ECONOMY OF FUEL IN ELECTRIC GENERATING STATIONS.

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All Public or Municipal Lighting Authorities are required to furnish "Yearly Returns" to the Board of Trade, giving their costs of generating current. From these returns "The Electrical Times" has compiled a Table of Costs, which is kept up to date, and published weekly. The following remarks and figures are based on this Table, published on 1st January 1903.

Most of the Municipal Bodies end their financial year on 31st March; therefore the figures given in Tables 1 to 11 (pages 523-536) mainly refer to the financial year ending March 1902. It must be borne in mind that this was a period of exceptionally dear coal.

The first point that attracts attention is the great difference in cost per unit generated in these stations. They are located in various parts of the country; some are condensing, others partly condensing, or non-condensing stations, the price paid for coal varies largely, and different systems of supply are used. All these considerations affect the costs.

In the returns for the Lighting Stations, the figures are based on units sold to consumers, and therefore include the large leakage or loss in the mains, which is debited to the Generating Plant. This may be as much as 20 per cent., and is a very important factor to be kept in mind when comparing purely Lighting Stations with Tramway or Railway Plants, that "meter" the current as it leaves the Station.

Engineers would naturally expect that condensing stations would show a better fuel economy than non-condensing, both for tram and lighting purposes, but so far as lighting only is concerned, it is just the reverse; the average, both in fuel and works costs, is considerably in favour of non-condensing stations. Where trams are added to lighting, the condensing plants show a better economy than non-condensing, but in all cases the partly condensing station is the most economical both in fuel and works costs.

Works costs include fuel, oil, water, waste, stores, wages of workmen, repairs and maintenance. It is manifestly unfair to compare purely Lighting Stations, which have only a poor load factor, with stations that combine Lighting and Tramways, and generate large quantities of current all day long, and meter it as it leaves the station.

The author has therefore subdivided the stations given in the Table of Costs published by "The Electrical Times," and arranged them as follows:—

22 METROPOLITAN STATIONS.

Lighting only.

		Units sold.
Non-Condensing	. . . Table 1 (page 523)	. 24,014,141
Partly Condensing	. . . „ 2 („ 524)	. 11,305,581
Condensing	. . . „ 3 („ 525)	. 41,318,891

These stations are fairly comparable; they are all generating current for lighting purposes, and pay London prices for coal and labour. In comparing the costs of these three types, it is found that the non-condensing stations produce current at 18 per cent. and the partly condensing 21 per cent. less cost than the condensing stations. For fuel only, the saving in favour of non-condensing and partly condensing plants is about 14 per cent. and 17 per cent. respectively.

116 PROVINCIAL STATIONS.

Lighting only.

		Units sold.
Non-Condensing	. . . Table 4 (pages 526-7)	. 18,430,119
Partly Condensing	. . . „ 5 (page 528)	. 20,873,145
Condensing	. . . „ 6 (pages 529-531)	. 35,933,215

These stations, as a rule, are small, and situated in various parts of the country; on the whole, they will have the advantage of cheaper coal and labour, as compared with the Metropolitan stations, and they show that their average cost of producing current is 18 per cent. less than the Metropolitan stations. Here again the non-condensing and partly condensing stations are more economical than the condensing, the saving in works costs being 14 per cent. and 16 per cent. respectively, and the saving in fuel $12\frac{1}{2}$ per cent. and $20\frac{1}{2}$ per cent.

32 PROVINCIAL STATIONS.

Supplying Current both for Lighting and Tramways.

		Units sold or generated.
Non-Condensing	. . . Table 7 (page 532)	7,968,426
Partly Condensing	. . . „ 8 („ 533)	30,040,162
Condensing	. . . „ 9 („ 534)	39,898,928

In these stations the condensing plants are found to be more economical than the non-condensing by about 9 per cent. in works costs, and 19 per cent. in coal, but the partly condensing stations are still better than the condensing, showing an economy of 23 per cent. in works costs, and nearly 4 per cent. in fuel.

4 PROVINCIAL STATIONS OR POWER-HOUSES.

Generating Current for Electric Tramways.

All Condensing.

Total units generated 20,066,089

Table 10 (page 535) gives particulars of these Stations.

It is surprising to find that at least two of the Lighting Stations, Leeds (Table 6, page 530) and Edinburgh (Table 4, page 526), deliver current at the consumers' meters at 9 per cent. lower average cost than these four power-stations averaged at their switchboards; moreover Edinburgh is a non-condensing station.

Glasgow, the most economical of the four power-houses, with an annual output of over 10,000,000 units and a tramway load-factor, delivers current at the switchboard at a cost of 0.6 penny per unit works costs; whereas Leeds Lighting Station, with only 3,000,000 output and a lighting load-factor, shows a works costs of 0.62 penny per unit, including the heavy loss in the mains.

If the Leeds current was metered at the switchboard the works costs would read considerably lower than Glasgow, the most economical power-house in the country.

2 METROPOLITAN AND 1 PROVINCIAL POWER-HOUSES.

Generating Current for Electric Railways.

Total units generated 26,513,997

Particulars of these Stations are given in Table 11 (page 536).

These are beaten in economy by the tramway power-houses, already mentioned, by over 20 per cent. in works costs, and $5\frac{3}{4}$ per cent. in fuel costs. The extra for coal in the three railway power-houses may be accounted for by their geographical position, but the 20 per cent. excess in works costs appears unduly heavy.

The Diagram on the opposite page shows in graphic form the average costs of the various classes of stations or power-houses. The results from any station given in the various Tables, may be compared with the average in its own, or any other class of station by means of this Table. Take Leeds Lighting Station, with fuel costs of 0.27 penny per unit, or works costs of 0.62 penny, it is found to be considerably lower than the average of the tramway power-stations, the lowest average on the diagram.

Taking coal at 10 lbs. for a penny, or 18s. 8d. per ton, then each decimal point of a penny on the diagram represents 1 lb. of coal. If the Metropolitan (Condensing) Lighting Stations, Table 3 (page 525), purchased their coal at 18s. 8d. per ton, they would appear to be using on an average over $11\frac{1}{2}$ lbs. of coal per unit sold, or 8.6 lbs. per electrical H.P., or say $7\frac{1}{2}$ lbs. per I.H.P. per hour, taking a combined efficiency of 87 per cent. During the period under review these stations were no doubt paying more than 18s. 8d. per ton. This would modify the above figures, but it is impossible that coal could have been sufficiently dear to bring them within reasonable limits. An economical condensing engine and boiler should not require more than $1\frac{1}{2}$ lbs. of good coal per I.H.P. per hour, or $2\frac{1}{4}$ lbs. per unit generated. In everyday work, $2\frac{1}{2}$ lbs. per unit at the switchboard may be considered very good economy.

From these figures it would appear that the Metropolitan Condensing Stations, Table 3 (page 525), after allowing 30 per cent.

Diagram of Average Costs.

Works-Costs include Fuel, Oil, Waste, Water, Stores, Wages of Workmen, Repairs, and Maintenance.

for outside losses and banking fires, &c., were using at least twice the amount of fuel that economical plants ought to require. They generated during the year over 41,000,000 units, at a cost for fuel of over £200,000. A very large percentage of this amount could have been saved by the use of well-managed, economical generating plant. It must be remembered that most of these stations were pioneers in the electric lighting industry of this country. Each extension was in a measure a large experiment. They have had to contend with difficulties too numerous to mention, and, like "Topsy," they have just "grewed" to what they are. Could their engineers start afresh, with a "clean slate," there is no doubt that these stations, with their enormous output, would take their place amongst the most economical in the country. There is a good deal to be said in favour of the "clean slate." Taking the average station throughout the country there is great room for improvement; on the other hand, one finds a few stations that leave nothing to be desired; some remarkably economical results are recorded even in small provincial stations.

Condensing Plants.—Separate condensing plants are used in most lighting stations. The vacuum in the main engine low-pressure cylinder is usually poor, owing to the long lengths of exhaust pipe, often overcharged, and having numerous sharp bends; 11 inches vacuum in the cylinder has been recorded with 23 inches in the condenser. Station engineers as a rule do not pay sufficient attention to this. The engines of separate condensing plants, and other auxiliary machinery, are often fitted with piston valves. Such engines may be fairly economical when new, but soon develop a great appetite for steam. They are usually fixed in inaccessible places out of sight, and out of mind; their inflated exhaust passes direct to the condenser unobserved. It is quite common to find this type using 10 per cent. of the steam required by the main engines, when working at their full load, this percentage increasing rapidly as the load falls off. A recent test of a separate condensing plant revealed the fact that it used 4 lbs. of steam per unit generated by the main engines.

Engines fitted with their own condensers have a great advantage over those exhausting into one main serving several engines; usually

a saving of 5 to 10 per cent., due to the better vacuum, is effected. Add to this the 10 per cent. of steam used by the separate plant; the loss in the auxiliary steam main with its traps; the loss in starting up separate plants for short runs; the loss at light loads; the loss of vacuum through leaky atmospheric exhaust valves; and it is not so surprising that under these conditions, the economy due to condensing reaches the vanishing point, or even falls 13 per cent. behind well-equipped non-condensing stations, as shown by the Tables. The author's firm usually guarantee 7½ per cent. less steam per kilowatt-hour if the engines are to be fitted with their own condensers, and drive their own pumps. The total cost of these engines is less than those fitted with separate condensers, and the steam required by the auxiliary machinery is altogether saved.

Partly-Condensing Stations.—It is rather remarkable that the partly-condensing stations show the best average economy. Partly condensing is a very vague term; it may mean one engine in ten is non-condensing, or *vice versa*. No doubt, most of them might be classed as condensing stations. Without more exact data it is impossible to come to any definite conclusion as to the reason for this good average economy.

Non-Condensing Stations.—In "The Engineer" of 15th May, 1903, the compound engines for the Tooting Electric Tramways are illustrated, and a few particulars are given as to guarantees, &c. The lowest guarantee, when working condensing, is 13½ lbs. of steam per I.H.P. per hour; the lowest when working non-condensing is 16 lbs. per I.H.P. per hour. If the latter figures can be obtained, the money sunk in condensers, &c., will only yield a poor return, after the steam used by the condensing plant has been debited to the main engines. It is well to note that the figures here given are those guaranteed; the figures actually obtained have not been published.

About fifteen years ago, the author's firm devoted considerable attention to the manufacture of small compound non-condensing engines and boilers combined. Professor Barr and Mr. Druitt Halpin carefully tested one of the smallest sizes of these engines, with the following results, when using an exhaust steam feed-heater:—

Size of Cylinders :— $5\frac{1}{2}$ inches and 9 inches by 15 inches stroke, working at 24 I.H.P.

Steam per I.H.P. :—18·8 lbs. per hour.

Welsh coal per I.H.P. :—1·8 lbs. per hour.

Water evaporated per lb. of coal, from a temperature of 203° F. :—
10·44 lbs. Boiler pressure, 140 lbs.

Mechanical efficiency of engine, 86 per cent.

The above results in fuel and steam may be considered very good for non-condensing compound engines even of much larger sizes.

The results obtained from the smallest size of triple-expansion condensing engines, made by the same firm, and tested by Mr. Wilson Hartnell and Professor Goodman, were as follows :—

Sizes of Cylinders :—9 inches, $14\frac{1}{2}$ inches, and $22\frac{1}{2}$ inches by 24 inches stroke, working at 120 I.H.P.

Steam per I.H.P. per hour :—12·54 lbs.

Welsh coal per I.H.P. per hour :—1·25 lbs.

Water evaporated per lb. of coal from a temperature of 110° F. :—
10·11 lbs.

Water evaporated per lb. of coal from and at 212° F. :—11·34 lbs.

Boiler pressure :—157 lbs. per square inch.

Mechanical efficiency of engine, including the driving of all the pumps, and brake-wheel friction :—93·5 per cent.

These triple engines were fitted with surface condensers, and drove their own air, circulating, and feed-pumps. The feed-water was pumped direct from the hot-well to the boiler. Taking 18·8 lbs. of steam per I.H.P. for the non-condensing, and 12·54 lbs. of steam for the triple-condensing engine, the economy in steam, due to condensing, is 33 per cent., the economy in coal 30 per cent. The triple-condensing engines had the advantage of being larger in size, and working at 17 lbs. higher boiler pressure, but as regards economy of fuel, the non-condensing engine had the advantage of the feed-heater. If 25 per cent. be taken as the saving in fuel due to condensing, when the best engine of each type, working at the same steam-pressures, is used, it will be very near the mark.

The Tables show that in Lighting Stations the non-condensing engines beat the condensing by 13 per cent. in fuel economy; this is the average over the whole country, $13 + 25 = 38$ per cent. to be accounted for to bring matters as they ought to be. Uneconomical,

three-crank compound, tandem, condensing engines, largely used in Lighting Stations, no doubt account for some of this, and, as already shown, separate condensing plants are also steam wasters.

All non-condensing stations should be fitted with efficient exhaust steam feed-heaters; their cost is comparatively small, and the saving in fuel is a clear 13 or 14 per cent. over cold feed. Feed-heaters or economisers fixed in the boiler flues cool the waste gases, and to a certain extent spoil the draught. If this has to be made good by using steam-jets under the grates, the actual saving in fuel may be small. The best results are to be got by employing both types of heater, the water entering the economiser at nearly boilingpoint. It is interesting to note that Edinburgh and Motherwell, the two most economical non-condensing stations given in Table 4 (pages 526-7), are both fitted with exhaust steam feed-heaters. About fifteen years ago, the author fitted this type of heater on a condensing engine with good results. It is now the common practice in America to fit these heaters on condensing engines.

Engines in General.—The steam losses in electric generating engines are mostly due to valve or piston leakage; mainly the former. This applies more especially to condensing stations using engines fitted with piston valves; unless these are very carefully looked after, heavy leakage is likely to occur, the steam passing direct to the condenser. In non-condensing engines the exhaust pipe usually gives warning of leaky valves. Many station engineers do not appear to realise how serious this loss may be, and allow their piston-valves to run in a very leaky condition. Others give this matter most careful attention, and are well rewarded for their trouble; in fact, some of the most economical non-condensing stations are fitted throughout with piston-valve engines, carefully looked after and kept steam-tight. Balanced slide-valves, and valves of the Corliss type, having some pressure on the back to keep them up to the port faces, require much less attention, and will run for many years practically steam-tight.

Two recent tests of condensing engines (in different stations), fitted with piston-valves, disclosed the fact that they required over 45 lbs. and 50 lbs. of steam per kilowatt-hour respectively. When

previously tested the consumption was about 30 lbs. per kilowatt in each case. Outwardly they appeared to be running as well as ever.

Coal to the value of £839,613 was used in the 177 stations given in the Tables, during the year under review. It is safe to assume that £100,000 was lost in engine leakages alone. There is no doubt it would pay to employ an engineer in each of the larger stations to do nothing else but make tests and report on fuel losses with a view to their remedy.

Boiler-House Plant.—There are great differences in the qualities of steam generated by boilers. Engine-builders find much less difficulty in getting their guarantee figures from the honest steam of the Lancashire or other cylindrical boiler than they do from the high-pressure "Scotch Mist" given off by the now fashionable box of water-pipes. In lighting stations there are great fluctuations in the demand for steam. Only those who really understand the "art" of firing, can appreciate the difficulty of working mechanical stokers with economy under such conditions. Extra grate area may be the salvation of the "tyro" at the higher loads, but with such men, it is fatal to economy at the lighter loads, especially when steam-jets to force the draught are used.

An efficient method of forced draught is a decided advantage in lighting stations, if it is properly used, for it enables steam to be maintained over the peak of the load. The latest system of Mr. Halpin's thermal storage is the ideal method of obtaining the same end. At light loads the steam-jet method of forcing draught is often greatly mismanaged. A peep through the small side door, at the back of the grates, in a Babcock boiler, fitted with moving grates and forced draught, and carrying, say, half load, is often a revelation of how not to do it. One-third of the grate may be covered by a spouting volcano of fire, the remainder employed in carrying away dead ashes and clinker, allowing large quantities of cold air to pass, all of which has to be heated up to the temperature of the escaping gases. Under these conditions, a low flue temperature is no criterion of economy.

Some makers of steam-jet draught-producers only require 3 per cent. of the steam generated to supply their blowers; others state that they require 3 per cent., but their fittings are found to be large enough

to pass four times that amount, even when the full rating of the boiler is taken. The average fireman, as a rule, goes for all he can get under any conditions; hence it comes that he is able to maintain steam under the conditions already described, and waste large quantities of fuel by heating up the great excess of air passing through the uncovered bars.

Some years ago the author made a steam-economy test of a large pumping plant in the Colonies. The boilers were fired with wood, and the draught was got by means of steam-jets. It was found that they used 19 per cent. of the total steam generated. In a recent test of a modern stoker the numerous steam-jets used 12 per cent. of the total steam generated. By the use of fans, especially when heated air is used, good economy is obtainable. Feed-pumps and other boiler-house auxiliary engines require a considerable percentage of the steam generated. In condensing stations, better economy is obtained by utilizing the exhaust of the auxiliary engines in heating the feed than working them as condensing engines. In lighting stations the losses in the ring steam main, with its numerous traps, is a serious consideration; it is seldom less than 5 per cent., and may be very much more if the traps are not kept in perfect order and properly regulated.

Superheating, especially when piston-valve engines are used, shows a good steam economy, but the saving in fuel is not so marked. In lighting stations its proper regulation is rather difficult. The extra wear and tear on the main engines, and on the superheaters themselves, are items that have to be considered.

The Station Engineer.—He should note that the average works costs for the non-condensing lighting stations, Table 1 (page 523) and Table 4 (pages 526-7), are 16½ per cent. less than the condensing stations, given in Tables 3 and 6. One explanation of this may be that less plant requires less looking after and less repairs; there is also less capital invested. But a well-managed condensing station with economical engines, fitted with their own condensers, &c., is certainly the most economical type of station, especially where trams are coupled with lighting. The figures already given prove that the great economy due to condensing may be frittered away by using unsuitable plant, and by careless management. In his specifications,

he should insist that the total steam used by the main engine and its condensing plant be included in the guaranteed consumption; and that the evaporation of the boilers be taken in dry steam, delivered to the engine, and exclusive of steam used for various purposes in the working of the boiler. He would then be much better able to decide on the best type of plant to use.

Steam Turbines.—There are only four stations given in the Tables wholly using steam turbines:—Newcastle District, Table 5 (page 528), Scarborough, Cambridge, and Melton Mowbray, Table 6 (pages 529–530). Newcastle Station is the lowest, both in coal, and works costs; yet it is easily beaten by South Shields, a station with vastly less output, situated on the same river, and using triple-expansion condensing engines, which comes out 35 per cent. less in fuel, and 25 per cent. lower in works costs than the turbine station.

Gas-Engine Stations.—In the costs Table of the “Electrical Times,” particulars are given of only two gas-engine stations.” Northwich, using “Mond” producer-gas, has an output of 104,000 units. Its fuel cost is 0·48 penny per unit; works costs are 1·48 per unit. This is handsomely beaten by Leigh, Table 4 (page 526), a station with a larger output, using non-condensing steam-engines, which comes out at 28 per cent. less in fuel, and 15 per cent. less in works costs.

Redditch, the other gas-engine station, using “Dowson” producer-gas, has an output of over 172,000 units; coal costs are 1·3 pence per unit, and works costs are 2·61 pence per unit. There are over a dozen smaller sized steam-engine stations given in the Tables that beat these results.

It is encouraging to note from recently published returns that the costs in various stations throughout the country show a decided tendency to improvement. This is partly owing to cheaper coal, but there is also a healthy rivalry between station engineers, stimulated no doubt, by the “Electrical Times” publishing their results. This should in time bring the electric generating stations into the front rank as regards economy of fuel.

If any remarks in this Paper assist the station engineer towards obtaining this better economy, the author will feel amply rewarded.

TABLE 1.

Metropolitan Stations. Non-Condensing.

LIGHTING ONLY.

	Coal per Unit sold.	Units sold.	Units × Coal Cost.	Works Costs per Unit sold.	Units × Works Costs cost.
	<i>d.</i>		<i>d.</i>	<i>d.</i>	<i>d.</i>
Blackheath . . .	1·22	359,554	438,655	2·18	783,827
Chelsea	0·81	2,011,150	1,629,031	1·70	3,418,955
Islington	1·16	2,186,044	2,535,811	1·98	4,328,367
Notting Hill . . .	0·84	947,491	795,892	1·58	1,497,035
St. James's . . .	0·86	5,842,496	5,024,546	1·37	8,004,219
Shoreditch . . .	*1·48	2,247,055	3,325,641	2·25	5,055,873
Southwark . . .	1·35	484,431	653,981	2·29	1,109,346
Stepney	0·5	1,008,037	504,018	0·81	816,509
Westminster . . .	1·04	8,927,883	9,284,998	1·59	14,195,333
TOTAL	—	24,014,141	24,192,573	—	39,209,464

$$\frac{24,192,573}{24,014,141} = 1.007 \text{ pence per unit sold for Coal.}$$

$$\frac{39,209,464}{24,014,141} = 1.632 \text{ pence per unit sold for Works Costs.}$$

* Steam partly supplied by Refuse Destructor.

TABLE 2.

Metropolitan Stations. Partly Condensing.

LIGHTING ONLY.

	Coal per Unit sold.	Units sold.	Units × Coal Cost.	Works Costs per Unit sold.	Units × Works Costs cost.
ipton . . .	d. 0·77	1,702,749	d. 1,311,116	d. 1·27	d. 2,162,491
ing Cross .	0·85	6,553,792	5,570,723	1·39	9,109,770
pstead . .	1·21	2,127,173	2,573,879	1·89	4,020,356
beth . . .	1·67	921,867	1,539,517	2·74	2,525,915
TOTAL . . .	—	11,305,581	10,995,235	—	17,818,532

$$\frac{10,995,235}{11,305,581} = 0·972 \text{ pence per unit sold for Coal.}$$

$$\frac{17,818,532}{11,305,581} = 1·576 \text{ pence per unit sold for Works Costs.}$$

TABLE 3.

Metropolitan Stations. Condensing.

LIGHTING ONLY.

	Coal per Unit sold.	Units sold.	Units × Coal Cost.	Works Costs per Unit sold.	Units × Works Costs cost.
	d.		d.	d.	d.
City of London . .	1·06	12,719,872	13,483,064	1·81	23,022,968
Clerkenwell . . .	0·81	2,839,713	2,300,167	1·53	4,344,760
Hammersmith . .	0·79	1,461,427	1,154,527	1·47	2,148,297
Kensington . . .	0·81	3,058,680	2,477,753	1·54	4,710,367
London Electric .	1·28	3,546,461	4,539,470	2·36	8,369,647
Metropolitan . .	1·57	11,122,022	17,461,574	2·42	26,915,293
St. Pancras . . .	1·04	4,729,840	4,919,033	1·90	8,986,696
Wandsworth . . .	1·07	1,511,392	1,617,189	2·32	3,506,429
Woolwich District .	1·12	329,484	370,022	1·91	629,314
TOTAL. . . .	—	41,318,891	48,322,799	—	82,633,771

$$\frac{48,322,799}{41,318,891} = 1·169 \text{ pence per unit sold for Coal.}$$

$$\frac{82,633,771}{41,318,891} = 1·999 \text{ pence per unit sold for Works Costs.}$$

LE 4 (continued on opposite page).

Provincial Non-Condensing Stations.

LIGHTING ONLY.

	Coal per Unit sold.	Units sold.	Units × Coal cost.	Works Costs per Unit sold.	Units × Works Costs cost.
	<i>d.</i>		<i>d.</i>	<i>d.</i>	<i>d.</i>
ystwyth . . .	1.72	78,815	135,561	2.95	232,504
ley . . .	1.03	29,853	30,748	2.23	66,583
or. . .	2.05	86,820	177,981	3.3	286,506
ley . . .	0.79	200,112	158,088	1.41	882,157
nhead . . .	0.61	391,516	238,824	1.34	524,631
St. Edmunds	1.21	73,042	88,380	2.08	151,927
nsford . . .	1.79	82,906	148,401	2.72	225,504
a . . .	0.59	310,505	183,197	1.01	313,610
ngton. . .	0.57	162,563	92,660	1.16	188,573
bury . . .	0.60	263,076	157,845	1.61	423,552
n . . .	1.85	625,580	1,157,323	3.24	2,026,879
burgh. . .	0.34	7,760,307	2,638,504	0.65	5,044,199
r . . .	1.49	311,160	463,628	2.7	840,132
stone . . .	1.25	464,392	580,490	1.9	882,344
l . . .	0.42	409,397	171,946	1.22	499,464
ock . . .	1.00	157,681	157,681	1.75	275,941
w. . .	1.53	183,908	281,379	3.02	555,402
. . .	1.15	629,427	723,741	1.8	1,132,968
. . .	0.88	403,144	354,766	1.33	536,181
f Wight . . .	1.56	182,384	284,519	2.43	443,193
. . .	0.35	151,048	52,866	1.01	152,558
. . .	0.84	511,765	429,882	1.36	696,000
n . . .	0.68	811,141	551,575	1.36	1,103,151
ool District.	1.13	126,689	143,158	2.4	304,053
rindod . . .	1.35	79,420	107,217	2.8	222,376
y . . .	1.03	99,205	102,181	2.28	226,187
Carried over	—	14,585,856	9,612,541	—	18,236,575

TABLE 4 (concluded from opposite page).
Provincial Non-Condensing Stations.

LIGHTING ONLY.

	Coal per Unit sold.	Units sold.	Units × Coal cost.	Works Costs per Unit sold.	Units × Works Costs cost.
	<i>d.</i>		<i>d.</i>	<i>d.</i>	<i>d.</i>
Brought over		14,585,856	9,612,541		18,236,575
Motherwell . .	0·46	166,860	76,755	0·98	163,522
Nelson	0·68	106,189	72,208	2·15	228,806
Newmarket . .	1·19	60,676	72,204	2·1	127,419
Northampton . .	0·80	286,890	229,512	1·7	487,713
Oswestry . . .	1·37	50,649	69,389	2·87	145,862
Pontypool . . .	0·75	70,491	52,868	1·88	132,523
Richmond . . .	1·19	217,789	259,168	1·96	426,866
Shrewsbury . .	0·99	249,263	246,770	1·65	411,283
St. Annes' . . .	0·57	98,369	56,070	1·39	136,732
Stirling	0·90	111,369	110,255	1·98	220,510
Stockton . . .	0·84	205,322	172,470	2·2	451,708
Watford	1·94	290,947	561,437	3·05	887,388
West Hartlepool .	0·61	268,523	163,799	1·69	453,803
Wimbledon . .	*1·18	806,280	951,410	1·7	1,370,676
Winchester . .	1·36	192,385	261,643	1·69	325,130
Windsor	1·24	366,534	454,502	2·01	736,733
Wycombe . . .	1·17	295,727	346,000	1·66	195,179
TOTAL	—	18,430,119	13,772,001	—	25,137,428

$$\frac{13,772,001}{18,430,119} = 0\cdot747 \text{ pence per units sold for Coal.}$$

$$\frac{25,137,428}{18,430,119} = 1\cdot363 \text{ pence per unit sold for Works Costs.}$$

* Steam partly supplied by Refuse Destructor.

TABLE 5.

Provincial Partly-Condensing Stations.

LIGHTING ONLY.

	Coal per Unit sold.	Units sold.	Units × Coal Cost.	Works Costs per Unit sold.	Units × Works Costs cost.
	d.		d.	d.	d.
Altrincham . .	1·83	354,615	648,945	3·76	1,333,352
Belfast . . .	0·61	1,206,699	736,086	1·27	1,532,507
Birmingham . .	1·00	3,391,099	3,391,099	1·82	6,171,800
Bournemouth . .	1·04	1,003,401	1,043,537	1·77	1,776,019
Cardiff . . .	0·67	1,005,763	673,861	1·46	1,468,413
Coventry . . .	0·80	404,968	323,974	1·8	728,942
Eastbourne . .	1·82	447,295	814,076	2·74	1,225,588
Glasgow . . .	0·36	9,282,043	3,341,535	0·95	8,817,940
Guildford . . .	1·97	99,150	195,325	2·78	275,637
Middlesbrough . .	0·60	284,332	170,599	1·36	386,691
Morecambe . . .	1·28	202,967	259,809	2·61	529,743
Newcastle District . . }	0·69	1,619,671	1,117,572	1·22	1,975,998
Preston . . .	0·51	912,142	465,192	0·92	839,170
Tunbridge Wells	1·5	659,000	988,500	1·98	1,304,820
TOTAL. . .	—	20,873,145	14,170,110	—	28,366,620

$$\frac{14,170,110}{20,873,145} = 0\cdot678 \text{ pence per unit sold for Coal.}$$

$$\frac{28,366,620}{20,873,145} = 1\cdot359 \text{ pence per unit sold for Works Costs.}$$

TABLE 6 (continued on next page).

Provincial Condensing Stations.

LIGHTING ONLY.

	Coal per Unit sold.	Units sold.	Units × Coal cost.	Works Costs per Unit sold.	Units × Works Costs cost.
	d.		d.	d.	d.
Accrington . .	*0.16	97,869	15,659	1.54	150,718
Ayr	0.97	490,496	475,781	1.53	750,458
Barking Town .	1.16	285,916	331,662	2.07	591,846
Barnes	1.34	44,370	59,455	2.27	100,719
Barrow	0.96	284,709	273,320	1.93	549,488
Bath	0.68	743,607	505,652	1.59	1,182,335
Bedford	1.49	655,574	976,805	2.22	1,455,374
Bexhill	1.22	231,734	282,715	1.7	393,947
Bristol	0.91	2,756,624	2,508,527	1.55	4,272,767
Bromley	1.01	306,323	309,386	1.54	471,737
Burton	0.36	241,534	86,932	1.76	425,099
Bury	0.49	323,337	158,435	1.26	407,404
Cambridge . . .	0.77	382,224	294,312	1.67	638,314
Canterbury . . .	*0.80	288,455	230,764	1.32	380,760
Cheltenham . . .	1.25	653,364	816,705	2.15	1,404,732
Chester	0.56	840,960	470,937	1.22	1,025,971
Colchester . . .	1.29	180,166	232,414	2.24	403,571
Derby	1.43	754,952	1,079,581	2.28	1,721,290
Ealing	1.71	705,786	1,206,894	2.21	1,559,787
Eccles	1.35	155,247	209,583	2.63	408,299
Fareham	1.12	64,115	71,808	2.39	153,234
Gloucester . . .	0.58	270,713	157,013	1.32	357,341
Hanley	1.05	697,602	732,482	2.16	1,506,820
Harrogate . . .	0.79	648,677	512,454	1.54	998,962
Hastings	1.55	703,814	1,090,911	2.31	1,625,810
Hereford	0.64	96,012	61,447	1.71	164,180
Carried over	—	12,904,180	13,151,654	—	23,100,963

* Steam partly supplied by Refuse Destructor.

TABLE 6 (continued on opposite page).

Provincial Condensing Stations.

LIGHTING ONLY.

	Coal per Unit sold.	Units sold.	Units × Coal Cost.	Works Costs per Unit sold.	Units × Works Costs cost.
	d.		d.	d.	d.
Brought over		12,904,180	13,151,654		23,100,963
Huddersfield	0·51	1,179,849	601,722	1·14	1,345,027
Hull	0·84	1,490,099	1,251,683	1·74	2,592,772
King's Lynn	0·59	286,679	169,140	1·26	361,215
Kingston	2·46	346,332	851,976	3·35	1,160,212
Lancaster	*0·82	341,536	280,059	1·79	611,349
Leeds	0·27	3,055,165	824,894	0·62	1,894,202
Leicester	0·55	1,042,302	573,266	1·34	1,396,684
Lincoln	0·58	263,216	152,665	1·35	355,341
Llandudno	*0·69	279,292	192,711	1·35	377,044
Melton Mowbray	0·93	43,742	40,680	2·19	95,794
Newport	0·50	578,275	289,137	1·39	803,802
Norwich	0·85	1,332,109	1,132,292	1·59	2,118,053
Oxford	0·89	569,561	506,909	2·21	1,258,729
Paisley	1·41	370,521	522,421	2·92	1,081,921
Portsmouth	1·11	1,847,790	2,051,046	1·7	3,141,243
Prescot	0·99	215,231	213,078	1·7	365,892
Rathmines	0·85	362,552	308,169	1·34	485,819
Reading	0·89	464,580	413,476	1·42	659,703
Rochdale	0·89	91,632	81,552	2·24	205,255
Salford	1·35	716,355	967,079	2·87	2,055,938
Salisbury	0·46	150,222	69,106	1·21	181,768
Scarborough	1·31	379,743	497,463	2·1	797,460
Sheffield	0·46	2,487,584	1,144,428	1·0	2,487,584
South Shields	0·44	985,646	433,684	0·92	906,794
Stafford	0·62	245,803	152,397	1·77	435,171
Carried over	—	32,029,996	26,872,687	—	50,275,735

* Steam partly supplied by Refuse Destructor.

TABLE 6 (concluded from page 529).

Provincial Condensing Stations.

LIGHTING ONLY.

	Coal per Unit sold.	Units sold.	Units × Coal Cost.	Works Costs per Unit sold.	Units × Works Costs cost.
	<i>d.</i>		<i>d.</i>	<i>d.</i>	<i>d.</i>
Brought over		32,029,996	26,872,687		50,275,735
Torquay . . .	2·41	199,369	480,479	3·47	691,810
Wakefield . .	*0·32	331,183	105,978	1·05	347,742
Wallasey . . .	0·69	269,424	185,902	1·42	382,582
Walsall . . .	0·80	340,232	272,185	1·83	622,624
West Ham . . .	0·95	1,583,421	1,504,241	1·7	2,691,815
Wolverhampton .	0·67	746,318	500,033	1·44	1,074,697
Wrexham . . .	*1·01	76,390	77,153	2·32	177,224
Yarmouth . . .	1·85	356,882	660,231	2·63	938,599
TOTAL . . .	—	35,933,215	30,658,889	—	57,202,828

$$\frac{30,658,889}{35,933,215} = 0·853 \text{ pence per unit sold for Coal.}$$

$$\frac{57,202,828}{35,933,215} = 1·591 \text{ pence per unit sold for Works Costs.}$$

* Steam partly supplied by Refuse Destructor.

TABLE 7.

Lighting and Tramways.

NON-CONDENSING.

	Coal per Unit sold or gener- ated.	Units generated or sold.	Units × Coal cost.	Works Costs per Unit sold or generated.	Units × Works Costs cost.
Blackpool . .	d. 1·01	2,018,132	d. 2,038,313	d. 1·82	d. 3,673,000
Nottingham. .	0·46	4,094,897	1,883,652	0·81	3,316,866
Southampton .	0·94	1,430,222	1,344,408	1·67	2,388,470
Stockport . .	0·62	425,175	263,608	1·43	608,000
TOTAL . .	—	7,968,426	5,529,981	—	9,986,336

$$\frac{5,529,981}{7,968,426} = 0·693 \text{ pence per unit sold or generated for Coal.}$$

$$\frac{9,986,336}{7,968,426} = 1·253 \text{ pence per unit sold or generated for Works Costs.}$$

TABLE 8.

Lighting and Tramways.

PARTLY CONDENSING.

	Coal per Unit sold or gener- ated.	Units generated or sold.	Units × Coal cost.	Works Costs per Unit generated or sold.	Units × Works Costs cost.
Aberdeen . .	d. 0·66	1,546,569	d. 1,020,735	d. 1·1	d. 1,701,225
Ashton . . .	0·69	977,044	674,160	1·18	1,152,911
Blackburn . .	0·71	2,002,141	1,421,520	1·09	2,182,333
Bolton . . .	0·44	3,120,709	1,373,111	0·80	2,496,567
Liverpool . .	0·50	20,018,142	10,009,071	0·81	16,214,695
Sunderland . .	0·73	2,375,557	1,734,156	1·11	2,636,868
TOTAL . .	—	30,040,162	16,232,753	—	26,384,599

$$\frac{16,232,753}{30,040,162} = 0\cdot540 \text{ pence per unit sold or generated for Coal.}$$

$$\frac{26,384,599}{30,040,162} = 0\cdot878 \text{ pence per unit sold or generated for Works Cost.}$$

TABLE 9.

Lighting and Tramways.

CONDENSING.

	Coal per Unit sold or gener- ated.	Units generated or sold.	Units × Coal cost.	Works Costs per Unit sold or generated.	Units × Works Costs cost.
	<i>d.</i>		<i>d.</i>	<i>d.</i>	<i>d.</i>
Bootle . . .	0·59	1,327,432	783,184	0·90	1,194,688
Bradford. . .	0·39	4,901,172	1,911,457	0·76	3,724,890
Brighton . . .	0·74	4,860,430	3,596,718	1·43	6,950,414
Burnley . . .	0·40	505,736	202,294	1·07	541,137
Carlisle . . .	0·71	494,475	351,077	1·61	796,104
Cork	0·32	1,701,996	546,638	0·61	1,038,217
Croydon . . .	0·92	1,810,387	1,665,556	1·34	2,425,918
Dover	1·24	781,809	969,443	2·13	1,665,253
Dundee	0·82	1,041,800	854,276	1·33	1,385,594
Grimsby . . .	0·84	292,094	245,358	1·46	426,457
Halifax . . .	0·48	2,557,548	1,227,623	1·09	2,787,727
Manchester . .	0·41	10,502,299	4,305,942	1·15	12,077,643
Newcastle . .	0·48	2,562,383	1,229,943	0·94	2,408,640
Oldham	0·71	1,042,055	739,859	1·33	1,385,933
Plymouth . . .	1·17	832,435	973,948	1·72	1,431,788
Southport . .	0·49	1,462,407	716,579	0·97	1,418,534
St. Helens . .	0·35	910,736	318,757	0·82	746,803
Taunton	1·11	285,907	428,356	1·63	629,028
Tynemouth . .	0·74	449,467	332,605	1·41	633,748
Whitehaven . .	0·7	228,887	160,220	1·44	329,597
Wigan	0·45	579,904	260,956	1·13	655,291
Worcester . . .	0·85	662,569	563,183	1·45	960,725
TOTAL	—	39,893,928	22,383,972	—	45,614,129

$\frac{22,383,972}{39,893,928} = 0·561$ pence per unit sold or generated for Coal.

$\frac{45,614,129}{39,893,928} = 1·143$ pence per unit sold or generated for Works Costs.

TABLE 10.

Electric Tramways.

CONDENSING.

	Coal per Unit gener- ated.	Units generated.	Units × Coal cost.	Works Costs per Unit gener- ated.	Units × Works Costs cost.
	<i>d.</i>		<i>d.</i>	<i>d.</i>	<i>d.</i>
Blackpool and Fleetwood }	0·46	917,930	422,247	1·16	1,064,798
Dublin . . .	0·43	6,651,113	2,859,978	0·79	5,254,379
Glasgow . . .	0·19	10,527,489	2,000,222	0·6	6,316,493
Hull	0·54	1,969,557	1,063,560	0·99	1,949,861
TOTAL . .	—	20,066,089	6,316,007	—	14,585,531

$$\frac{6,316,007}{20,066,089} = 0\cdot316 \text{ per unit generated for Coal.}$$

$$\frac{14,585,531}{20,066,089} = 0\cdot721 \text{ per unit generated for Works Costs.}$$

TABLE 11.

Electric Railways.

CONDENSING.

	Coal per Unit gener- ated.	Units generated.	Units × Coal cost.	Works Costs per Unit gener- ated.	Units × Works Costs cost.
	d.		d.	d.	d.
Central London	0·38	16,753,292	6,366,250	0·92	15,413,028
City and South London . . }	0·28	4,850,420	1,358,117	0·94	4,559,394
Liverpool Over- head . . . }	0·24	4,910,285	1,178,468	0·83	4,075,536
TOTAL . .	—	26,513,997	8,902,835	—	24,047,958

$$\frac{8,902,835}{26,513,997} = 0\cdot335 \text{ per unit generated for Coal.}$$

$$\frac{24,047,958}{26,513,997} = 0\cdot907 \text{ per unit generated for Works Costs.}$$

The Paper is illustrated by 1 Figure in the letterpress.

Discussion.

Mr. McLAREN said the Paper had been written deliberately to promote discussion, so he hoped the members would not be sparing in their criticisms. Before the discussion commenced he wished to emphasise the last three lines in paragraph 3 (page 511), namely, "The price paid for coal varies largely, and different systems of supply are used. All these considerations affect the costs." He had taken the whole of the stations in the country, so that the average cost of fuel might be got throughout the country. Metropolitan stations were kept separate, and compared with metropolitan, as he presumed they paid the same for coal and labour in all these stations. The different systems of supply was a very important point, and he hoped that some of the electrical members present would throw some light on their effect, so far as works costs were concerned. The losses in the mains were debited to the generating plant in all lighting stations that measured the current at the consumers' meters. Trouble would have been saved if the current had been metered at the stations, and comparisons of the merits of the various generating plants could have been made much easier. Metering the current at the consumers' premises, however, emphasised the fact that there must be a great reduction in the costs of generating and distributing current, if central power stations were to compete for mill and factory driving.

Mr. Ade Clark in his Paper had compared the most economical oil-engine with a steam-engine that no self-respecting power-user would keep for long on his premises, and he considered that advocates of central power-stations were doing very much the same thing. They compared the best they could put down with old antiquated engines, thus making a good comparison; but he would like some of the mill-engine builders to give those engineers a few figures of what they would have to compete with, if they wished to get the driving of mills or factories of any size. The wages of the engine men was a large factor in a small power plant; it was not so important when one got to 100 H.P. and upwards; in one or two cases that he had investigated, the mill engines were generating

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their power on the premises at three-eighths of a penny per I.H.P., including interest and depreciation, etc. He considered that the best oil-engine should be compared with the best steam-engine; a gentleman should be compared with a gentleman, not with a rogue. With regard to gas-engines in central stations, he hoped that some of the manufacturers of gas-engines would shed some light on how it was that, with their highly perfected engines, they were not getting any better results, if as good, as the steam-engine. Costs per unit generated in central stations fitted with turbines did not show up better than the steam-engine stations. The figures he had given were taken from actual work. The steam-engine makers, gas-engine makers, and turbine makers were all pouring their most economical engines and prime movers into the capacious maw of the central station, and how was it that they did not get any better results out of the central station? He thought, perhaps, if they were to try two or three highly economical Diesel engines they might give out a better economy, but as yet they had not been tried. So far as gas-engines, steam-turbines, and steam-engines were concerned, the cost per unit at the consumers' meters were high out of all reason.

The PRESIDENT was sure it would be the pleasure of the members to convey their thanks to Mr. McLaren for his most interesting Paper; he had thrown down the gauntlet most handsomely.

Mr. DRUITT HALPIN thanked the author for his kindly reference to himself in connection with boilers and Thermal Storage. Before proceeding to deal with the subject of the Paper, he wished to give one or two figures of comparison between gas and steam-engines which might be of use to the members, which came under his notice within the last fortnight. The gas plant was quite new, having been put down last year with all the latest improvements. The engines were of 250 H.P., and very accurate accounts were kept of what they were indicating, braking, and burning. Close by them in the same works there was a steam-engine, and the owners noted carefully for a month what that steam-engine was doing. The engine was a tandem compound with

a jet condenser, was of about 80 H.P., working at 60 lbs. pressure, which it had been doing during the last 28 years. The boilers that were driving it had been working for 32 years at 60 lbs. pressure. The gas-engine used 0.89 lb. of coal; the steam-engine used 3 lbs. of coal. But that was not the end of the story. The coal for the gas-engine cost 23s. a ton; the coal for the steam-engine cost 6s. 6d. a ton, so that, if it were taken out in money, the gas-engine was using 5 per cent. more money than the engine 28 years old. This charge was for fuel only, and was exclusive of repairs, which were very heavy in the case of the gas-engine plant.

Coming to the subject of the Paper, it might possibly be interesting to give some particulars of what was being done at the present moment. For a good many of the figures he intended to give he had to thank Mr. Miller, the engineer of the joint station of the Kensington and Notting Hill Co. at Shepherd's Bush. That Company was making polyphase current at 5,000 volts, and sending it down to town where it was transformed. The full line, Plate 14, showed the load curve for the maximum load in January 1903, reaching about 2,000 kw., and the maximum load for January 1904, reaching 2,750 kw. The stations were increasing their load very fast, and the engineers found they would have to provide for an additional 1,200 I.H.P. in the coming winter. That 1,200 H.P. was shown by the difference in the height between the top and bottom load curve lines, and was built up from the result of their previous experience in their extensions. The dotted lines showed either coal or thermal units put into the boilers. When they were working in the old ordinary way ^{without Thermal Storage} the coal curve would be the top one for 1904, and with Thermal Storage in use it would be the lower one, the hatched area showing the amount of heat stored in the Thermal Storage vessels. The increase in steam-producing power when the boilers were being fed from the Thermal Storage vessels was 22 per cent., which was taken off the top of the curve; that was to say, the work stored in the bottom cross-hatched areas was given out on the peak of the load. If anyone wanted to say that was incorrect, he would not be wrong, because the heat curve was given taking the varying feed temperature into account. The feed temperature was 150° F. with

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a large volume of water, and also a large volume of gas going through the economisers, and it was higher at light load, coming up to as much as 220° F.

Fig. 2, Plate 15, showed the combined general arrangement of one of the existing boilers and the Thermal Storage vessels now being fitted, two to each boiler. The existing boilers were marked A, and the boundary line below the top girders which carried the condensing tanks limited the available room. In the remaining space the vessels were placed. The only alteration that was made was that a hole was cut in the top of the boiler shell, a saddle piece riveted on, and a pipe put up which acted as a support to the vessel and had a connection for the steam and feed-water into the boiler, so that the pressure and the temperature in the Thermal Storage vessels and in the boiler drums were always constant. The Thermal Storage vessel was only rigidly connected at one point, so that it was perfectly free to expand in all directions, being carried at the other end by a suitable cast-iron supporting saddle-piece. The only other change that was made was in the feed-pipes, which were disconnected from the boiler steam drums and carried up into the Thermal Storage vessel, and the whole of the feed passed direct into the vessels, and then passed through the feed regulating cock and pipe into the boiler, as shown on the diagram. Supposing in the morning with a light load the water was down to the lowest water-level in the Thermal Storage vessel: if 10,000 lbs. an hour was being used in the engines, 20,000 lbs. would be pumped in; 10,000 went into the engines and the remaining 10,000 gradually accumulated until 3 or 4 o'clock, when the heavy load came on, so that when the vessel was full there was a charge of 20,000 lbs. available in each vessel at the same temperatures and pressures as existed in the boilers; thus at the top of the load, instead of having to evaporate from 150° F., they were only putting in the latent heat, as the temperature of the feed from the vessels was already 388° F., equal to the temperature in the boiler. In order to give some idea of what that meant, he might say, that as 20,350 lbs. were stored in each vessel, and 4,843,300 British thermal units were therefore contained in each vessel (this amount

being the product of the available amount of feed-water into the difference between the temperature at which the feed was received at top load, viz., 150° F. and the temperature at which it entered the boiler, viz., 388° F.), the total working pressure was 215 lbs. per square inch, this increase temperature being, of course, 238° F., and there were ten of those vessels. The steam used for the engines in that particular station was 23 lbs. per kw.-hour.

Each of the ten vessels stored up 250 kw.-hours, which gave 2,500 kw.-hours to help them over the top of the load. The reason that system was adopted in connection with the new plant was very simple. The engineer went very closely into the question of the figures, and obtained tenders for the boilers and buildings, and without making any allowance for the value of land, which was very high in London, it was found that Thermal Storage only cost 70 per cent. of the price of new boilers without contingencies. In connection with the question of price, Mr. Miller was good enough to give him the figures that actual electric storage batteries power had cost him. Four batteries were put in of 1,200 kw.-hours, which, without buildings, cost £7,500, so that the electric battery power cost exactly $6\frac{1}{4}$ times as much as the Storage. Another point in connection with the battery was what would be got out of it. Fortunately on that head he was able to give very exact figures. In one of the Thermal Storage vessels Messrs. Willans and Robinson had put up at their Rugby Works they kept the vessel filled with steam for eleven hours. They put a thermometer in the top, in the middle, and in the bottom of the vessel, and calibrated them carefully with a very accurate steam-gauge. They worked with the thermometer to see what result was being obtained, the final planimetered that in the test the drop in the temperature of the feed-water entering the boiler was 3° F. below the steam temperature. A drop of 3° F. represented a loss of 0.8 of 1 per cent. He did not know whether any of the electric accumulator people would get a less loss than 25 per cent. in watts delivered.

Referring to what the actual losses by radiation were on the vessels, the results obtained at Rugby on a vessel 4 feet in diameter by 16 feet 8 inches long, showed that they were condensing

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something like 24 lbs. or 25 lbs. of steam per hour, representing 3.2 lbs. of coal. In another vessel 6 feet in diameter by 19 feet long, in another place, the measured condensation over ten hours was 1.125 lbs. of coal per hour. That showed that at Rugby 1 lb. of coal was sufficient to deal with the radiation from 73 square feet of heating surface, whereas in the other case 1 lb. of coal would deal with the radiation of 234 feet of radiating surface, a proportion of 3 to 1 merely in the efficiency of the two different non-conducting materials. Messrs. Willans and Robinson used a most beautiful and costly material, but unfortunately it had not the same effect. He could give some other figures which might be of interest. Last April he tested with an assistant a plant of the old type, which had been at work for ten or twelve years. For one day they ran nine-and-half hours without storage, and the next day ten hours with storage. The water was very carefully measured by a Schönheyder water-meter, which was calibrated before and after the test; the coal was also weighed, its value on both days being tested by a calorimeter, so that they knew exactly what they were doing. The result was an increase of evaporative efficiency of 21.7, when Storage was being used, without giving credit for the difference in the thermal value of the coal.

A test much more interesting to the meeting would be the last one he would give, which took place practically without his knowledge; the tests were finished before he knew they were being made, his clients determining to test the apparatus for themselves. They ran from the 10th May last to the 7th June, day and night, Sundays included, with varying loads, which were very light during eight hours of the night, carefully measuring the whole of the coal and water. The result was that 334,560 lbs. of coal were burned, and 2,786,720 lbs. of water evaporated, showing that with exceedingly low class Midland slack, costing 6s. 6d. per ton delivered in the bunkers in Birmingham, an evaporation of 8.12 was being done from and at 212° F. They then ran from the 21st June to the 19th July under the same conditions, evaporating 2,223,270 lbs. of water, and burning 352,464 lbs. of coal, and in that case the evaporation, from and at 212° F. as before, was 6.7. That test

confirmed the figures he obtained in his own test, his figure for two months being 21·7, while his clients' was 21·35. In addition to the advantage of an increase of economy during the whole time of evaporation, there was a further advantage in getting the greater part of the dirt and lime in the feed-water deposited in the vessel, and in some cases, the whole of the dirt in the feed-water was precipitated; whereas, if they passed the feed-water through an economiser in order to get the benefit of the increased temperature, the lime in the water was deposited inside the pipes, where, owing to the relatively high temperature outside, it was baked on in a very hard condition, and was very difficult to remove.

On page 23 of Mr. Stromeyer's report for 1902 to the Manchester Steam Users' Association, he referred very fully to the undesirable amount of heat stored up in the brickwork of water-tube boilers, which became most inconveniently evident when the boilers had suddenly to be taken off the load. In this case, in order to get rid of this accumulated heat, it was necessary to continue pumping in feed-water, and allow the steam produced to blow off through the safety valves. Where Thermal Storage was used this waste did not occur, as the heat remaining in the brickwork was all usefully applied in raising the temperature of the feed-water pumped into the Thermal Storage vessels for use during the time the next heavy load came on.

The apparatus had also been applied to locomotives, the boiler being fed from the Thermal Storage vessel when going up hill, the vessel having been previously filled while the engine was running down hill. By this means an increase in boiler steaming power was produced amounting to 30 per cent.

Mr. GEORGE WILKINSON thought the Paper was full of interest to all engineers connected with the generation of power; it simply bristled with points upon which profitable and interesting discussion might be raised. The one statement which impressed him most in reading the Paper was that on page 512, namely, that, taking the average results from the tabulated statements in 1902, condensing stations were not, by some considerable extent, so efficient, in point of works costs and fuel costs, as non-condensing

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stations. Having read that, he looked through the Paper to find out if the author gave any reasons for such a startling conclusion. He found one (page 521) under the heading "The Station Engineer," where the author said "One explanation of this"—i.e., the economy of non-condensing plants—"may be that less plant requires less looking after and less repairs; there is also less capital invested." The capital invested did not affect the works costs, but the other did. The author continued, "But a well-managed condensing station with economical engines, fitted with their own condensers, &c., is certainly the most economical type of station." He had emphasized the "well-managed" because he thought that probably condensing stations, taking them all round, were as well-managed as non-condensing stations. He was thoroughly in accord with the author when he advocated the use of complete units, such as he described (page 516). The author pointed out there a general instance of a station which was fitted with a separate condensing plant common to the whole of the generators in the station, and it was not surprising to him, after having seen a number of such stations, that the economy came out so low; because when one came to consider that the range of output of those stations, especially lighting stations, varied from 100 per cent. for a short time down to 10 per cent. for a very much longer period, and that in such stations one often found the condensing plant engine of larger size than the day-load engine, and of a less economical type, it was a fertile source of loss; whereas if each generating unit were fitted with its own condenser, and made to drive its own air and circulating pumps, very much better results might be obtained.

He would like to ask the author whether he could give more in detail the black sheep amongst the condensing stations which lowered the averages so much that they compared unfavourably with non-condensing plants. The author mentioned (page 521) a fertile source of loss in station plants, namely, the capacious appetite of the boiler feed-pumps for steam. That was a loss which was common to both non-condensing and condensing stations, but he did not hesitate to say that in stations where the output varied very considerably, as it did in most electricity works, feed-pumps were altogether a

mistake for boiler-feeding purposes. He had designed and successfully introduced into several electric-supply stations in the country a new arrangement of injectors for this purpose, shortly described as follows:—Injectors in various sizes (so that a wide range of feed could be obtained) were “banked” in a row; the bank was divided in the centre by valves inserted in the steam, water, and delivery pipes. The steam to the injectors was taken in at each end of the bank, thus providing a duplicate service; a dual water-supply was also furnished by connecting at each end of the bank, and in like manner duplicate deliveries to the boilers were provided. Instead of using live steam from the steam ring, all the water separators and all the steam-jackets of the engine cylinders were connected to a small steam-pipe, which in its turn fed the bank of injectors. By this method, although the duty of each individual injector was curtailed, the enormous advantage was obtained of doing away with steam-traps; and the injectors were able to pass the whole of the condensed water from the separators and cylinder jackets through again into the boilers. It was found also that the injectors were quite capable of taking hot water from any ordinary hot-well, providing the injectors had no high lift on the suction. This arrangement was simple, efficient, and very economical, as proved by a number of years of continuous working.

The author drew certain conclusions (page 522) between steam-turbines and reciprocating plant, and he rather joined issue with him on that matter. The Newcastle station was quoted as being the most economical steam-turbine station, but that came out rather at a disadvantage when compared with the South Shields station mentioned also in the same paragraph. He thought it was only fair to say that many of the steam-turbines in the Newcastle station were of an old type; much of the pioneer work had been done there, and their economy could not be equal in any sense to the present-day turbines. Another point was that South Shields, which had triple-condensing engines, had a load factor of 14.6 per cent., whereas the Newcastle station had a load factor of only 13.67 per cent. Of the other steam-turbine stations mentioned, Scarborough had a load factor as low as 9.81 per cent., Cambridge only 8.59 per

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cent., and Melton Mowbray only 6.16 per cent. In connection with this matter he had a few months ago the advantage of testing a 300-kw. triple condensing engine, direct-coupled to a generator, and a 300-kw. turbo-generator working under precisely the same conditions, excepting that in the case of the vertical triple-expansion engine the superheat was somewhat greater than in the turbine, but in the turbine test the vacuum was a little better. At full load the vertical triple engine came out at 23.9 lbs. per kw. generated against the turbine 22.76; at half-load the vertical triple engine came out at 29.4 against the turbine 24.1. He did not mention these figures in any spirit of cavil, but to show that there was little difference between a modern steam-turbine plant and a high-class triple-expansion reciprocating engine plant in point of steam consumption.

Likewise in connection with gas-engine stations, the author quoted Leigh against Northwich. Leigh had a load factor of 12.32 per cent., and also had the advantage of being on a coal-field where coal was cheap, whereas Northwich had a load factor of only 9.34 per cent., and purchased their gas from the Brunner-Mond Co., which company, no doubt, made a profit on the transaction. With regard to losses in mains, the author allowed 20 per cent. (page 511). He thought he had erred on the safe side there, because at any rate in alternating systems 30 per cent. or 33 per cent. would be much nearer the mark.

Mr. CHARLES FORGAN thought the Paper would have been of more value to central station engineers, if the author had investigated his figures before publishing them, not merely taking them from the "Electrical Times," because he did not think they went to the point. For instance, the author stated (page 514) that the works costs of the three railway power-stations were heavy. He would like to know whether the other power-station results were obtained on a similar basis as the railway generating stations. Being connected with one of those railways, the Central London, he thought the figures were very misleading; more details might have been given. For instance, on page 536 the Central London Railway's works costs per unit was given as 0.92d. That included power-house costs, the wages of

locomotive drivers, costs of repairs to locomotives, and the wages of the men employed in that department. The total cost which the 0·92*d.* referred to was £31,537 for the half-year. The power-house costs were £18,049, while £13,488 represented the cost of the locomotives and car department. Taking the power-house costs and works costs alone, the figure obtained was just a little over 0·5*d.* per unit generated, that was taking the wages of the office staff, working expenses, water, gas, waste, store repairs and maintenance of the power station. He thought 1½ lbs. of coal per I.H.P. was a very good figure if it was maintained in most stations.

He thought the author was in the same boat as the speaker referred to on the previous day in comparing badly equipped condensing stations with well-equipped non-condensing stations; if the author had taken modern well-equipped condensing stations, he would have found the comparisons come out better. For instance, the Central London Railway had not the best condensing plant, and the engineers very soon knew it in the matter of boiler-power if they had trouble with the condensers. With reference to the Scotch mist, there was no doubt that Lancashire boilers had good staying powers; and he thought it was an advantage to power stations to have them in parallel with water-tube boilers, because the Lancashire boiler was very good for steady loads, but if one was in a hurry a water-tube boiler was wanted. He had had a good experience with water-tube boilers at the London Electric Supply Corporation and the Central London Railway, and in an extension which had just been carried out four Lancashire boilers had been put in, and a saving resulted when the boilers were run with the water-tube boilers.

He thought it would have been more to the advantage of station engineers had the author dealt more with the different costs of coal. The mechanical stoker had a good deal to do with the question. A lot of engineers thought the mechanical stoker a boon: he thought otherwise. At the Central London Railway two years ago they changed from using the mechanical stoker to hand-firing—he would not mention the particular type—because he did not think there was much to choose between them. Difficulty was experienced in getting

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the men to do exactly as one wanted, but after six months' running the coal costs were £4,000 a year less than they were previously with mechanical stokers. He could not say that that saving was all due to the stokers, because he had not much to do with the company while the mechanical stokers were in use; but, under instructions from his chief, he made the change he had referred to. The units generated were practically the same in both cases, while the engines had only undergone the usual overhaul and adjustment; therefore the stoking had a good deal to do with the saving in fuel.

Mr. J. D. BAILIE thought the author was not quite fair to station engineers in general in regard to condensing. They were not blind to the advantages of a good vacuum, and the case cited (page 516) of 23 inches at the condenser and 11 inches at the engine exhaust was quite an exception. Driving from the main engine had one disadvantage, in that if anything went wrong with the air and circulating pumps it disabled the main engine temporarily, until the pumps were disconnected. Probably, in general, the best method for central-station working would be to drive the pumps by motors, and to have intercommunication pipes and valves between the condensers, so that, in the event of any hitch occurring on the one condenser, a reasonably good vacuum could be obtained by coupling on to another one. He did not think that the last sentence of the first paragraph on page 517 was quite correct, for the author stated that the steam required by the auxiliary machinery was altogether saved. That, of course, was not so; for the air-pumps and the circulating pumps had work to do in moving the water against a certain head, which entailed an expenditure of power and steam, whether by the main engine or by an auxiliary engine.

The author quoted (page 518) a test of a 120-H.P. triple-expansion condensing engine, the exceptionally good result of 12.54 lbs. of steam per I.H.P. per hour being obtained, with a boiler pressure of 157 lbs. per square inch, and no superheat. The mechanical efficiency of this engine, including the driving of all the pumps and the brake-wheel friction, was given as 93.5 per cent. This certainly

seemed a high mechanical efficiency for a triple-expansion engine, and 12.54 lbs. per I.H.P. was an exceedingly low steam consumption under the conditions stated. Working these figures out they came to 13.4 lbs. per B.H.P., and, if coupled to a dynamo with only 90 per cent. efficiency, which was low for a dynamo, an electrical H.P. consumption of about 15 lbs. would be obtained, or a consumption per kilowatt of say 20 lbs. With all respect, he did not think the author's firm would care to guarantee a consumption of 20 lbs. per kilowatt per hour under those conditions.

MR. McLAREN interjected that he had given the names of the men who had carried out the tests.

MR. BAILIE said he would like to know, in connection with these tests, what the vacuum and the temperature of the steam were. It did not state the amount of superheat, if any, and what allowances were made for leakage, etc.

MR. McLAREN replied that there was no superheat.

MR. BAILIE, continuing, said that the author advocated running the auxiliary engines non-condensing and using the exhaust steam for heating the feed. Why not combine the two, by running both the main engines and the auxiliary engines condensing, and, as was done at West Bromwich, pass the exhaust steam through feed-heating tubes first and then through the condenser, imparting say 60° F. to the feed, and maintaining a vacuum of say 26 inches on the condensers? He thought perhaps the greatest economy was obtained in that way.

The author referred in a somewhat disparaging manner to steam-turbine stations. It was rather a pity he had done so, unless, as he said, it was for the purpose of provoking discussion, because it was quite unfair to compare an old station like the Newcastle and District with a practically new station such as South Shields. The Newcastle and District station was partly condensing; the South Shields

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station was wholly condensing. The Newcastle and District station had to pay for the carting of coal and also for the carting of ashes, whereas in the South Shields station the coal was practically taken from the boats to the furnaces. The heading "Fuel Costs" was quite misleading, in that it did not take into account the different items which were included. The author also gave the stations mentioned by him as the only four stations wholly equipped with turbines, but of course there were others, including West Bromwich, Shipley, etc. Three of the four cited, namely, Newcastle, Cambridge, and Scarborough, were the oldest. The fourth, Melton Mowbray, was a very small station, with a total capacity of only 150 kilowatts, so could not fairly be compared with a large station. For comparison with turbine stations, the author selected South Shields, a comparatively new station with every facility for economical working, but he omitted to take a station such as Oxford. At Cambridge the total cost of fuel per unit sold was 0·66*d.*, whilst at Oxford it was 0·74*d.* The stations were started in the same year, and the conditions as to irregularity of load were probably much alike, both being University towns, yet the cost of coal, the total works cost, and everything else came out higher at Oxford than at Cambridge. A comparison between Cambridge and Oxford would have been fairer than one between Cambridge and South Shields, though probably the author would dispute this, and would say that the reason for the higher fuel cost at Oxford was the system of distribution in vogue; if so, his whole Paper fell to the ground at once, for it showed the fallacy of abstracting isolated columns from tables such as those published in the "Electrical Times," and assuming the figures in them to represent the economy of the engines. Melton Mowbray was, as previously stated, a very small station, with 150 kw. capacity and an output of 43,000 odd units per annum, as against 1,600 kw. capacity and a million odd units output at South Shields.

After reading the author's Paper, he wrote to the Melton Mowbray engineer, who informed him in reply that, since the addition of a larger turbo, the cost of coal had been reduced to 0·388*d.* per unit sold, and that it was coming down every week.

He also wrote to the engineer of West Bromwich, who had very kindly furnished him with a copy of their official returns as prepared for the Board of Trade. The total works cost there, although it was comparatively a small station, came out at 0.65*d.* per unit sold, and the cost of fuel at 0.35*d.*—they were below that at the present time. That was a better result by far than South Shields, considering the difference in size of the stations, etc.

In regard to the question of superheat, he presumed the author's remarks referred to separately fired superheaters. If they referred to flue superheaters, he did not agree with him; there was very little upkeep or attention required with the flue type of superheater, except in cleaning out the soot deposited from time to time—a simple matter. With superheaters of the ordinary Babcock and Wilcox type, about 1,500° F. superheat was regularly maintained at a number of stations which he knew—West Bromwich, etc. The economy of superheat to that extent was about 15 per cent. of the steam consumption, so that he could not quite see that superheaters were a disadvantage in a station.

Mr. T. L. MILLER thought the point in the Paper which probably interested engineers most was that referring to the superior economy of the non-condensing electric lighting stations over the condensing. He did not think, however, that if all the facts bearing upon the question were taken into consideration, the difference shown would be found to be due to whether the engine were non-condensing or condensing. In the remarks he made after the reading of the Paper, the author, he thought, gave one reason for the figures, and Mr. Wilkinson in his remarks gave another which he proposed to deal with very shortly. Dealing first with the relative economy of non-condensing and condensing engines, it was a well-known fact that working under similar conditions the condensing engine, at all loads, gave a greater economy in water consumption per horse-power hour than the non-condensing engine. Provided, then, that the conditions of loading were the same in the non-condensing and condensing stations, it appeared to him that there could be no

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increased economy of the non-condensing engine over the condensing. This being so, it was necessary to look in some other direction for an explanation of the very startling figures given by the author. Now, in addition to the type of plant employed, the efficiency of a generating station, stated in terms of cost of coal per Board of Trade unit sold, depended, amongst other things, upon:—

1. The system of supply.
2. The "load factor."
3. The cost of fuel.
4. The personal factor in the management.

All these factors had a considerable bearing upon the costs of production. Dealing with the first factor, namely, the system of supply, it might be pointed out that the stations in this country could be divided roughly into two classes, one the high-tension and the other the low-tension stations. The high-tension stations, for the most part, were put down in districts where the demand was sparse, when one had to go for considerable distances in order to get consumers. On the other hand, low-tension stations were put down in more densely populated districts. Leeds was an example to the contrary, and there were other such exceptions throughout the country. In the high-tension stations the difference between the units sold and the units generated was very much greater than in the low-tension stations; for example, from an examination of the records of fourteen low-tension stations and twenty high-tension stations, he (the speaker) found that the average percentage of units sold to units generated was 86·6 in the low tension, and but 67·3 in the high-tension stations. Allowing for these losses, it might reasonably be expected that the coal costs in the high-tension stations would be higher than those in the low-tension stations. In addition to this, however, the low-tension stations had the advantage of batteries, which, in the smaller stations, tended to further reduce the costs; as well as a considerable motor load during the day, giving an increased "load factor." Bearing in mind these facts, and dividing the stations into two classes, high and low tension, it would be seen what a great effect the system of supply had on the

costs, and how fully their ideas of the economy, in terms of coal consumption per unit sold, of the condensing engine over the non-condensing were borne out. Leaving out of consideration the Metropolitan Company's stations, part of which were condensing and part non-condensing, and also the eight stations where steam was partly supplied by refuse destructors, the stations might be grouped as follows :—

	Metropolitan.		Country.	
	H. T.	L. T.	H. T.	L. T.
Non-condensing	2	6	6	36
Partly condensing . . .	3	1	8	6
Condensing	5	3	36	17

It would be noticed from these figures that in the non-condensing stations the low-tension systems of supply were greatly in excess of the high-tension, and from the data already given regarding the better efficiency of the low-tension systems, it would be readily understood that the non-condensing results would show a high average efficiency. In the condensing stations, on the contrary, the high-tension systems of supply were in excess of the low-tension; and as a consequence a lower average efficiency would be obtained for the condensing stations. This disproportion between the high and low-tension systems of supply in the non-condensing and condensing stations appeared to him to account largely for the supposed superior economy of the non-condensing stations referred to by the author.

Dealing, then, with the author's figures of coal costs per unit sold, and omitting as before the figures for the Metropolitan stations, and the eight "destructor" stations, he (the speaker) subdivided the purely "lighting" stations into two groups from which he obtained the following figures for the average coal costs per unit sold :—

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	Metropolitan.		Country.	
	H. T.	L. T.	H. T.	L. T.
Non-condensing	1·17	0·93	1·72	0·63
Partly condensing	1·14	0·85	1·03	0·54
Condensing	1·04	0·95	0·90	0·61

Referring to the high-tension stations, he pointed out that in both the metropolitan and country stations the condensing stations showed a greater economy than either the partly condensing or non-condensing, and that the partly condensing stations in like manner showed a better economy than the non-condensing. In the low-tension stations, however, the coal costs in both non-condensing and condensing stations were sensibly the same, while the partly-condensing stations appeared to better advantage than either the condensing or non-condensing stations. This difference in the metropolitan low-tension stations, he thought, might be accounted for by the better load factor of the non-condensing stations, which, according to the "Electrical Times," varied from 11·38 per cent. to 22·74 per cent. in the non-condensing stations, was 18·6 per cent. in the case of the partly condensing, and varied from 7·87 per cent. to 16·55 per cent. in the case of the condensing stations. In the country stations again, the load factor and the price of coal would very largely affect the results, some stations being in the neighbourhood of the coal-fields, and having good motor loads, while others had to pay a heavy price for coal and at the same time had practically no day-load. In addition to these points the personal factor in management had a very considerable influence on the reduction of costs, and while he (the speaker) thought that the system of supply had a great influence on the question of costs, particularly in the smaller towns, he was fully aware that it could not account for all the variations noted. The "policy" of putting condensing plants down in purely lighting stations was not under discussion, and he did not therefore touch on it.

The next point to which he wished to refer was with regard to the driving of auxiliaries. The author had given some very high figures of steam consumption for driving auxiliaries, but he thought that in most modern stations the auxiliaries, and especially the air and circulating pumps, would be electrically driven. In that connection he would refer to a Paper read before the Manchester Section of the Institution of Electrical Engineers* by Messrs. Taite and Downe, in which the results of the running of the plants at the Salford and Southport stations were given. In those stations the auxiliaries were electrically driven and the energymetered. Regarding the metered units, it was found that the condensing plants taken throughout the year accounted for 4·67 per cent. of the total units generated, and the boiler feed-pumps 1·18 per cent. The electrically driven plant cost about three and a half times the steam plant; but even allowing for the increased capital cost there was still a considerable saving in electrical driving. Mr. Drutt Halpin earlier in the discussion gave some figures with regard to gas-driven plants; he (the speaker) would like to give some figures with regard to another gas-driven plant, a 500-H.P., in which Mond Gas was used, without ammonia recovery. The load factor of the plant was 55 per cent., and the cost of fuel 11s. 8d. per ton. Under these conditions the costs were as follows:—

Fuel	0·138 penny per unit
Stores	0·055 " "
Labour	0·151 " "
Total	<u>0·344 " "</u>

The only other point to which he would refer was the question of the gas-driven stations. Attention had already been drawn to the fact that the Northwich station, referred to by the author, bought its gas from Messrs. Brunner Mond and Co., the price paid being 2d. per 1,000 cubic feet. The author also gave some figures for another gas station, Redditch, where the fuel costs were 1·3d. per unit. The most recent gas station was that at Walthamstow, where Dowson gas-producers and anthracite coal were used. From the return of the past

* Journal 1903, vol. 32, page 1050.

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year's running, which had just been issued, he found that the fuel costs at Walthamstow amounted to 0·42*d.* per unit, and the works costs to 1·18*d.* per unit, figures that were very much below those given for Redditch.

Mr. MARK ROBINSON, Member of Council, thought the members were very much indebted to the author for deducing so many instructive and valuable conclusions from statistics which indeed were always before them, but which without such guidance they too often found dry and uninteresting. No doubt what would attract attention chiefly were the remarks upon the comparative economy of condensing and non-condensing engines—a very important subject, to which, in his opinion, not nearly sufficient attention had been given by engineers. He could not help thinking that the last speaker had chiefly been showing how figures might be made to prove anything, because there was nothing to be surprised at in the fact that the non-condensing lighting stations gave the best results. The old idea of a non-condensing engine was that it was a sort of poor relation, a sort of deformed example, of the only proper kind of steam-engine, the condensing engine—a view which might have been reasonable when all steam-engines worked at very low pressures. If one cut off the part of the indicator diagram which was below the atmospheric line, in a case where the initial pressure was not very far above that line, there was of course very little diagram left, but when one worked with high pressure, the part of the diagram above the atmospheric line was very much the largest part. In order to retain the smaller part, below the line, one had to spend much money upon condensing plant, and if the engine ran only for a few hours in the week, it was quite natural that it did not pay to do so. And not only would they have to pay interest upon the cost of the condensing plant, but the engine itself must be enlarged. It was sometimes thought that if one had a non-condensing engine and then added a condenser to it, more power should be obtained from it. That was a wrong idea altogether; the use of condensing, that is of the artificial removal of atmospheric back-pressure, was to enable expansion to be carried

further, but for that purpose the cylinder volume must be increased to correspond. The non-condensing engine therefore was much cheaper and smaller than a condensing engine giving the same power, altogether apart from the outlay on air-pumps. When these considerations were taken into account, it was not at all surprising that in stations not running with good load curves the non-condensing plants came out the best. In a power station, with a fairly even load, of course condensing paid, but for almost any other class of station it appeared to him that the system of partial condensation was likely to be the best. When, on the normal average load, condensation could be used, the occasional higher load, the peak of the curve, would be best met by starting an extra non-condensing engine or engines.

It was with satisfaction that he noticed in Mr. McLaren's tribute to the non-condensing engine, what was really a recognition of the work of another Leeds man, the late Mr. Willans, who nearly 20 years ago made non-condensing engines which used less than 18½ lbs. of steam per I.H.P., the same engines using about 12½ lbs. when working condensing. Between those figures there was no doubt a great difference, but in an engine which ran only intermittently, and for a very short time in each day, it quite possibly might not be worth while to save it. The author had endeavoured to account for the comparative non-success of the London condensing stations by speaking of them as pioneer stations, but he did not think that was correct, except with regard to the big station at Deptford, which fortunately was a law unto itself, and exceptional. The old pioneer plants of the London stations had long since been done away with; the real pioneer stations in London were the non-condensing stations, such as those of the St. James's and Pall Mall, and of the Westminster Companies; those stations used Willans non-condensing high-speed engines, and gave excellent results. Only one power station, the great tramway station at Glasgow, seemed to do better in works costs per unit than the best of the lighting stations, and then it was only by the tiniest decimal, the figures for Glasgow being 0·6d. against 0·62d. for Leeds and 0·65d. for Edinburgh. He did not know the comparative cost of

(Mr. Mark Robinson.)

coal in Edinburgh and Leeds, but he imagined Leeds had the advantage in that respect, perhaps sufficient to alter the order in which they stood. It was very remarkable that Edinburgh, which took this high position in the entire list, was another example of a non-condensing station. In view of this he felt justified in entering a protest against the author's condemnation (page 519), where he mentioned "uneconomical three-crank compound, tandem, condensing engines largely used in lighting stations," because these words seemed to refer to the very engines, the Willans high-speed three-crank engines, which, even without the advantage of condensation, gave such splendid results at Edinburgh. Further, in connection with the London stations, it would be found in Table 3 (page 525) that the Kensington condensing station, which had those very three-crank engines, tied with another London condensing station for the second place on the list, and was only just beaten by one other station, which had engines of another kind.

Mr. McLAREN, interposing, stated that he specially mentioned that the most economical stations were fitted with non-condensing engines.

Mr. MARK ROBINSON, continuing, said that piston-valves were somewhat strongly condemned in the Paper. He could say, from an experience of many years, based upon the use of many hundreds of Willans engines fitted with piston-valves, that these valves, when properly made (which was often not the case) remained tight and efficient. His firm had the strongest reason for discovering the best valve, and their continued faith in the piston-valve was simply the outcome of long and oft-repeated experiments; they could simply find no sort of valve which in actual use was, and remained, so tight. The Edinburgh engines were, of course, piston-valve engines, and they had for the most part been running for years.

Mr. MICHAEL LONGRIDGE, Member of Council, said the most striking fact brought out by the Paper was the superior economy of non-condensing over condensing engines. One reason had been given by a previous speaker, but there was another which he thought

must have suggested itself to many of the members, that was the exceeding badness of many of the condensing plants put down by electrical engineers. It was true that electrical engineers had taught steam engineers much, but it was equally true that they had much to learn themselves from the steam engineers. The surface of evaporative condensers, the capacities of air pumps, and the water cooling arrangements were often utterly inadequate, and the idea of the independent central condensing plant which seemed to find favour among electrical engineers was, when reduced to practice, generally a fraud. He strongly advised a separate condenser for every engine. The objection generally urged against this arrangement was the high speed of the engines, which made the driving of the air-pump difficult. But he would remind the members that there was a condenser which required no air-pump, and was therefore independent of the speed of the engine, a condenser which moreover occupied very little floor space, and that was the barometric 33-feet pipe condenser. The water could be supplied either by a centrifugal pump electrically driven, or by a small steam-pump such as the Worthington pump. If, however, a steam-pump was used, he thought it well to caution the members that the stop-valve for admitting the steam to the cylinder must be made exceedingly small. The ordinary stop-valve supplied with such pumps was well adapted for starting the run when the water had to be lifted to the top of the condenser; but the moment the vacuum was established, and the steam-pressure in the pump had only to overcome the friction of the water in the rising main, the quantity of steam taken by the pump became so small that the ordinary stop-valve had only to be opened a fraction of a turn, and he had found that when working in this way the vibration of the pump was very liable to shut the valve and stop the action of the condenser.

Professor ARNOLD LUPTON said that he had several barometrical condensers working successfully. There could be no doubt at all, as stated by Mr. Mark Robinson (page 557), that in considering the kind of engine required for a central power station it was necessary to take into account the load factor. One kind of engine was very

(Professor Arnold Lupton.)

suitable for 5 per cent. load factor, and another kind more suitable for 50 per cent. load factor. Most of the stations were electric-lighting stations. But in future they would have to deal more with electric power distributing stations. He had had some share in getting passed through Parliament two Acts providing for two large electric power generating stations involving two millions of capital each, so that naturally he had given a good deal of consideration to the question. He quite agreed with the author's remark that it was rather absurd to think that one could get an engine, turn its power into electricity, take it ten miles and drive a factory, and compete with another factory which bought its fuel as cheap and could buy an equally good engine. He and his colleagues never proposed such a thing. They thought they might supersede existing steam-engines of a bad type, using from 5 to 10 lbs. or even 20 lbs. of fuel per horse-power. Where extensions of power were required, and it was not convenient to put down a big engine, then electrical transmission would come in useful. There were economies. He had made a few calculations to show what could be done theoretically. Taking the cost of fuel at a central generating plant distributing power over, say, a radius of ten miles, and taking the cost of fuel in a town for one of the bad engines, which someone said was iniquitous, he found that £1 spent in fuel at an electrical power central generating station would do as much work upon the material that had to be worked upon at the factory as £10 spent on fuel at the factory. Taking the cost of 4s. a ton at the central generating station near the coal mines—which he knew to be a reasonable price in some districts—and taking the cost at 10s. a ton in the town at the small mill of 20 or 30 H.P., at the generating station, with every known device for economy, the I.H.P. would require only $1\frac{1}{2}$ lbs. of fuel per hour; and at the suggested small factory with second-class engine, it would require 6 lbs., thus making a ratio of $4 \times 2\frac{1}{2} = 10$ to 1 in fuel cost. In the electrically-driven factory the motor would be on the machine or on the countershaft, and in each case the power actually utilised in the machine was taken at one-half of the I.H.P. This calculation took no notice of any costs but the fuel cost.

Mr. W. PRICE ABELL thought that not the least important part of Mr. McLaren's Paper was the pertinent diagnosis of the work done at central stations, enabling him to point out with such clearness the weak spots, some of which were a surprise to engineers—namely, that non-condensing plants on an average acted more economically than condensing plants. He (the speaker) could not pass over Mr. Forgan's condemnation of mechanical stokers;—some certainly failed, but the recognised good makes of mechanical stokers got over the three great causes of loss in hand-firing in steam generating, namely, first, the entrance of cold air whilst charging the furnace by hand; secondly, the entrance of cold air whilst cleaning the bars; and, thirdly, the entrance of an excess of air though parts of the furnace charged too thinly, or where combustion had been quicker than in the remaining parts. In most of the stokers used in the Leeds electric light and power stations, members could see how the third loss was prevented by the utilization of a movable bar taking its own restricted air; so that in case of one part of the fire burning faster than another, it did not allow excess of air to pass through the thin part and rob the thicker layer of fuel of its allotted share. In several factories with which he had been connected, attention to these three points had reduced the fuel consumption very considerably, even in cases where expensively watched scientific hand-firing had been practised, and much more so when the stoking had been done with efficient mechanical stokers.

Mr. ALFRED SAXON said there was one aspect of the triple-expansion condensing engine which had not been referred to, and which, he thought, would account for its apparent loss of economy, namely, that in a short run a triple-expansion engine would not be seen at its best advantage nor even at light loads. A triple-expansion engine of 1,400 I.H.P. made by his firm was tested in November last year. In the first test of three hours in the morning the steam consumption worked out, with saturated steam, to 12·6 lbs. per I.H.P. In the afternoon run the steam consumption worked out

(Mr. Alfred Saxon.)

at 12·21 lbs., with practically the same load.* The following day the tests were continued with almost identical results. That served to show that in a long run, up to a given point, the triple-expansion engine became more efficient the longer it ran. The author had asked for some cotton mill engineer to give the cost of running a cotton mill for a week. A cotton mill in Lancashire, with an engine developing 1,000 H.P. could be run for £20 worth of coal per week of fifty-six hours, including the heating of the rooms and the stand-by losses. Taking fifty working weeks to the year and £20 per week, this would equal £1,000, and thus an engine of 1,000 I.H.P. could run for fifty-six hours in the week at a cost of £1 per I.H.P. for a year.

Mr. McLAREN, in reply, said that Mr. Wilkinson asked for the names of the black sheep. He had only to look down the Table of the costs per unit to find them. In connection with auxiliary machinery Mr. Wilkinson mentioned his injectors. That was a very interesting system. He had seen the method at work at Harrogate, and had adopted it with great success, using the injectors to feed the boilers, and taking the steam for the injectors from all the steam separators. Some engineers might think that injectors would not work with water in the steam supply, but they did; as a matter of fact they worked splendidly.

He was not at one with Mr. Wilkinson with regard to the turbine and the triple engine. Mr. Wilkinson's triple engine was practically a compound engine, the cylinders being proportioned for a low steam-pressure—it was only 120 or 125 at the time of the test; he had now got up to 130 by squeezing the Boiler Insurance Co. The condenser coupled to the engine was of the ejector type, and only gave a very poor vacuum indeed, something about 15 inches. The turbine worked with a splendid vacuum. It was well known that

* Corroborating the figures given by the author, a similar new triple-expansion engine to the one described above was indicated by the Engine and Boiler Insurance Co., on 2nd April 1903, and showed an efficiency of 91 per cent.

about $1\frac{1}{2}$ per cent. in economy was gained for every extra inch of vacuum obtained; if one intended to compare engines with engines, this must be borne in mind. Mr. Forgan explained (page 547) how it was that the works costs on the Central London Railway were apparently high, through outside expenses, that were not included in other stations, being added to them. He, the author, specially mentioned in the Paper that that was a point which required explanation, and the explanation given was satisfactory. Mr. Bailie mentioned (page 548) that the Metropolitan was not all condensing. As he already explained, he took the figures from the Tables published by the "Electrical Times." Mr. Bailie also doubted the possibility of the 12.5 and the 93.5 per cent. efficiencies being correct. There was no need for doubt in regard to the 12.5; it was easily obtained with good engines, as Mr. Robinson and Mr. Saxon had explained; but the 93.5 per cent. certainly required explanation. The efficiency came out rather over 91 for engine and brake combined. The brake wheel was 10 feet in diameter, and the trough-shaped rim was for water cooling. Their contract stated that they finished at the shaft-coupling. They had nothing to do with the alternator, so he demurred to driving this large brake and including its friction as engine losses. Mr. Wilson Hartnell settled the point; he sent for a motor, obtained a light strap, and drove the wheel uncoupled, in its own bearings without brake straps on, but with equivalent weight added so as to give it the same pressure on the bearings; it was rather surprising to see how long it took to get the meter pointer quite steady; he believed it was found that $2\frac{1}{4}$ E.H.P. was required to run the wheel to proper speed. That was how the figures were got out, and he knew no man whom he would sooner trust to make a brake test than Mr. Hartnell.

Mr. Bailie also made some remarks with regard to the turbines and engines. He took the Newcastle station because it was the best. He thought it was an error in the "Electrical Times" tables to say that the district station at Newcastle was partly condensing; it was a fully condensing station. The turbines were not antiquated and out-of-date; and there were some of the best and latest types of them in that station. There was very little difference between Newcastle and

(Mr. McLaren.)

South Shields as regards coal supply. He believed that South Shields at that time was paying very much more for coals than Newcastle. Mr. Bailie also mentioned Oxford and Cambridge; but there was no parallel between those two towns. Oxford was an isolated case practically, in regard to the system of distribution. The current left the station at 4 lbs. of coal per kw.; and the members could easily reckon out from the Tables what it amounted to when it was distributed. The price of coal was much higher at Oxford than at Cambridge, Cambridge being on one of the main coal lines to London. Mr. Miller gave some interesting details in connection with the mains and their effect on the costs; but he would reply to his remarks more fully in writing (page 573).

There was one point he would like to mention in connection with the method of distribution of power by electric energy. Ten years ago in his works they took out their steam-engines and boiler used for driving the works and put in a new one, thereby saving over 60 per cent. in fuel. If there had been any electricity employed, all that saving would have been put down to the electricity, but luckily there was no electricity connected with it. It would thus be seen that a great saving could be made, by simply putting in an efficient steam-engine in place of a wasteful one.

Communications.

Mr. E. G. CONSTANTINE wrote that Mr. McLaren was to be heartily congratulated on bringing before the Institution such an important subject as "Fuel Economy in Generating Stations" and the anomalies which existed in the generation of steam in this enormous and rapidly extending industry. It might come as a surprise to the author that, although, as he stated (page 520), "Engine-builders (may) find much less difficulty in getting their guarantee figures from the honest steam of the Lancashire or other cylindrical boiler than they do from the high-pressure 'Scotch mist' given off by the

now fashionable box of water-pipes," an analysis of the figures supplied showed that the boxes of water-pipes gave better results in working than either Lancashire or other shell types of boilers. Of the more economical stations (lighting and traction) referred to in the Tables, 29 generated or sold electricity at a coal cost per unit of 0·5*d.* or under. Of these stations 10 were equipped exclusively with Lancashire boilers, 3 with shell boilers other than the Lancashire type, 10 with a mixture of water-tube and shell boilers, and 6 stations with water-tube boilers exclusively.

The average coal cost per unit sold or generated at the 29 stations worked out as below :—

	<i>d.</i>
10 stations with Lancashire boilers only	0·435 per unit.
3 " " shell boilers other than Lancashire	0·393 " "
10 " " mixed water-tube and shell boilers	0·390 " "
6 " " water-tube boilers only	0·385 " "

It would thus be seen that the coal cost per unit was highest in those stations in which only Lancashire boilers were employed, and that those exclusively equipped with water-tube boilers generated their electricity at the lowest cost for fuel. In passing, it might be noted that in the very best example given in the Tables, that of Glasgow Electric Tramways, the cost of 0·19*d.* per unit was obtained with the author's "boxes of water-pipes." Had the 10 stations fitted with Lancashire boilers been equipped with "boxes of water-pipes" working at the average cost for the 6 stations given in the Tables, the saving in cost of fuel would have amounted to over £7,000 per annum.

Carrying the comparison farther, it was interesting to observe that the works costs per unit generated were also the lowest in the stations furnished exclusively with water-tube boilers, and highest in those having Lancashire boilers exclusively—the relative figures being 0·86*d.* in the water-tube boiler stations against 1·024*d.* in the Lancashire boiler stations. It might be contended that the better results shown by the water-tube boiler stations were due to cheaper fuel, more economical engines and better management, but the first reason was disposed of by the fact that of the Lancashire boiler stations six were actually on the coalfields, and four were within a

(Mr. E. G. Constantine.)

distance of 30 miles of collieries producing steam-coal; while of those stations equipped with water-tube boilers—one was in London, two were in Ireland, two in the Glasgow district, and only one on the coalfields. Doubtless economical engines and good management were responsible to some extent for the results, but these advantages were certainly not peculiar to exclusively water-tube boiler stations. The Lancashire boiler was a good old faithful servant, but where economy, space, and high pressures were in question it was not the best boiler, and must give place to the "box of water-pipes."

Although the "Scotch mist" box of water-pipes (illustrated in connection with Mr. Halpin's remarks, Plate 15) was by no means the most efficient water-tube boiler in use, even it has been proved more efficient than the Lancashire boiler; and one might almost be tempted to infer that, when once the engine-builders' guarantees were fulfilled, engines worked more economically on "Scotch mist" than on the honest steam referred to by the author.

Lt.-Colonel R. E. CROMPTON, C.B., wrote that Mr. McLaren dealt with matters of supreme interest not only to electrical engineers but to all users of power. They were indebted to him for calling attention to certain matters which were far too much neglected by all users of steam power. He thoroughly agreed with his remarks on page 519, in which the author attributed a very large share of the want of economy of steam-engines of all classes to valve and piston leakage, especially the former. He also agreed with him that huge losses occurred through leaky piston-valves, and that Corliss valves, plain slide-valves, and properly balanced flat slide-valves were much easier to keep steam-tight. The author's remarks on this matter must be read in connection with Callendar and Nicolson's valuable Paper* on "The Law of Condensation of Steam." Their Paper showed conclusively what a large proportion of the so-called condensation losses were really due to valve leakage losses and subsequent re-evaporation of the steam, and that this leakage was great when saturated steam was used, but became negligible when

* Proceedings Institution of Civil Engineers, 1897-98, vol. cxxxi., p. 147.

the steam was sufficiently superheated; in fact that the reduction of this leakage was the chief cause of the economy shown when superheated steam was used. Experiments made since the date of their Paper showed that certain steam-engines driving dynamos, and which had been designed to give high economy, entirely failed to do so when using saturated steam, on account of the heavy leakages past the piston-valves, and that this leakage had been so reduced by superheating the steam that the consumption had been reduced in the proportion of 100 to 45, a reduction which could not be explained thermodynamically.

He thought that Mr. McLaren was aware of this two years ago from remarks which he had made to the writer in conversation which took place at Newcastle; and since that time he himself had found that by carefully considered superheating he had been able to obtain economies from ordinary engines, which had enabled him to obtain such economy in electric light and power stations that in two important cases he had reduced the works costs to figures far below any of those given in Mr. McLaren's Tables for condensing stations; for instance, the whole of the power at his own works had been for some years past supplied by a separate power station. In this case he had reduced the fuel in pounds and pence per unit delivered into the works from 5 lbs. and 0.42d. in 1900 to 3.8 lbs. and 0.32d. in 1903. It would have added greatly to the value of the Paper if the author had attempted to do what he did in former cost-papers addressed to the Institution of Electrical Engineers, namely, attempted in each case to find the actual weight of coal used per unit as well as its cost in pence.

Although they were greatly indebted to Mr. McLaren for bringing such interesting facts together, he was sorry to say that he could not agree with some of the conclusions the author had arrived at. For instance, on page 520, under the heading of boiler-house plant, he stated that engine-builders found much less difficulty in getting their guarantee figures from the honest steam of the Lancashire or other cylindrical boiler than they did from the high pressure "Scotch mist" given off by the now fashionable box of water-pipes. He considered such a statement to be not only erroneous but mischievous,

(Lt.-Colonel R. E. Crompton, C.B.)

and it was entirely contrary to his own experience. It was no doubt made in good faith, but was in no way based on the results of average practice. No doubt Mr. McLaren and any other engine-builder putting down plant and taking his supply of saturated steam from new and clean Lancashire boilers would find it somewhat easier under those conditions to get sufficiently dry steam, than he would by taking the supply from equally new water-tube boilers; but water-tube boilers were now almost invariably fitted with superheaters, and with reasonable management it was found in practice that, under varying conditions of load, it was far easier to obtain regularly superheated steam from these latter boilers than from Lancashire boilers with the separate superheater usually employed with them. At any rate the writer's best results, which were certainly as high as any that had ever been obtained in practice, had been obtained with water-tube boilers using chain-grate stokers, but, and here followed a condition of the greatest importance, the setting of these boilers must be as carefully considered as the design of the boilers themselves. It was only of late years that Mr. Miller had shown at the Wood Lane joint station of the Kensington and Notting Hill Companies, that the space allowed in the combustion chambers of this class of boiler had been altogether too small when bituminous or smoky coals were used. If this matter was attended to, not only was the production of steam from this kind of boiler quite as regular and as free from moisture as from the Lancashire boilers, but the superheating could be carried on in the same flues with extreme regularity.

Another point in which he criticised the Paper was that little notice was taken of the question of lubrication. Whenever condensation was used, it was most desirable that the quantity of oily matter which passed into the return feed-water should be minimised, and one of the problems of the modern station engineer was to effect this. Of late years it had been found that the sight-feed lubrication was unsatisfactory. Far more satisfactory lubrication had been obtained by positive lubricators, in which either the oil or a paste of oil and graphite was forced into the steam-pipe with perfect regularity. Callendar and Nicolson drew

attention to the important part that lubrication played in the steam-tightness of sliding surfaces. His own experience agreed with theirs. He found that if they desired to obtain satisfactory and sufficient lubrication, so as to minimise the amount of greasy matter that went forward with the steam and still kept the sliding surfaces in the most steam-tight and perfect condition, they did so best by keeping the steam dry. All water passing forward with the steam rapidly removed the lubrication from the sliding surfaces, but, on the other hand, he found that with supply at the higher temperature involved with regular superheat even up to a total temperature of 800° F., on account of the facts just mentioned, surfaces could be kept in better order with a small use of oily matter than was possible with engines using saturated steam said to be sufficiently dry for economy.

Mr. CHARLES DAY wrote that from the various Tables given by Mr. McLaren it would appear that no advantage was to be derived from the adoption of condensing at electric-lighting stations; such a conclusion was, however, quite contrary to facts, as condensing plant properly applied was of very material benefit even in a generating station where current was supplied for lighting only, and this fact was best appreciated when the condensing plant at a station was for any reason stopped for a time.

It was to be noted that the figures from which Mr. McLaren made his deductions in regard to condensing might equally be used to show whether water-tube boilers gave more economical results than Lancashire boilers: whether slow-speed engines were more economical than high-speed, or for almost any comparison in regard to the equipment of electrical stations that one might wish to make. Conclusions based on figures covering such a wide area, and including so many variables, proved nothing beyond the truth of the old saying that "Statistics can prove anything."

Apart from the question of economy in coal, the Tables appeared to show that the works cost, exclusive of coal, was lower in stations which had condensing plant in addition to their engines, than it was in stations which had not got the additional condensing plant;

(Mr. Charles Day.)

thus, in the Metropolitan non-condensing lighting stations the total works cost was 1·632*d.* per unit, and the fuel cost 1·007*d.* per unit, the difference being 0·625*d.* per unit. Turning to those Metropolitan stations which were partly condensing, one found that instead of the difference being 0·625*d.* it was 0·604*d.* Again, in Provincial lighting and tramway non-condensing stations the works cost, exclusive of coal, was 0·56*d.* per unit, whereas the corresponding cost in the partly condensing stations was 0·838*d.*, and in the condensing stations 0·405*d.*; thus, the works cost, exclusive of coal, in the non-condensing lighting and tramway stations was about 70 per cent. higher than in those stations which had some condensing plant also.

Excluding coal, the works cost included oil, waste, water, stores, wages of workmen, repairs and maintenance. The most enthusiastic advocate of condensing plant would, he thought, hardly be prepared to say that the addition of condensing plant would reduce any of these items except water. Generally speaking, therefore, the Tables showed that condensing plant, instead of reducing fuel cost, reduced the other items forming the works cost; this deduction was, however, so absurd that he believed the sounder conclusion was that the Tables proved nothing.

Mr. McLaren instanced (page 516) a case of 11 inches vacuum being recorded in the cylinder, whilst 23 inches were recorded in the condenser; this case only showed that the pipes between the cylinder, or the ports into the cylinder, or both, were absurdly small, or that there was a distinct air-leakage near the cylinder. If independent condensing plant was placed within a reasonable distance of the engine with which it was connected, there was no difficulty whatever in getting a vacuum at the cylinder outlet within $\frac{1}{2}$ inch of the vacuum in the condenser. The author instanced a case where the steam used by a separate condensing plant was excessive. There was no reason why such a state of affairs should exist any more than that the steam used by the main engines should be excessive. Each could be kept satisfactory by proper attention, as had been shown in another part of the Paper.

It was stated (page 517) that when condensers were attached direct to engines the steam required by the auxiliary machinery was

altogether saved. That statement was clearly wrong, as in either case the same amount of work had to be done in driving the pumps; the only difference in steam consumption was that arising from the possibility of the larger engine using less steam per H.P. than the smaller condensing engine. On the other hand, when an engine was but lightly loaded, the independent condensing plant might be run at half-speed, in which case the steam consumption would be less than if the pumps were driven direct from the engine. Several disadvantages were brought in when pumps were coupled to the main engine. First, the design of the main engine usually required modification to permit of direct connected pumps. Second, it was generally now preferred to run engines driving dynamos at higher speeds than it was desirable to run air-pumps. Consequently if the pumps were so connected, they themselves were not so satisfactory as if worked independently and at lower speed; or the speed of the main engine had to be reduced to suit the pumps, with consequent increase in its cost, and in that of the dynamo. In designing engines, vibration troubles required careful consideration, and these troubles were very likely to be increased if the pumps were connected to the engine direct.

The author's suggestions as to the various ways in which improvements in economy could be obtained were excellent, but in almost every instance they applied with equal force to stations which had condensing plant as to those which had not. Mr. McLaren stated (page 518) that 25 per cent. might be taken as the saving in fuel due to condensing, other conditions being equal. The writer's own experience quite confirmed this statement, but he would modify it by saying that, after taking into account the capital invested in condensing plant, and the slight increase of maintenance and works costs, excepting fuel and water, the safe estimate of the net gain obtained by the adoption of condensing was 20 per cent.

Mr. McLAREN wrote, in further reply to those who took part in the discussion, and to the written communications since received, that it was evident from Mr. Druitt Halpin's remarks (page 558), that there was a manifest saving in fuel, by simply passing the feed-water through the storage vessel before it reached the boiler proper,

(Mr. McLaren.)

quite apart from the advantage derived from storage. Trapping the dirt and lime at the storage vessel instead of allowing it to pass into the boiler was also a great advantage, especially where water-tube boilers were used.

Mr. George Wilkinson stated (page 546) that the losses in the mains, between the station and the consumer, might be as much as 30 to 33 per cent. where alternating current was employed. This was a very important point to be borne in mind when settling the system of supply from a central station.

Mr. Charles Forgan remarked (page 547) that if well-equipped condensing stations had been compared with the non-condensing, the former would have shown up better, which was no doubt true, but any result could have been obtained had stations been selected in each class. As already stated, the Paper was based on the broad fact that all the stations throughout the country were taken. It was impossible to compare station with station, unless the price and calorific value of the fuels used in the various stations were known, but by taking all stations, using fuel at all prices, it was possible to compare one class with another in a fair manner.

Mr. J. D. Bailie considered (page 548) that the author was rather unfair to the engineers of condensing stations. This was disclaimed by the author, who was personally a strong advocate of condensing stations, and in making suggestions where the efficiency of these stations could be improved, he did so in the most friendly spirit. The figures given (page 516), namely 23 inches at the condenser and 11 inches at the engine, were certainly the worst the author had found, and were not intended to be taken as normal conditions in condensing stations. Respecting Mr. Bailie's remarks concerning steam used by auxiliary condenser engines not being all saved, the author would call his attention to the whole of the paragraph (page 517) from which he quoted. It read that the author's firm usually guaranteed $7\frac{1}{2}$ per cent. less steam per kw.-hour if the engines had their own condensers and drove their own pumps. The $7\frac{1}{2}$ per cent. was the net saving in the main engines, after deducting the power required to drive the pumps. It was found that the better vacuum obtained at the engine cylinders more than

compensated for the power required to drive the pumps. It was under these circumstances that the whole of the steam that would have been used by the auxiliaries was saved.

It was the practice in this country for engineers who made engines with separate condensers not to include the steam used by the condenser engine in their guarantee for the main engines. The author pointed out that this steam ought to be included in that used by the main engines.

Mr. Bailie also considered that the steam turbines had been treated in a disparaging manner, and objected to Newcastle District Station being compared with that of South Shields. The author admitted that there were objections to comparing individual stations, unless the whole of the conditions and cost of fuel, etc. were known. He had therefore got out the average cost per unit generated in the four turbine stations, and found that it was 5 to 6 per cent. higher than the average in the non-condensing steam-engine stations, both for coal and works costs. Great steam economy was claimed for turbines when tested individually, but the figures given in the "Electrical Times" Table of Costs did not substantiate that claim for turbine stations as a whole. Mr. Bailie added some particulars concerning Melton Mowbray and West Bromwich, to show that the costs in these stations had come down rapidly during the present year. This applied equally to steam-engine stations, but as the Paper only dealt with the complete year 1901 to 1902, a period of dear coal, these additional figures could not be discussed.

Mr. Bailie in his remarks concerning superheaters said that he could not quite see that they were a disadvantage. The author agreed that superheating was a great aid to economy, and only mentioned the fact that the economy of fuel was not so marked as the economy of steam. This was especially the case where separately-fired superheaters were used.

Mr. T. L. Miller added a valuable contribution to the discussion (page 551). His remarks went to prove that the system of supply had an important bearing on costs. He selected fourteen low-tension stations, and showed that the loss between the switch-board and the consumer was 13·4 per cent. and that in the high-tension stations it

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was as much as 32·7 per cent. The latter figures closely agreed with Mr. Wilkinson's estimate of the loss in high-tension alternating systems. Had Mr. Miller taken the whole of the stations in the country as a basis, his figures would have been more valuable, though perhaps less startling. In dealing with the coal costs of the lighting stations using low tension, he found that the coal costs in the condensing and non-condensing stations were practically identical, whereas the condensing stations ought to have shown a large saving. In the high-tension stations in London, he showed the condensing stations to come out better than the non-condensing, but to obtain this result, he omitted the Metropolitan Companies' Stations from the condensing list. They generated 11 million units out of a total of 41 millions, and their cost per unit was about 50 per cent. higher than the remaining stations which he took; whereas on the non-condensing side, he omitted Shoreditch, which only generated $2\frac{1}{4}$ million units, at about the same cost per unit. Had he included all stations, the non-condensing side would have certainly come out the best. In the Country Lighting Stations there were only seven working non-condensing, and using the high-tension system of supply. From these he selected six, the seventh (Wimbledon) having a destructor. The six selected stations were Aberystwyth, Chelmsford, Dublin, Exeter, Morley, and Watford. The total output of these stations was under $1\frac{1}{2}$ million units, out of a total of over 75 millions generated in the Country Lighting Stations. Dublin accounted for over 42 per cent. of the total units generated in the six stations, at a cost for coal of 1·85d. per unit, which was abnormally high for a large station. The cost of coal in the other five stations was also high. It would therefore appear that high-tension non-condensing stations were not economical. Mr. Miller somehow managed to divide the whole of the current generated, as coming from separate high- or low-tension stations, but about 20 per cent. of the whole came from stations using both systems of supply. It would be interesting to know how he ascertained the amount of current supplied through each system at these stations. On the whole, Mr. Miller's figures went to prove that the system of supply had a very important bearing on the cost per unit of electricity supplied to the consumer.

Mr. Mark Robinson mentioned (page 558) that Edinburgh and Kensington, both economical stations, had three-crank compound engines. The author ventured to assert that had these stations been fitted with three-crank engines, having only three cylinders, side by side (triple-expansion engines), they would have come out still better in economy. A 300-H.P. three-crank tandem compound engine was simply three engines of 100 H.P. each, and therefore had a larger proportion of loss due to clearance, initial condensation, and other losses inherent in small engines. The great economy in the stations mentioned by Mr. Robinson was no doubt largely due to good and careful management. The author would remind him that quite a number of firms made, or had made, three-crank tandem compounds.

Mr. E. G. Constantine wrote (page 564) giving some particulars concerning water-tube boilers, which he said might come as a surprise to the author, but, strange to say, he gave no figures to disprove the only thing the author inferred, namely, that the quality or dryness of the steam given off by the water-tube boiler was not so good as that given off by the cylindrical boiler. To an engine builder who guaranteed the amount of saturated steam his engine would use, the quality of the steam was of vital importance; 10 lbs. of "Scotch Mist" per lb. of fuel might in the long run be cheaper to the station engineer than 8 lbs. of honest steam, but under the circumstances already mentioned, the "Scotch Mist" penalised the engine builder, yet added to the apparent evaporation of the boiler, a point to be borne in mind by the station engineer when making engine and boiler tests. Mr. Constantine's remarks and figures were certainly interesting, but they did not bear on anything said by the author. When superheaters were added to water-tube boilers, the steam of course was dry, and good economy was obtained from its use. Mr. Constantine did not state how many of the water-tube boilers mentioned by him were fitted with superheaters. The cost of cleaning and scaling a water-tube boiler, as compared with a Lancashire, was an important item; repairs and upkeep had also to be considered; those came in the works costs, and were important items to the station engineer. As

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Mr. Constantine had shown, works costs were in some cases lower where water-tube boilers were in use, and no doubt many cases could be cited where high works-costs and water-tube boilers went together.

Lt.-Colonel Crompton considered (page 567) the "Scotch Mist" statement not only erroneous, but mischievous; then he proceeded to state that it might be easier to get drier steam from a new cylindrical than a new water-tube boiler, but a water-tube boiler fitted with a superheater he considered gave good dry steam. With this statement most people would agree. The author was dealing with the quality of the steam given off by the boiler, not by the superheater.

Mr. Charles Day wrote (page 569) that he considered the conclusions drawn from the figures given in the Tables quite contrary to facts. The author would remind him that the figures given were actual facts; conclusions drawn from them might be influenced by what Mr. Day termed variables, and they might be drawn on too wide an area for comparisons to be made between individual stations. This was the very reason that induced the author to include the whole of the stations throughout the country. A wide base demanded a proportionate structure; there was no getting away from the fact that the average cost per unit of electricity generated in the whole of the non-condensing stations was 16 per cent. less than that generated in the whole of the condensing stations throughout the country. His remarks on condensers and bad vacuum &c., had already been answered by the author in his reply to other contributors to the discussion. Mr. Day's remarks on works costs exclusive of coal were ingenious but specious. If he took the wide base, he must also take the whole structure, not select a portion of it.

In conclusion, the author desired to thank all those who had taken part in the discussion. Many points had turned up well worthy of consideration by those interested in the Economy of Fuel in Electric Generating Stations.

(Mr. Druitt Halpin's remarks.)

Fig. 1. *Thermal Storage of Feed Water for Varying Loads.*

(Mr. Druitt Halpin's remarks.)
Thermal Storage.

Fig. 2. Arrangement applied to a Water Tube Boiler.

Fig. 3. Arrangement applied to a Lancashire Boiler.