may be expected to become practically a straight line. The amounts annually set aside for depreciation of plant are not dealt with in the diagram, as such sums only serve to average the charges for maintenance from year to year, and the sums so set aside are determined by opinion. Moreover, when the plant to be maintained is very large, and the period under review long, the averaging of the charge for maintenance from year to year becomes nearly automatic, and a depreciation fund cannot well be distinguished from an ordinary reserve.

The Author would have been glad to give similar curves for the Hull hydraulic-power undertaking, which has now been in existence for sixteen years; but as this was impracticable, he thought it would be of interest to give the curves shown in *Fig. 9*, in which the ordinates indicate the percentage of total cost to receipts. Though this method is not strictly comparable to the previous analysis of the London results, the curves point to the same conclusion (as the scale of charges is practically the same in London and Hull), notwithstanding that the Hull undertaking has only one-twentieth of the capacity of that in London.

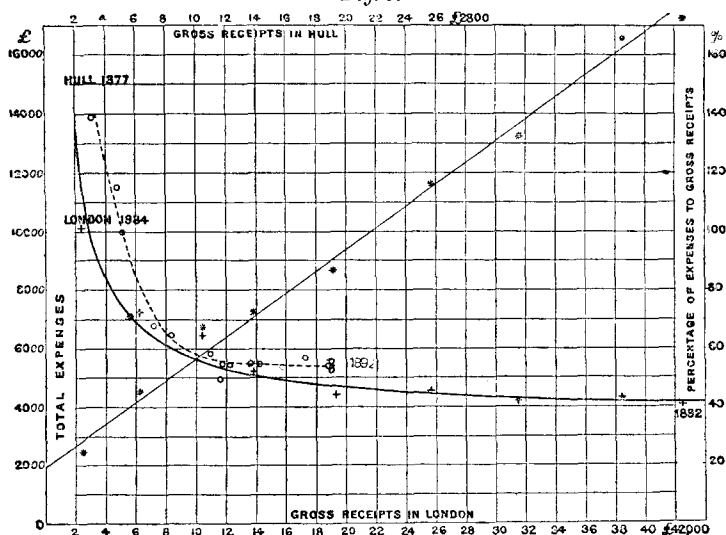
The influence of capital expenditure on plant in proportion to output, is obviously of as much importance as the actual expenses, in determining the cost at which the consumer can obtain his energy. Here the conditions are much more variable. In *Fig. 8* is given the curve of the capital per 1,000 gallons delivered expended in London on the hydraulic-power supply. An important factor governing the curve is the outlay on pumping-stations relatively to that on mains. Hitherto, the ratio has remained fairly constant. Eventually, the outlay on mains should become less, and the curve of capital would continue to droop. It is evident from the *Figs.*, as a whole, that there is small probability of power (including charges for depreciation and interest) being profitably supplied much under current minimum rates.

The diagonal straight line across the diagram, *Fig. 9*, shows in a striking manner the way in which the expenses grow in direct proportion to the increase of business. The stars on each side of the straight line indicate the gross expenditure in relation to the gross receipts taken from the published balance sheets of the

London undertaking. The straight line is a mean line between these points. It will be noticed that the diagonal line cuts the left boundary of the diagram at 2,000, and indicates approximately the minimum cost of working the undertaking irrespective of the amount of output. This minimum cost remains a constant charge on the undertaking, and its amount determines the percentage of reduction in the cost of working as the output is increased, and also the length of time or amount of increased output required to reduce the cost of working approximately to a minimum.

There is no reason to believe that experience in connection with hydraulic supply in London is likely to be materially

Fig. 9.



different from that of other undertakings established for supplying energy in towns from central artificial sources. The general form of the curves will probably be the same. The numerical values only will vary in particular cases. A very important element of the numerical value is, in all cases, the scale on which the works are originally planned. If works are planned on a moderate scale in relation to the probable output, and will allow of extensions as required, the minimum cost of supply will be approximated to within a comparatively short period; and under existing institutions and methods of business, further development is unlikely to exercise any material influence upon it.

It is assumed that due care is taken throughout to avoid waste of all kinds, and that at each stage of the enterprise there is practically no opportunity for what is called cutting down expenses without sacrificing efficiency.

#### APPLICATIONS OF THE POWER.

Since 1887, there have been few new important applications of hydraulic power. Progress has been made in the private use of the Greathhead high- and low-pressure ejector fire-hydrant. Some public buildings have been fitted with them, notably, the National Gallery and New Scotland Yard, and a few private buildings such as Queen Anne's Mansions. It is still to be regretted that no public use is made of the sixty miles of main in the most important districts of the metropolis, where valuable property is collected, by providing a thoroughly adequate and reliable fire-extinction service such as cannot possibly be obtained from the ordinary hydrants attached to the Water Companies' mains alone. A few Pelton water-wheels, specially designed for high-pressure supplies, have been satisfactorily at work for some time past, and constitute a great improvement upon the hydraulic engines hitherto used. The Pelton Company assert that the high-pressure wheel will give 80 per cent. efficiency. This has not so far been realized here in practice, though an efficiency exceeding 70 per cent. has been obtained. By mounting the motor on the dynamo shaft, there can be no doubt that 66 per cent. of the hydraulic energy can be utilized as electrical energy. Taking the rate of power supplied at 2s. per 1,000 gallons, the cost of the electrical energy obtained in this way works out at about 6d. per Board of Trade unit. It is possible, therefore, that there may be considerable development of the use of the hydraulic power for this purpose. At the present time, the electric lighting of Antwerp is being established upon a combined hydraulic and electric system devised by the late Mr. van Rysselberghe of Ghent. Hydraulic power is obtained at the central station by steam plant as in London, and is conveyed through pipes to various sub-stations in the city, being there converted by means of turbines and dynamos into electrical energy for distribution through the network of conductors. The Author expresses no opinion on the merits, or otherwise, of the arrangement, but he understands the efficiency of Mr. van Rysselberghe's turbine is no greater than that of the Pelton wheel. The Pelton wheel, at any rate, is an extremely simple, economical and convenient apparatus.

Taking all circumstances into account, there does not seem to be any reason why the use of hydraulic power in London should not in the future continue to increase as it has done in the past; and there are good grounds for holding the opinion that the hydraulic method of transmitting power will be able to maintain the position it occupies at the present moment, as the most effective and economical mechanical system in existence for the supply of energy for intermittent power-purposes in large cities.

The Paper is accompanied by ten drawings, from which Plate 6 and the *Figs.* in the text have been engraved.

## APPENDIX.

TRIALS OF A TRIPLE-EXPANSION COMPOUND VERTICAL SURFACE-CONDENSING  
STEAM PUMPING-ENGINE AND FAIRBAIRN-BEELEY BOILER AT THE WAPPING  
PUMPING-STATION OF THE LONDON HYDRAULIC POWER COMPANY.

	1 March 7th, 1892.	2 March 11th, 1892.	3 March 18th, 1892.	4 March 25th, 1892.
Duration of trial . . . . . hours	9	8	9	9
<i>Engines.</i>				
Diameter of high-pressure cylinder . . } in inches }	15	..	..	..
"    " intermediate cylinder "    " }	22	..	..	..
"    " low-pressure "    " "    " }	36	..	..	..
Stroke . . . . . feet	2	..	..	..
Total revolutions . . . . .	31,972	28,235	32,815	49,006
Average revolutions per minute . . .	59.76	58.82	60.77	90.70 <sup>1</sup>
Barometer . . . inches of mercury	29.8	29.4	29.9	Not taken.
Vacuum . . . . . "    "	28.0	27.74	28.43	
Total I.H.P. . . . .	179.80	185.63	206.55	
Thermal efficiency of engines, per cent.	14.25	14.73	15.25	..
<i>Boilers.</i>				
Total heating-surface . . square feet	800	..	..	..
"    " grate area . . . . . "    "	20	..	..	..
Pressure of steam in lbs. per square inch	118.3	142.8	143.0	141.3
Temperature of issuing gases ° Fahr.	..	..	557.5	..
Temperature of issuing gases before } passing economiser. . . ° Fahr. }	355.7	345.3	328.1	436.2
Temperature of issuing gases after } passing economiser. . . ° Fahr. }	247.3	253.8	238.5	271.3
Amount of condensed steam from } jackets . . . . . lbs. }	2,479	2,620	2,674	..
<i>Coal.</i>				
Quality . . . . .	(Inland) (Nixon's Navigation.)			
Total weight fed on to grates . . lbs.	3,287	3,200	2,774	3,744
"    " of clinker, etc. . . . "	114	196	237	162
Fuel burnt per hour (including clinker, } etc.) . . . . . lbs. }	365.2	400.0	308.2	416.0
Fuel burnt per square foot of grate "    "	18.26	20.0	15.41	20.8
"    " consumed per I.H.P. per hour "    "	2.03	2.155	1.49	..
Calorific value of dry coal . . . . . } lbs. of water per lb. of coal }	13.75	11.76	15.65	15.5

<sup>1</sup> Two engines running, one at 55.4, and the other at 35.3 revolutions per minute.

TRIALS OF A TRIPLE-EXPANSION COMPOUND VERTICAL SURFACE-CONDENSING STEAM PUMPING-ENGINE AND FAIRBAIRN-BEELEY BOILER AT THE WAPPING PUMPING-STATION OF THE LONDON HYDRAULIC POWER COMPANY.—*contd.*

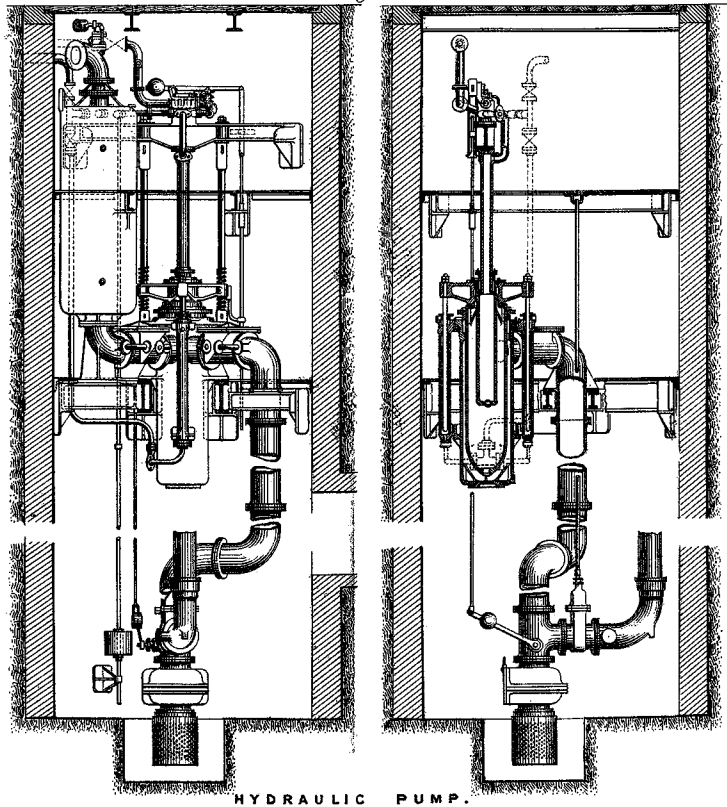
	1 March 7th, 1892.	2 March 11th, 1892.	3 March 18th, 1892.	4 March 25th, 1892.
<i>Feed-Water.</i>				
Feed temperature on entering econo- miser. . . . . ° Fahr. }	67·4	66·3	72·2	63·5
Feed temperature on entering boiler . ° Fahr. }	204·7	203·2	194·1	215·8
Heating-surface of economiser . . . square feet }	1,375	..	..	..
Total water evaporated . . . lbs.	26,199	23,005	28,365	41,584
Water evaporated per lb. of fuel (wet) lbs. }	7·97	7·19	10·22	11·11
" " " (dry) from and at 212 " (calculated) lbs. . }	9·96	9·27	12·25	13·44
Thermal efficiency of boiler, including economiser . . . . . per cent. }	72·5	78·9	78·2	86·7
Amount of feed-water per I.H.P. per hour (engine) . . . . . lbs. }	15·14	14·59	14·10	..
Steam-pipe condensation and loss <sup>1</sup> per I.H.P. per hour . . . . . lbs. }	1·05	0·9	1·16	..
Total feed-water . . . . .	16·19	15·49	15·26	..
Total quantity of water pumped, gallons	160,800	140,600	160,880	235,228 <sup>2</sup>
Accumulator pressure . . . . . lbs. per square inch }	727·3	728·5	795·0	800·0 <sup>3</sup>
Water pumped per cwt. of coal con- sumed . . . . . gallons }	5,530	4,920	6,495	7,036

<sup>1</sup> Long range of steam-pipes for several engines. The condensation alone was about 0·5 lb. per I.H.P.

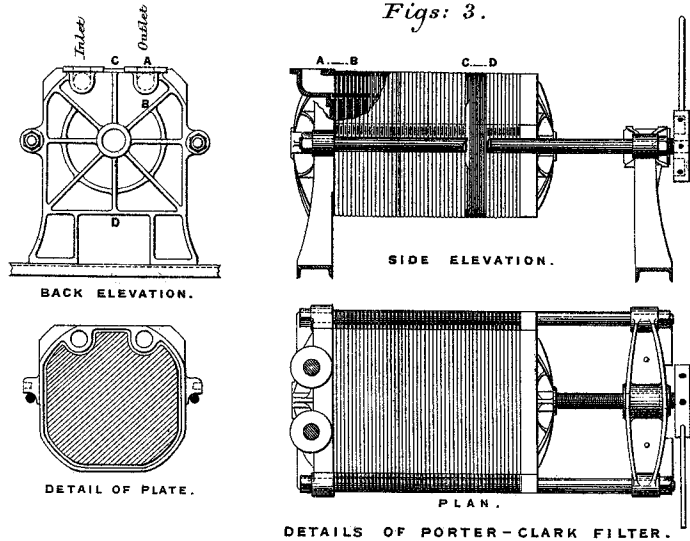
<sup>2</sup> Calculated at 4·8 gallons per revolution.

<sup>3</sup> Approximately.

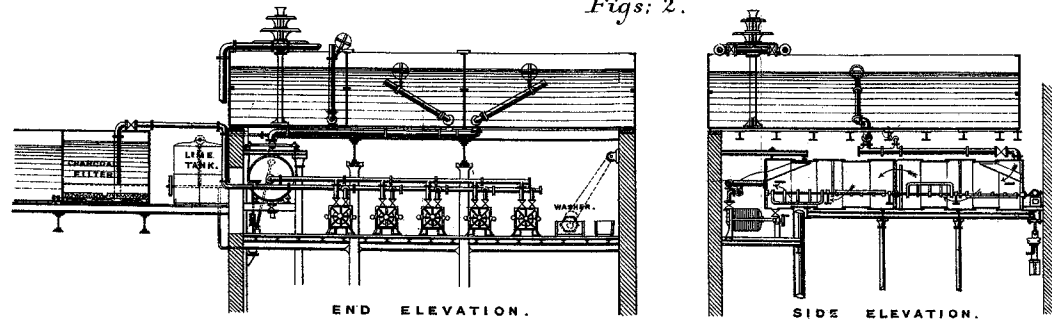
Figs: 1.



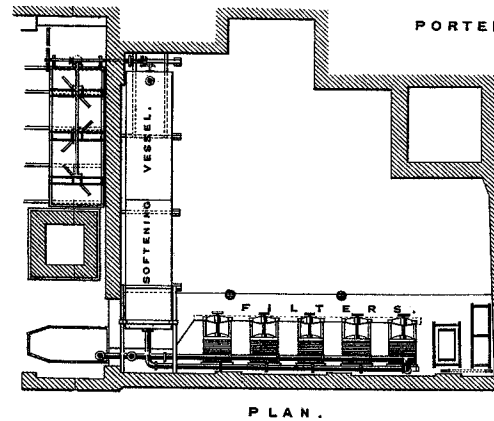
Figs: 3.



Figs: 2.

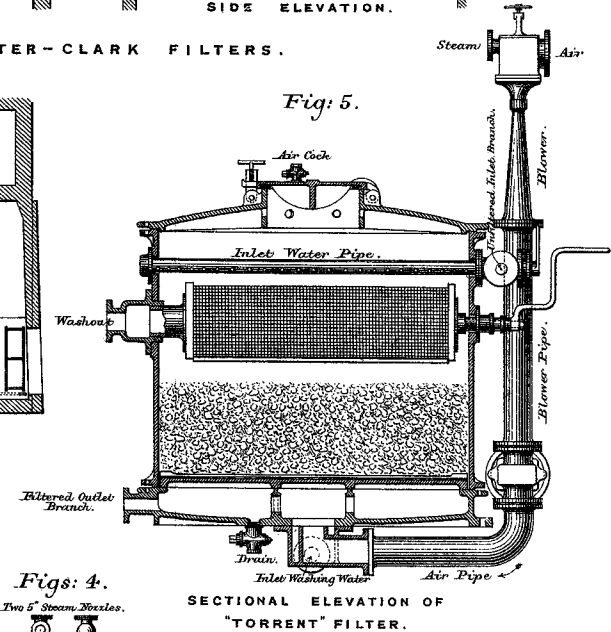


PORTER-CLARK FILTERS.

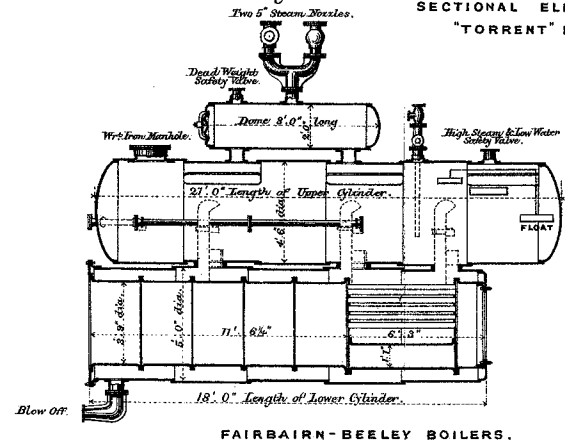


PLAN.

Fig: 5.



Figs: 4.



FAIRBAIRN-BEELEY BOILERS.