COST OF POWER PRODUCTION BY INTERNAL COMBUSTION ENGINES

BY

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BLACKIE AND SON, LIMITED
50 OLD BAILEY, LONDON; GLASGOW, BOMBAY
1924

Printed in Great Britain by
Blackie & Son, Limited, Glasgow

PREFATORY NOTE

The period covered in this volume includes that of the Great War, and accordingly many of the figures given are of special interest in showing the great increase in costs of all kinds as hostilities proceeded, and the subsequent slower decline towards pre-war levels as the world gradually settled down towards normal peaceful conditions.

A series of typical cases has been selected to illustrate the subject, and these, it is hoped, will be found of sufficient variety and suggestiveness to enable a general view of the details affecting power production cost by internal-combustion engines to be gained.

The author desires to thank the following firms for kindly furnishing him with information in connection with this little work: Messrs. Crossley Bros.; The Diesel Engine Users Association; James Pollock, Sons, & Co.; John I. Thornycroft & Co.; The Lilleshall Company; The National Gas Engine Company; and Messrs. Ruston & Hornsby, Ltd.

G. A. B.

September, 1924.

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Cost of Power Production by Internal-combustion Engines

1. HISTORICAL

From the commercial standpoint the era of the modern internal-combustion engine began in 1876 with the introduction by Messrs. Crossley Brothers of the world-famed Otto Silent Gas Engine. This was followed ten years later by the epoch-making small quick-revolution engine, or " petrol motor ", of Gottlieb Daimler, which has revolutionized our transport by land and water, and enabled mechanical flight to be successfully achieved. In 1878 an engine of 3 b.h.p. was regarded as large; in 1881 the " King of Gas Engines " developed only 20 b.h.p.; while even in 1898 the largest gas engine built gave scarcely 200 b.h.p.

The era of the " large " or " high-power " gas engine may be considered to have begun in 1895, when Mr. B. H. Thwaite showed the hitherto wasted blast-furnace gas to be an excellent fuel for the internal-combustion engine. Large, or high-power gas engines are here taken to be such as develop 400 b.h.p. and above; thus defined, the large gas-engine industry is only about thirty years old, yet engines of 5000 b.h.p. are now (1924) regularly at work.

2. PRINCIPAL TYPES

The principal types of internal-combustion engine are:

Class 1.—Large gas engines (400 b.h.p. and above) including:

(*a*) The Continental type of horizontal, slow-revolution, four-stroke or two-stroke, single-cylinder, or tandem, or twin-tandem, single-acting or double-acting engines of The Nuremberg Company (M.A.N.), Ehrhardt & Sehmer, Cockerill, Deutz, Oechelhauser, Körting, &c. The fuel used in these engines is usually producer gas, coke-oven gas, blast-furnace gas, and occasionally coal gas; and in the United States, " natural " gas (principally CH_4).

(*b*) Multi-cylindered, inverted-vertical, four-stroke, single-acting, tandem, medium quick-revolution engines as built by the National Gas Engine Company, Ltd., up to a maximum of 1500 b.h.p. The 1500-b.h.p. engine comprises twelve cylinders acting in pairs on a six-throw crank-shaft. These engines are arranged to work with either coal gas, coke-oven gas, water gas, producer gas, or blast-furnace gas.

(*c*) Diesel engines, usually of few-cylindered, inverted-vertical type, single-acting, working on the four-stroke or two-stroke cycle and using as fuel " heavy ", crude, residual, and tar oils. All the types in this class are now in regular use in central-station work, producing energy—most commonly in electrical form—for distribution and sale for use in lighting, power, heating, and general industrial purposes. Marine applications of Diesel engines are also now numerous and important

Class 2 —Stationary gas and " heavy oil " engines, including the normal " Otto ", Akroyd, Diesel, semi-Diesel types, &c., in horizontal or vertical, single- or twin-cylindered, single-acting, 4-stroke designs running at 200 to 400 revolutions per minute, developing anything from 1 to about 400 b.h.p., and using as fuels producer gases, coal gas, and petroleum oils ranging from kerosenes to residuals, and " crude " oils. Employed for general industrial purposes of all kinds, including important marine applications.

Class 3 —The small, light, quick-revolution, 4-stroke or 2-stroke, single-acting, usually multi-cylindered petrol motors, using as fuel petrol, benzol, paraffin (kerosene), alcohol, &c., alone or mixed. These engines are employed principally for purposes of transport by land, water and air

The substances now successfully used either directly or indirectly, as fuels for internal-combustion engines form a large, increasing, and very varied collection Included are bituminous and anthracite coals coke, slack, peat, lignite, scrap wood, bark, sawdust, straw, coco-nut husks and shells, sunflower and cotton seeds, rice and olive husks, and tea prunings These are all treated in special gas producers and the inflammable gases formed, suitably cooled and freed from dust and tar, are used in the engines As gaseous fuels, coal gas, coke-oven gas, blast-furnace gas, water gas, and natural gas are used, and, in a few instances, acetylene gas Of liquid fuels, suitably vaporized, there are the following:—Crude, intermediate and residual mineral oils; tar oils; crude tar; kerosenes (lamp oils, or paraffins); petrol; benzol; occasionally alcohol; and mixtures in very varying proportions of petrol, benzol, and kerosene, and sometimes also alcohol. Thus the " cost of fuel " is an extremely variable item, both on account of the great variety of substances employed, the mode of their production, and the location of the power plant relatively to that of the fuel used

Petrol, benzol, the mineral oils, and coal gas are expensive fuels; next in order come producer gases from anthracite, bituminous coal, coke, &c ; while in the cases of blast-furnace gas, coke-oven gas, natural gas, and producer gas from waste products of manufacture, the raw fuel costs nothing, the only expense involved being that of the installation and maintenance of the necessary producer and (or) gas-cleaning apparatus necessary to render the gas sufficiently cool and free from dust and tarry impurities

In 1913 it was usual in estimates to take the cost of petrol in Great Britain at about 16·5*d.* per gallon; in 1921 the figure taken was 37*d.* per gallon; in 1924 it had fallen to 18*d.* per gallon, in bulk. Benzol is obtainable only to a very limited extent, and its price exceeds that of petrol. Industrial alcohol is still a fuel of the future, but it is of interest to note that alcohol engines have been considerably used in Germany since 1898, and that even in 1904 alcohol in quantities of not less than 1500 gall. could be purchased in that country at 9*d*. per gallon. In the German alcohol engine trials of 1902, a Deutz engine of 16·5 h.p. consumed only 0·79 pt., costing 0·89*d*. per brake horse-power hour. The production of alcohol for power purposes on a commercial scale was begun in Great Britain in 1923; the motor fuel " Discol ", for example, is a mixture of 50 per cent denatured alcohol and 50 per cent of liquid hydrocarbons. During 1923 also, importers of liquid fuels into France were required to purchase from the French Government at least 10 per cent of power alcohol to ensure the disposal of the State supply produced from grain and beets, and to encourage the use of home-produced liquid fuel for power purposes. In the case of engines using kerosenes or paraffin, the following figures are of interest as showing the great increase in costs immediately after the war, and the subsequent decline with the return towards normal conditions:

KEROSENES

Trade Name	Price, in pence per gallon, landed Liverpool.			
	August, 1913.	August, 1914.	April, 1921.	March, 1924.
" American oil " ..	8·5	7·5	27·0	11·0
,, water white	9·5	8·25	28·0	12·0
Russian oil	8·75	7·0	No quotations	No quotations
Roumanian oil	8·0	6·75	Do	Do.
Galician oil..	8·25	6·75	Do.	Do.

Fuel oils as used by engines of the special heavy oil, semi-Diesel, and Diesel types, show similar great fluctuations in price:

FUEL OILS

Trade Name.	Price, in shillings per ton, landed Liverpool			
	August, 1913.	August, 1914.	April, 1921.	March, 1924.
Ordinary fuel oil ..	70	50	160	82·5
Admiralty fuel oil ..	—	55	—	—
Mexican fuel oil ..	—	45	—	—
" Diesel " oil	—	--	220	115

" Diesel oil" is a lighter fuel oil specially suitable for use in Diesel and similar oil engines. Crude oils are but little used; the New York quotations for Pennsylvania crude oil, in dollars per ton, were $16·75, $11·05, $21·77, and $4·50 on the above four dates.

Coal gas is largely used by low-powered gas engines employed in driving the machinery of small factories, laundries, cooling plants, &c. The following figures illustrate the variations in cost of coal gas supplied for such motive purposes in a London district:

Date:—	1912.	1914.	1916.	1918.	1920.	1921.	1924.
Price in pence per 1000 c. ft.:	31·5	30·5	37	48·25	64·25	66	33·7

The cost of coal gas as a fuel for power purposes is specially dependent upon the location of the power plant; for example, even in different parts of the London district at the same time, the price ranged from 21·5*d.* at Wandsworth to 44*d.* in north Middlesex, per 1000 cubic feet. Taking a larger area, it was sold for this service at Widnes, Sheffield, and Lancaster during the same period at the very low price of 12*d.* per 1000 cubic feet, and there were then also a further thirty towns in Great Britain wherein the price for power uses did not exceed 21*d.* per 1000 c. ft.

During the past fifteen years the British coal industry has suffered such violent upheavals that little of any value can be stated regarding prices. In 1913 the price in London of Welsh steam coal, as so largely used in the boilers of steam lorries, was from 27*s.* to 28·5*s.* per ton; in 1921, when obtainable, the price of the same fuel exceeded 60*s.* per ton; by 1924 it had fallen to 45*s.* per ton, f.o.r. London.

The above short reference to fuel costs brings out clearly the necessity for careful examination of this item in any projected undertaking, and indicates also the care that must be taken in order to enable a true comparison to be made of the relative economy of power plants, even when of similar type, located in different situations.

3. POWER CAPACITY OF LARGE GAS ENGINES

Writing in 1911, Haeder and Huskisson * point out that with steam engines a power output considerably above the normal is readily obtainable by using a later cut-off, whereas a gas engine has no such corresponding advantage; hence they recommend that in estimates the maximum output of a gas engine should be taken at 1·4 times the normal output of the steam engine it is intended to replace.

In 1913 Sir D. Clerk† stated that to keep heat troubles within practicable limits, it is found necessary in large-cylindered gas engines (30 in. diameter and over), to limit the heat-supply from 40 to 35 B.Th.U. per cubic foot of *working* stroke swept by the piston. This may also be expressed by saying that in such large gas engines the mean (indicated) effective pressure should not exceed from about 65 to 55 lb. per square inch. A simple relation exists between these two statements, for if h B.Th.U. of heat be evolved per cubic foot of swept working stroke, i.e. by 1 sq. ft. of piston area moving through 1 ft., and if ϵ denote the absolute thermal (indicated) efficiency of the engine, then $778 h\epsilon$ ft.-lb. of indicated work are obtained. But if p

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* *Handbook of the Gas Engine.*

† *The Gas, Petrol, and Oil Engine.* Clerk and Burls, Vol. II (Longmans).

TABLE I.—SOME APPROXIMATE DATA RELATING TO TYPICAL LARGE 4-STROKE CYCLE GAS ENGINES

Item No.	Date.	Makers of Engine.	Type of Engine.	Cylinder Diameter in Inches, d.	Stroke in Inches, s.	Revs. per Minute, n.	Horse-power (Maximum Normal)		Mean Effective Pressure, lb. per sq. in.		Assumed Abs. Indic. Th. Eff. ϵ.	B. Th. U. per c. ft. of Swept Stroke h.	B.H.P. Rating for 52 lb. per sq. in. as p.
							Brake.	Indic.	Brake, ηp.	Indic. p.			
1	1898	Cockerill Co.	1-cylinder single-acting horizontal	31·5	39·5	105	173	213	43	53	0·3	33	170
2	1899	Cockerill Co.	1-cylinder single-acting horizontal	51·2	55·1	90	600	800	46·8	62	0·28	41	500
3	1899	Deutz Co.	4-cylinder single-acting horizontal	33	39·3	135	1200	1500	52·3	65	0·3	40	960
4	1903	Deutz Co.	1-cylinder double-acting horizontal	21·25	27·5	150	223	279	60	75	0·3	46	155
5	1903	Nuremberg.	2-cylinder double-acting tandem horizontal	33·46	43·3	106	1186	1427	62·7	75	0·343	41	825
6	1903	Richardson-Westgarth	2-cylinder double-acting tandem horizontal	23·5	35·5	130	500	625	49·6	62	0·3	38	420
7	1904	Richardson-Westgarth	2-cylinder double-acting tandem horizontal	29·5	35·3	120	800	1000	55	69	0·3	43	600
8	1906	Ehrhardt & Sehmer	2-cylinder double-acting tandem horizontal	24·5	29·5	150	520	645	50	64	0·3	40	425
9	1908	Snow Co., U.S.A.	4-cylinder double-acting twin-tandem horizontal	42	60	90	5400	6350	71·3	84	0·3	52	3340
10	1909	Tod Co., U.S.A.	4-cylinder double-acting twin-tandem horizontal	42	60	75	3000	3400	48	54	0·3	33	2900
11	1909	Westinghouse Co.	2-cylinder double-acting tandem horizontal	23·5	33	150	500	620	47	58	0·3	36	450
12	1910	Thyssen & Co.	2-cylinder double-acting tandem horizontal	48	55·5	94	2600	3100	55	65	0·3	40	2080
13	1919	Galloways, Ltd.	2-cylinder double-acting tandem horizontal	45·3	51·2	94	2000	2500	51	64·5	0·3	40	1615
14	1920	Natl. Gas Engine Co.	8-cylinder 4-crank vertical single-acting tandem	17·22 mean	18	300	600	700	47·5	55	0·3	34	570
15	1920	Natl. Gas Engine Co.	12-cylinder 6-crank vertical single-acting tandem	22·1 mean	24	200	1500	1750	54	63	0·3	39	1240
16	1923	Premier Co.	4-cylinder 1-crank double-acting vertical	24·75	30	125	1000	1200	55	66	0·3	41	790

TABLE IA

SOME APPROXIMATE DATA RELATING TO TYPICAL LARGE 2-STROKE CYCLE GAS ENGINES

Item No.	Date.	Name.	Type of Engine.	Cylinder Diameter in Inches d.	Stroke in Inches, s.	Revs. per Minute, n.	Normal Maximum Horse-power.		Mean Effective Pressure, lb. per sq. in		Assumed Abs Indic. Th. Eff. ϵ	B. Th. U. per c. ft. of Swept Stroke, h.	B.H.P. Rating for $p = 52$ lb. per sq. in.
							Brake.	Indic.	Brake, ηp.	Indic., p.			
1	1899	Oechelhauser	2-cylinder 4-piston single-acting horizontal	18·87	31·5	135	600	(800)	50·2	67	0·39	32	465
2	1903	Borsig-Oechelhauser	1-cylinder 2-piston single-acting horizontal	26·6	37·4 mean	107	627	839	55	73·8	0·39	35	440
3	1909	Beardmore-Oechelhauser	1-cylinder 2-piston single-acting horizontal	24	30	130	400	(530)	45	60	0·39	28·5	350
4	1909	Beardmore-Oechelhauser	1-cylinder 2-piston single-acting horizontal	42	51	94	1500	(2000)	45	60	0·39	28·5	1300
5	1899	Siegener-Körting	1-cylinder double-acting horizontal	43·3	55·2	85	1600	2000	46	57·5	—	—	1450
6	1902	Körting Brothers	1-cylinder double-acting horizontal	25	43·3	100	500	(625)	47	58	—	—	450
7	1902	Körting Brothers	1-cylinder double-acting horizontal	37·38	63	70	1000	(1250)	41	52	—	—	1000
8	1904	Körting Brothers	1-cylinder double-acting horizontal	29·7	55·1	80	682	857	44·3	56	—	—	635
9	1909	Klein-Körting	1-cylinder double-acting horizontal	35·5	55·13	70	1050	(1300)	55	69	—	—	800
10	1918	Fullagar	6-cylinder 12-piston single-acting	18·0	27·0	171·4	1860	2000 app	52	56	0·307	34	1725

denote the mean effective pressure on the piston, in pounds per square inch, this amount of work is also expressed by $144\,p$ ft.-lb.; thus $144\,p = 778\,h\epsilon$; or:

$$p = 5{\cdot}4\,h\epsilon \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (1)$$

Taking ϵ as 0·3 average value, we have therefore 40 to 35 B.Th.U. per cubic foot, corresponding to 65 to 57 lb. per square inch mean effective pressure. Messrs. Crooke and Lyon-Ewan[*] (1920) express their views on this point very clearly. They state that so long as the load factor (see p. 15) does not exceed 30 per cent, a value of p of 68 is a practicable figure to take in power-rating, but that if anything approaching continuous full-load running is required, the mean effective pressure should not exceed 52 lb. per square inch in large gas engines. In Tables I and IA are given some data relating to the principal existing types of 4-stroke and 2-stroke large gas engines; values of the mean effective pressure, p, corresponding to the rated maximum brake horse-power are given, together with the B.Th.U. of heat, h, supplied per swept cubic foot of working stroke for an assumed average value of 0·3 for the absolute indicated thermal efficiency ϵ.

It will be observed that in many cases the values of p and h are high, and failures of pistons and cylinders through overheating have been in the past not unusual. The practicable limits of heat-supply in relation to output are now, however, well ascertained, and numerous cases of completely successful long-continued working can be cited.

As an example may be mentioned the case of a 2000-b.h.p. Nuremberg "blowing" engine, using blast-furnace gas, which ran day and night for a period of nineteen months; in 13,870 consecutive hours the engine actually ran for 13,687 hours, i.e. 98·6 per cent of the whole time. The stoppages were due to repairs needed by the blast furnace, and not to any defect of the engine, though advantage was taken of them to inspect and adjust valves and ignition details as necessary; at the end of this period the engine being still in very good order it was continued at work. In Table II some running data are collected relating to a number of large gas engines, about ten years old, employed in blowing, or coupled to direct-current generators:

TABLE II

(CROOKE AND LYON-EWAN)

Days elapsed since Previous Overhaul.	Days Actually Run.	Days lost for Valve Cleaning, &c.	Days lost in Changing Plugs.	Rated full B.H.P.	Revolutions per Minute.	Average Load in B.H.P.
286	275	11	0	825	125	770
411	400	10	1	630	83 to 95	600
449	428	20	1	630	83 to 95	600
530	508	18	4	630	83 to 95	600
353	330	19	4	630	83 to 95	600

[*] *Development of High-power Gas Engines* (The Lilleshall Co., Ltd.).

TABLE III

Some Overall Thermal Efficiencies of Large Gas Engines: From Trial Results

Item No.	Date.	Makers of Engine.	Fuel Employed.	Duration of Test Hours.	Horse-power.		Mechanical Efficiency, $\eta = \frac{\text{b h.p.}}{\text{i.h p.}}$	Overall Thermal Efficiency		Remarks.
					Indic.	Brake.		Indic ϵ.	Brake, $\eta\epsilon$.	
1	1900	Cockerill Co.	Blast-furnace gas	—	886	725	0·818	0·252	0·206	
2	1900	Premier Co.	Mond gas	5	489	368	0·753	0·340	0·256	Thermal efficiencies on gas as supplied to engine.
3	1903	Oechelhauser (Borsig)	Coke-oven gas	—	839	627	0·75	0·39	0·29	Thermal efficiencies on gas as supplied to engine.
4	1904	Otto-Deutz	Anthracite producer gas	10	278	223	0·8	0·302	0·242	Overall thermal efficiencies are of (producer + engine).
5	1904	Körting	Anthracite producer gas	1·5	857	680	0·79	0·23	0·18	Overall thermal efficiencies are of (producer + engine)
6	1904	Nuremberg Co.	Blast-furnace gas	0·57	1427	1186	0·831	0·343	0·285	
7	1906	Ehrhardt & Sehmer.	Coke-oven gas	—	—	600 Rated	0·83	0·375	0·31	Thermal efficiencies on gas as supplied to engine.
8	1908	Nuremberg Co.	Coke-oven gas	—	—	2200 Rated	0·897	0·374	0·336	Thermal efficiencies on gas as supplied to engine.
9	1908	Nuremberg Co.	Producer gas from lignite briquettes	—	—	1200 Rated	0·85	0·254	0·216	Overall thermal efficiencies are of (producer + engine).
10	1910	National Gas Engine Co.	Coal gas	1	335	276	0·824	0·360	0·297	
11	1919	Vickers (Barrow)	Blast-furnace gas	—	2160	1800	c·83	0·327	0·271	Tandem double-acting 4-stroke horizontal

TABLE IV

From Tests at Rombach, September, 1904, on a Tandem, Horizontal, "D.T.11" Gas Engine.

Output:				Consumption in B.Th.U. per hour.				Mechanical Efficiency of Engine, $\eta = \frac{\text{b.h.p.}}{\text{i.h.p.}}$	Electrical Efficiency, $\beta = \frac{\text{Elec. h.p.}}{\text{b.h.p.}}$	Overall Thermal Efficiencies:		
I.H.P.	B.H.P.	Electrical H.P.	Kilo-watts.	Per I.H.P.	Per B.H.P.	Per Electrical H.P.	Per * Kilowatt			Indicated ϵ.	Brake $\eta\epsilon$.	Electrical $\beta\eta\epsilon$
807	557	478	357	8420	12,200	14,200	19,000	0·690	0·858	0·302	0·208	0·178
1146	871	781	583	8200	10,800	12,000	16,100	0·760	0·897	0·310	0·236	0·211
1312	1037	935	698	7800	9,900	10,950	14,650	0·790	0·902	0·326	0·257	0·232
1359	1115	1012	755	7920	9,650	10,650	14,250	0·820	0·908	0·321	0·263	0·238
1388	1147	1040	776	7600	9,200	10,150	13,600	0·826	0·907	0·335	0·277	0·251
1427	1186	1076	803	7450	9,000	9,880	13,200	0·831	0·907	0·342	0·283	0·257

* The reader is reminded that 1 horse-power-hour = $33{,}000 \times 60 = 1{\cdot}98 \times 10^6$ ft.-lb. per hour $= \frac{1{\cdot}98 \times 10^6}{778} = 2545$ B.Th.U. of heat per hour. And that 1 kilowatt = 1000 watts = 1000 volt-ampere-seconds = 1·34 h.p. Thus 1 kilowatt-hour = $1{\cdot}34 \times 2545 = 3410$ B.Th.U. of heat per hour. Also $\epsilon = 2545$/heat supplied per i.h.p. hour; $\eta\epsilon = 2545$/heat supplied per b.h.p. hour; and $\beta\eta\epsilon = 3410$/heat supplied per kilowatt-hour.

As early as 1906 Messrs. Beardmore adopted a value of 55 lb. per square inch for p for rating the power of their Oechelhauser engines. From 1903 to 1913 between 400 and 500 Nuremberg engines were built, rated on a mean effective pressure of 72 lb. per square inch; in 1912, however, the Nuremberg Company reduced their rating to a basis of p = 64 lb. per square inch; these figures may be taken as representing current practice in 1924. From this it results that large gas engines are somewhat bulky and costly relatively to their power output, and hence it is found that the capital outlay involved in a gas-engine plant in general exceeds that of the corresponding steam plant; the strong point of the case for the gas engine lies in its greatly superior thermal efficiency, and, as is shown later, when total operating costs are considered it can frequently be shown that the gas engine has the advantage.

Under short-period trial conditions very high indicated and brake thermal efficiencies are obtainable with gas engines; as, e g the value ϵ = 0·415 obtained by Professor Burstall from trials of a Premier engine undertaken for the Gas Engine Research Committee of the Institute of Mechanical Engineers; in Table III some figures deduced from trial results are given for reference The average over-all values estimated on the heat value of the gas as supplied to the engine are ϵ = 0 36, and $\eta\epsilon$ — the brake thermal efficiency = 0·29 When the efficiency of the gas producer is involved the averages reduce here to ϵ = 0·26 and $\epsilon\eta$ = 0·21; the thermal efficiency of present-day gas producers may be taken as ranging from about 0·80 to 0·85.

Table IV (p 9) exhibits an interesting, consistent, and complete set of figures deduced from tests made in September, 1904, upon one of the horizontal tandem "D.T.11" gas engines at the great power installation of Rombach The piston speed was 800 ft per minute; the mean effective pressure, p, was 65 lb. per square inch; and the fuel used was blast-furnace gas having an average calorific value of 90 B Th U per cubic foot It will be observed that all the efficiency figures steadily increase with increase of load.

The best results, in respect of efficiency, attained by steam plants are, according to Messrs Crooke and Lyon-Ewan, those at the large turbine stations at Detroit (Michigan) and Chicago; they are collected in Table V.

TABLE V

Steam Turbine at	Capacity.		Efficiencies Attained.		
	In Kilowatts.	In B.H.P. (approx.).	Mechanical.	Boiler.	Overall Thermal.
Detroit	25,000	37,000	—	—	0·175
Chicago	25,000	37,000	0·9	0·82	0·20
Curtis Turbine (Rateau)	4,000	6,000	0·9	0·82	0·19

The value 0·175 was obtained at Detroit over a period of working of one year. The figures for Chicago are from *Power* of 6th February, 1917. And those for the Curtis turbine are from Acland's paper in the *Journal of the Society of Arts*, 6th June, 1919.

The overall thermal efficiency tabulated is the ratio of the heat equivalent of the electrical energy generated to that of the coal supplied to the boilers.

In his 1919 paper before the Society of Arts on " The Distribution of Heat . . . ," Sir Dugald Clerk stated that the largest and best steam turbines have a brake thermal efficiency of about 0·185, referred to the coal burnt under the boiler, while the gas engine using producer gas made from coke or anthracite would give 0·25, this figure including the efficiency of the producer, which may be taken as from 0·8 to 0·85.

Under the ordinary existing conditions of everyday working, usually with a low load factor (see p. 15) and large fluctuations in output rate, the overall efficiencies realized are necessarily much lower than those—obtained mostly under trial conditions—as given above. From running data of 118 municipal generating stations (all steam plants), relating to the year ending March, 1918,* Messrs. Crooke and Lyon-Ewan † have deduced approximate values of fuel consumption per kilowatt-hour and overall thermal efficiency on the assumptions that the average cost of the coal in 1918 was 30*s*. per ton, and its average calorific value 12,000 B.Th.U. per pound. Their figures are given in Table VI hereunder:

TABLE VI

ESTIMATED AVERAGE EFFICIENCY OF 118 STEAM PLANTS FOR YEAR 1917-8
(Crooke and Lyon-Ewan)

Capacity of Plant in Kilowatts.	Number of Power Stations included.	Load Factor.‡	Estimated Average Coal Consumption. Lb. per Kw.-hour.	Estimated Overall Thermal Efficiency.
Up to 1,000	16	0·190	6·45	0·044
1,000- 5,000	46	0·176	4·90	0·058
5,000-15,000	41	0·260	3·35	0·085
15,000-30,000	10	0·285	2·87	0·099
30,000-70,000	4	0·320	2·40	0·118
Above 70,000	1	0·340	2·30	0·123

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* *v. Electrical Times* for 3rd April, 1919 (Supplement).

† *Development of High-power Gas Engines* (The Lilleshall Co., Ltd.).

‡ The load factor is here the ratio of the number of units sold to the maximum simultaneous load on feeders in kilowatts × the number of hours of supply. The overall thermal efficiency is, of course, the value of the ratio $\frac{3410}{12{,}000 \times \text{pounds of coal per kilowatt-hour}}$. Even the best efficiency figure (0·123) obtained under ordinary conditions of working in this country, as deduced in Table VI, is thus seen to fall far short of the average (0·188) of the figures given in Table V; and the extremely low overall efficiency of small power stations, especially in combination with low load factors, is strikingly manifested.

Messrs. Andrews and Porter,* as early as 1908, stated that for 20 steam power stations generating about 326×10^6 units per annum with a mean load factor of 0·26, the average overall thermal efficiency was 0·067; and that for 8 gas-engine power stations generating about 30×10^6 units per annum with a mean load factor of 0·445, the average overall thermal efficiency was 0·1395, or rather more than twice as much.

Again, for the year ending 31st March, 1918, Mr. D. Wilson (adviser to the Coal Controller) estimated the total number of electrical units generated by the 421 steam stations in Great Britain at 4674×10^6 units, with an average coal consumption all round of 3·47 lb. per unit, and an average calorific value of 11,600 B.Th.U. per pound of coal. This implies an average overall thermal efficiency of $\frac{3410}{3{\cdot}47 \times 11{,}600} = 0{\cdot}085$, or $8\frac{1}{2}$ per cent. Working under similar existing everyday circumstances, the average overall thermal efficiency of gas-engine power plants may be taken safely at from 0·13 to 0·15, the lower figure including the efficiency of gas producer. Where exhaust-heated boilers are installed, the overall thermal efficiency is further increased, and when recovery producers are used, valuable by-products are also obtained in the gas-making process.

It appears clear, therefore, that the gas-engined power station, under ordinary everyday conditions of working, may be considered as possessing an overall thermal efficiency from $1\frac{1}{2}$ times to fully $1\frac{3}{4}$ times as great as that of the corresponding steam plant, with additional advantages in much-reduced stand-by losses, and production of valuable by-products in certain cases.

The extended use of high-powered gas engines for medium large central-station installations would thus enable a great saving of coal to be effected in this country; and coal economy has become a consideration of the very deepest importance under the changed economic conditions following the Great War of 1914–8.

4. POWER PLANTS CLASSIFIED

Plants for power production by internal-combustion engines are conveniently divided into three groups:—

Group I.—Large central stations producing energy for distribution, usually in electrical form, which is sold for purposes of lighting, power, heating, and miscellaneous industrial uses; of such there are at present but few in Great Britain.

Group II.—Plants for the production of power for driving the machinery of factories and mills; these are very numerous, and range in capacity from a few horse-power up to several thousands of horse-power; the majority of the cases included range, however, from about 50 to 500 b.h.p. only.

Group III.—Power employed in the transport of persons or goods by land, water, and air; in the aggregate an exceedingly large amount of power

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* *Proc. Inst. E. E.*, 1908.

is thus developed, and costs are commonly estimated upon a ton-mileage or passenger-mileage basis.

Complete details of installation and running costs are not usually obtainable, owners in general regarding such details as confidential. Sufficient data are, however, accessible to enable a good general idea to be formed of initial and running costs in typical cases.

Group I.—Large Central Stations

In large central-station plants the initial capital outlay is dependent upon: (*a*) The location and nature of the site. Proximity to great towns or thickly populated areas brings the station near to its customers, and thus avoids the outlay necessary to transmit the energy produced over perhaps considerable distances; but land in such situations is usually expensive, and this may render necessary a careful consideration of the type of engine to be adopted. The large slow-running, tandem, double-acting, horizontal engine requires, for example in a 4500-b.h.p. plant, about twice the area for its accommodation necessary for a plant of the smaller quicker-running, single-acting, tandem, vertical type developing the same power.

The nature of the site is another matter needing attention, as foundations for gas engines have to be very massive, and the cost of foundations varies considerably in different situations; thus in one case of an 80-b.h.p. (Group II) engine the foundation cost amounted to £0·7 per brake horse-power, while in another case of equal power on a marshy site the item rose to no less than £4·4 per brake horse-power. Proximity to a cheap and abundant supply of water is another desideratum.

The position of the power station in relation to that of the source of the fuel used is a matter of much importance. So far as the immediate production of energy is concerned, the ideal situation is near blast furnaces or coke-oven retorts where the gaseous fuel is a purely waste product produced in great abundance and requiring no more capital outlay than is involved in providing the piping, cleaning, and cooling apparatus necessary to enable it to be delivered to the engines in a sufficiently cooled, tarless, and dustless condition. Or in the immediate neighbourhood of coal mines, large timber mills, oil mills, &c., where inferior coals, waste wood, saw-dust, &c., can be utilized by means of producers to provide the necessary gaseous fuel. The cost of fuel transport is thus avoided; but with these solid fuels the capital outlay is increased by the necessity of a larger site area and buildings, and the provision of the requisite gas producers. On the other hand, where recovery producers are employed, the valuable by-products obtained enable a satisfactory item to appear upon the credit side of the costs account.

Even when the type and power of the engines required have been decided upon it is frequently found to be impossible accurately to forecast their cost; engine builders can only, in general, submit definite tenders when placed in possession of all the circumstances of a projected installation, and tenders are usually found to exhibit a considerable variation. In a recent case quotations were found to range from a minimum represented by 1 to a maximum represented by 1·6, and careful consideration must be given to the question of the tender best meeting the requirements.

(*b*) Initial capital outlay is also influenced greatly by the probable degree of uniformity in the public demand for the energy produced. Except in rare instances, experience shows that very large fluctuations usually occur in the amount of power taken, and the extent of this is usually difficult to estimate correctly beforehand, and also necessitates the laying down of a much larger power plant than would suffice to provide the average output. In this respect gas engines, being, as has already been shown, not suitable for long-continued working at even quite moderate overloads, are at some disadvantage as compared with steam, though this is usually more than compensated for by the marked superiority in fuel economy which they possess.

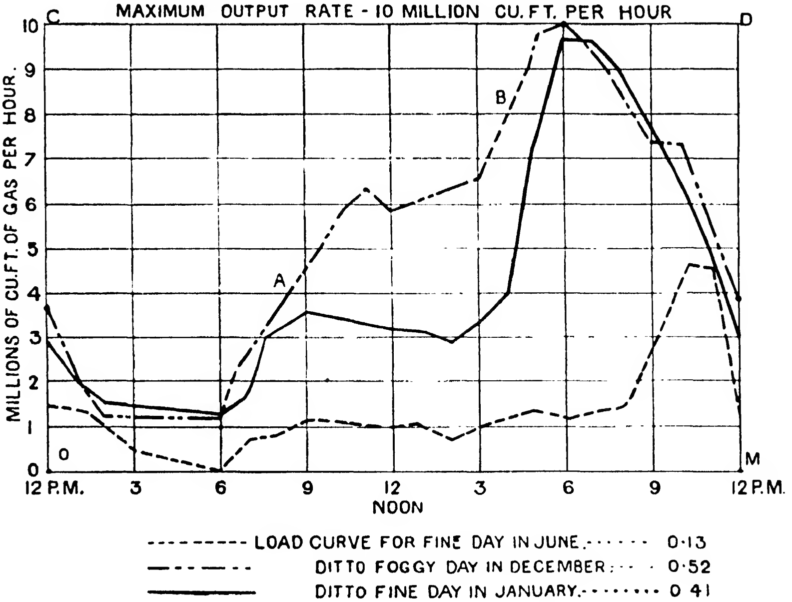

Fig. 1.—Illustration of Diurnal and Seasonal Load Variations

Central-station undertakings accordingly endeavour by every means in their power to create and foster the demand for their energy during their slack periods by granting specially favourable terms and rates at such times.

Fluctuations of demand are both diurnal and seasonal; for example, when the energy supplied is used mainly for lighting purposes it is obvious that the demand is, in most towns, very small during the day, at a maximum during the early hours of evening, and almost vanishes during the very early hours of morning. And, again, that much more energy will be taken during a foggy day in winter than a fine day in summer.

This is well shown in fig. 1, which is taken from the records of one of the large London gas companies' stations for a fine day in June, a foggy day in December, and a fine day in January.

The "load factor" is the name given to the ratio of the average load during any period of time to the maximum load during the same period; this is also, in fig. 1, the ratio of the area OABMO to the enclosing rectangle OCDMO. Values in the three cases illustrated are given below the figure. The difficulty of a low load factor, from the financial view-point, is one of the greatest with which the promoters of central-station enterprises have to deal.

The power stations at Heinitz and Luisenthal, in the Saar district of the German State Collieries, are of special interest as they furnish a case of a gas-engine plant and steam-turbine plant in combination. Initially there were seven Ehrhardt-Sehmer 1000-kw. gas engines at Heinitz using coke-oven gas, and three 3000-kw. steam turbines at Luisenthal using coal; later, the installations were enlarged to 10,800 kw. (9 engines) at Heinitz, and 12,200 at Luisenthal; the gas engines and turbines work in parallel and serve a network of conductors of upwards of 50 miles in extent. Thus the Heinitz station had at first a maximum output of 7000 kw. or (approximately) 10,500 b.h.p., and the Luisenthal of 9000 kw. or (approximately) 13,500 b.h.p. The original installation costs given hereunder were published in *Gluckauf*, Nos. 35 and 36, of 1910:

INITIAL CAPITAL OUTLAY

Heinitz.		Luisenthal.	
Item.	Cost in £.	Item.	Cost in £.
7 gas engines and piping	81,279	3 steam turbines and cooling water supply	51,085
Cooling water, auxiliary plant, crane, &c. ..	6,556	Boilers, economizers, and feed pumps	37,239
Buildings, complete ..	15,069	Auxiliary plant	2,697
Switch gear	4,655	Engine house	8,800
		Boiler house, foundations, and chimney	12,862
		Office buildings and stores	1,368
		Coal-handling plant ..	3,923
		Switch gear	5,246
Total cost	107,559	Total cost	123,220

The original installation costs per power unit were therefore:

Plant.	Per Kilowatt.	Per B.H.P.
Gas engines at Heinitz	£15·366	£10·243.
Steam turbines at Luisenthal	£13·691	£9·127.

The following figures relate to performance and costs after the enlargement of the two plants:

HEINITZ AND LUISENTHAL AFTER ENLARGEMENT, 1910

(1) CAPITAL OUTLAY

Item.	At Heinitz. (Gas.)	At Luisenthal. (Steam.)
Total cost of installation in £	159,510	136,307
Normal maximum output in kilowatts	10,800	12,200
Approximate normal maximum b.h.p.	16,000	18,000
Cost in £ per kilowatt installed	14·77	11·17
Cost in £ per b.h.p. installed	9·97	7·57

Thus the total cost per kilowatt as finally installed was here about 32 per cent greater for the gas-engine plant than for the steam-turbine plant.

(2) ATTENDANTS REQUIRED PER SHIFT

Class.	At Heinitz.	At Luisenthal.
Engineers	7	3
Stokers	—	3
Cleaners	2	—
Totals	9	6

So that 50 per cent more attendants were employed per shift on the gas engines than on the steam turbines and boilers.

(3) ANNUAL PERFORMANCE

Item.	At Heinitz.	At Luisenthal.
Hours worked per annum	31,874	11,307
Total output in kilowatt-hours	25,143,300	19,963,500
Load factor	0·265	0·187
Gas consumed (millions of cubic feet)	754	—
Coal consumed in tons	—	20,676
Heat value of coal, B.Th.U. per lb. (average) ..	—	11,465
Cubic feet of gas used per kilowatt-hour	30	—
Cubic feet of gas used per b.h.p.-hour	20·1	—
Pounds of coal used per kilowatt-hour	—	2·32
Pounds of coal used per b.h.p.-hour	—	1·56
Oil used per 1000 kw.-hr. in lb.	4·86	0·68
B.Th.U of heat used per kilowatt-hour	15,000	26,600
B.Th.U. of heat used per b.h.p.-hour	10,000	17,900
Overall thermal efficiency	0·227	0·128
Brake thermal efficiency	0·253	0·142

The above figures imply for the coke-oven gas at Heinitz the unusually high heat value of 500 B.Th.U. per pound. The overall thermal efficiencies are in the ratio of 177 to 100, i.e. the gas-engine plant showed a 77 per cent greater thermal efficiency than the steam-turbine plant.

(4) ANNUAL RUNNING COSTS

Item.	At Heinitz. £	At Luisenthal. £
Depreciation and repairs to gas engines at 15 per cent ..	16,126	—
Depreciation and repairs to steam turbines at 13 per cent	—	15,980
Salaries and wages	3,812	3,084
Coal at 11·6*s*. per ton	—	11,982
Gas at 2*d*. per 1000 c. ft.	6,280	—
Oils	1,076	127
Cleaning materials and general stores	138	82
Total	27,432	31,255
Total annual running costs per kilowatt-hour, in pence	0·262	0·376

Hence, estimated in the manner shown, the total running costs show in this case a considerable saving in favour of the gas-engine plant, though it must be noted that the gas plant enjoyed the advantage of a considerably higher load factor than the steam plant. It may also be remarked that the coke-oven gas is charged for at the rate of 2*d*. per 500,000 B.Th.U. supplied; if the gas engines had been worked with gas supplied by producers using the coal as used by the steam plant, each ton would probably have yielded roundly 150,000 c ft. of gas of a calorific value of say 140 B.Th.U. per cubic foot, or a total of 21,000,000 B.Th.U. per ton. At 11·6*s*. per ton, this corresponds to 3·31*d*. per 500,000 B.Th.U. supplied; thus the gas-engine fuel was charged for at only about three-fifths of the price of that for the steam plant; the coke-oven gas is, however, a purely waste product of manufacture, and not infrequently no charge is debited against the plant using it.

The Kamata Gas-power Station.—For the electrical energy required to operate the railway between Tokio and Yokohama a power station equipped with large gas engines operated by Mond producer gas, with recovery, was erected about 1912. The installation includes four large horizontal, tandem, double-acting, single-crank engines of Nuremberg type, each direct-coupled to a 1500-kw. alternator, built and installed by the Lilleshall Co., Ltd., of Oakengates, Shropshire The cylinders are 47¼ in. in diameter and the stroke is 51⅛ in. The engines were designed for a revolution speed of 100 per minute, the corresponding output being 2500 b.h.p.; it was decided to run them at Kamata, however, at only 94 revolutions per minute, with an output of 1500 kw. each, the corresponding brake horse-power being then about 2200. As may be realized from the following data, the engines are very massive:—The crank-pin is 23⅝ in. in diameter; the crank shaft at the fly-wheel seating is no less than 32¼ in. in diameter; and the fly-wheel, with the alternator pole-pieces mounted on its rim, has an overall diameter of about 22 ft. and width of 39·4 in. Each cylinder weighs 25 tons; fly-wheel, about 100 tons; and complete engine, about 400 tons, including the fly-wheel; this is about 410 lb. per brake horse-power as used. The great rotational energy of the huge fly-wheel reduces the coefficient of fluctuation of speed at full load to less than $\frac{1}{250}$.

The engine house (engines only) is 166 ft. long by 90 ft wide and about 40 ft. high, and is fitted with an electrically-driven 40-ton overhead travelling crane capable of traversing it from end to end.

About one-fourth of the steam required by the Mond producers is provided by boilers using the exhaust gases from the engines as their source of heat; and by the sale of the ammonium sulphate recovered, the whole cost of the fuel required to operate the station is estimated to be nearly met

The following estimate of cost furnished by the Lilleshall Company is based upon a 4500-kw. output from three of the four 1500-kw. engines, the fourth being regarded as a spare. The total cost of the plant is given as £115,000. Three engines are assumed as running continuously, day and night, at a load factor of 0·6; hence the assumed annual output is:

$$3 \times 1500 \times 365 \times 24 \times 0{\cdot}6 = 23{,}652{,}000 \text{ kw.-hr.}$$

The yield of gas per ton of Japanese coal gasified is taken, roundly, at 111,000 c. ft., and the consumption per kilowatt-hour as 156 c ft., or about 106 c. ft. per brake horse-power hour: this implies an efficiency of electrical generation of about 0·91 The quantity of fuel gasified per annum is taken at 33,200 tons, and for each ton of this fuel 1·75 tons of steam are needed; hence about 58,000 tons of steam are required per annum The exhaust-heated boilers supply 14,000 tons, leaving 44,000 tons to be obtained by the direct burning of fuel.

Per ton of coal gasified, it is assumed that 70 lb. of ammonium sulphate are obtained, or a total of 1037 tons per annum To obtain this, 1037 tons of sulphuric acid are required, and the cost of this is taken at £3 per ton, which was twice the English price; this was done to allow for freight charges, &c., to Japan

Hence the profit from the ammonium sulphate recovery appears as:

1037 tons sulphate sold at £15 per ton, £15,555; less 1037 tons sulphuric acid at £3 per ton, and bags, and packing sulphate, at 6*s.* 8*d.* per ton, £3457; or an annual net profit of £12,098.

ESTIMATED ANNUAL RUNNING COSTS AT KAMATA

(The Lilleshall Co., Ltd., 1912)

Item.	£
Interest and depreciation on whole plant at 10 per cent per annum	11,500
Gas-Making Plant:	
33,200 tons of coal gasified at 8s per ton	13,280
7333 tons coal at 8s., to provide balance of 44,000 tons of steam required for producers	2,933
Wages on gas-making plant at 1s. 6d. per ton of coal gasified, as in English practice	2,490
Labour on boilers at 9d. per ton of coal burned	275
Repairs, maintenance, and general stores of gas-making plant at 9d. per ton of coal gasified	1,245
Engines:	
Repairs and maintenance of engines	1,000
Labour on engines	1,480
Oil for engines	500
General stores for engines	150
Total per annum	34,853
Less £12,098 from sale of ammonium sulphate ..	12,098
Net annual cost of working	22,755

It will be noted that owing to receipts from the sale of the ammonia sulphate made, the annual cost of the coal gasified is reduced from £13,280 to £1182. The costs in pence per kilowatt-hour for an annual output of 23,652,000 kw -hr. are given below:

ESTIMATED RUNNING COSTS AT KAMATA, IN PENCE PER KILOWATT-HOUR

Item	Pence per Kw.-hour.
Interest and depreciation on whole plant at 10 per cent per annum	0·11670
40,533 tons coal at a net cost of £4115*	0·04176
Wages on gas-making plant (including boilers)	0·02806
Repairs, maintenance, and stores of gas-making plant	0·01263
Repairs and maintenance of engines	0·01014
Labour on engines	0·01502
Oil for engines	0·00507
General stores for engines	0·00152
Total running costs, pence per kilowatt-hour	0·23090

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* I.e. after deducting £12,098 obtained from sale of ammonia sulphate.

As a kilowatt-hour here corresponds to $\frac{1{\cdot}34}{0{\cdot}91}$ brake horse-power it follows that the running cost per brake horse-power hour is 0·157*d.*, estimated as above.

Tests carried out on this plant in 1914 furnished the following results:

KAMATA POWER STATION: RESULTS FROM TESTS MADE IN 1914

Load in Kilowatts.	Duration of Test in Hours.	Average Piston Speed Ft. per Min.	Calorific Value of Coal in B.Th.U. per Lb.	Consumption.		Thermal Efficiencies.	
				Lb. coal per Kw.-hour.	B.Th.U. per Kw.-hour.	From Engine to Alternator.	Overall; from Producer to Alternator.
4798	12	800	11,221	1·8	12,444	0·274	0·166
3367	12	810	10,893	1·9	13,162	0·259	0·158
2310	12	820	10,765	2·3	14,795	0·230	0·134
1119	12	820	10,929	4·0	18,518	0·184	0·078

Thyssen Engines.—The following cost details relating to an installation of seven large Nuremberg-type engines by Messrs Thyssen & Co., of Mulheim, are of interest:

The fuel employed was blast-furnace gas, and the installation comprised:

Four engines each of 1400-kw. capacity	5,600
Three engines each of 1800-kw. capacity	5,400
Total output capacity; kilowatts	11 000

The maximum possible output per annum would therefore be

$$11{,}000 \times 365 \times 24 = 96{,}360{,}000 \text{ kw.-hr}$$

The actual performance was as follows:

Item.	Kilowatt-hour per Annum.
Actual output	66,200,000
Power absorbed by station in gas cleaning, &c.	4,471,380
Energy remaining for delivery to transmission system	61,966,490
Load factor $\left(\frac{66{\cdot}2}{96{\cdot}36}\right)$	0·687

GENERATING COSTS

Item.	£ per Annum.
Interest on capital outlay (£155,800) at 5 per cent	7,790
Redemption of capital at 1 per cent per month	18,700
Taxes	370
Cost of gas at 0·5*d*. per 1000 c. ft.	20,900
Water	368
Current for final purification	2,280
Stores	779
Oil, grease, and waste	2,013
Miscellancous tools	742
Salaries	890
Wages	535
Miscellaneous general expenses, repairs, &c.	676
Total annual generating costs,	56,043

On the annual available output of 61,966,490 kw.-hr., this amounts to 0·217*d*. per unit. The blast-furnace gas is a waste product; had it not been charged for, the cost per unit would have been only 0·135*d*. An illustration of a large engine of this type is shown in fig. 2.

The Producer Plant of the Hoffmann Manufacturing Co., Ltd.—The account here given of this important installation has been mainly derived from the valuable paper by Mr. W. H. Patchell, M.I.E.E, in the *Journal of the Institution of Electrical Engineers* for June, 1920. In 1915 the Hoffmann Company of Chelmsford decided to extend their power plant by the addition of two Lymn recovery pressure-producer installations of the Mond type * each including two producer vessels capable jointly of gasifying 30 tons of coal per day of 24 hr., i.e. 60 tons per day total. These producers supply gas to six 500-b h.p , four-cylinder, four-crank, horizontal Premier gas engines running at 190 revolutions per minute. each coupled direct to a 360-kw , direct-current Crompton dynamo. The installation, situated on the banks of the River Chelmer, commenced operation in March, 1919, but up to March, 1920, had not been worked at its full output capacity. The producers have worked very well, and the engines run with the regularity and freedom from trouble of good steam engines. A view of the power house is shown in fig. 3. It was at first thought that one 30-ton pair of producers, with two 500-b.h.p. engines, would suffice, and these were accordingly ordered and proceeded with; before completion it was found necessary to instal a second pair of producers, &c., with four more 500-b.h.p. engines. This involved an increased capital outlay, as each pair of producers required four gas-washing and recovery vessels, &c., eight in all; whereas had the complete plant been installed at once, four larger vessels would have sufficed with material reduction in first cost owing to the saving that would have resulted not only from the vessels, &c., but also from the reduced piping, foundations, and auxiliary apparatus.

* For description, see *Modern Mech. Engineering* (Gibson and Chorlton), Vol. VI, pp. 240 *et seq.*

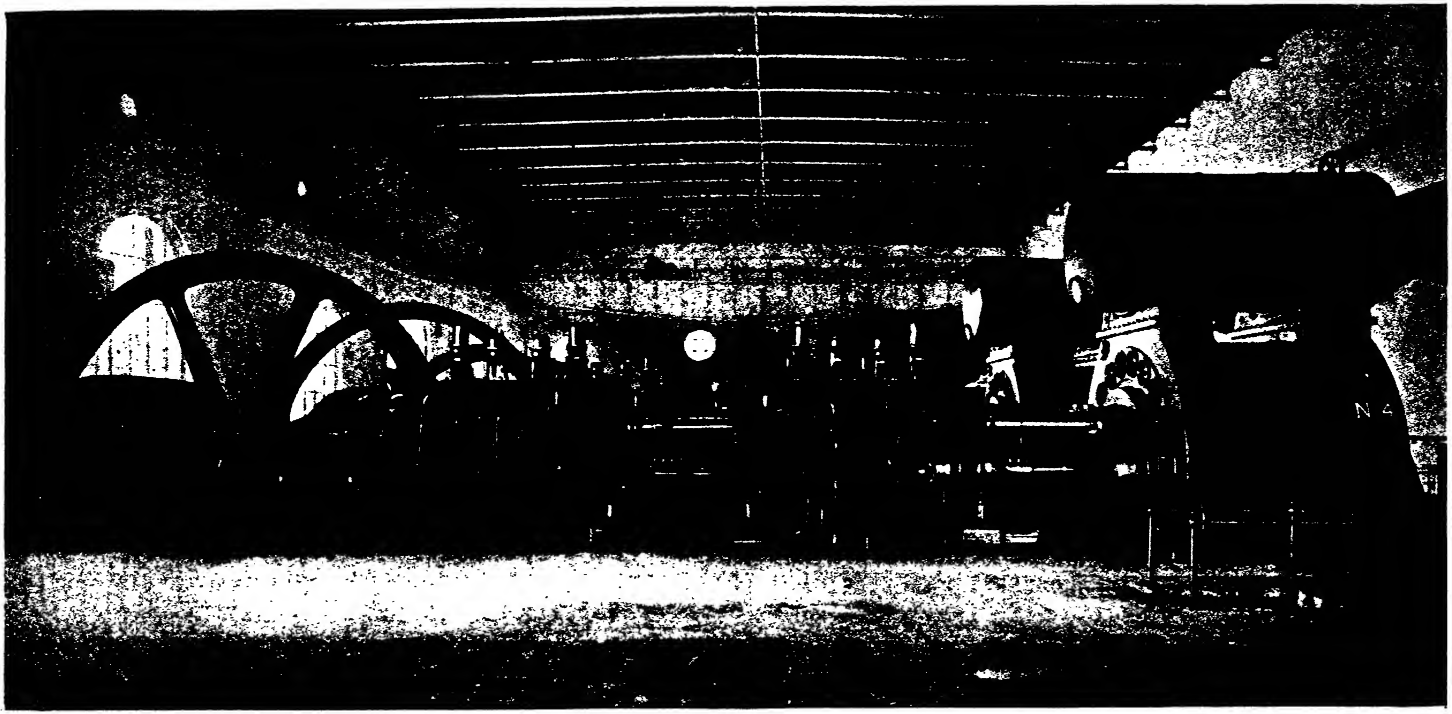

Fig. 2.—Large Nuremberg-type Blowing Engine using Blast-furnace Gas

Each producer consists essentially of a brick-lined chamber containing incandescent fuel through which a mixture of steam and air is blown at a pressure of about 8 in. of water; in recovery producers from 2 to 2½ lb. of steam are required per pound of coal gasified, and the provision of this large quantity of steam involves an item of running cost which is kept as low as possible by utilization of waste heat. In this case the gases formed in the producers undergo a preliminary cooling by contact with water, and this heated water is then used to warm up and saturate the air blown into the producers by Samuelson blowers; by this means about 0·75 lb of steam are supplied per pound of coal gasified. The balance of 1·25 to 1·5 lb. of steam required per pound of coal is provided by boilers heated by the exhaust gases from the engines and blown into the air mains As the introduction into the producers of air so heavily laden with moisture would result in too great a cooling of the incandescent fuel, a "regenerator" is provided wherein the temperature of this very moist air is raised to about 220° C. before it enters the producers; the regenerators are heated by the hot gases leaving the producer.

The hot, smoky, dusty, tar-laden mixture of gases formed in the producer is first passed through the regenerator; next through the No. 1 dust extractor "washer"; then through the No 2 ammonia absorber "washer", then through No 3 gas-cooling and air-saturating "washer"; next through No. 4 gas-cooling "washer"; next through a centrifugal cleaner by which further suspended water and tarry impurities are extracted. From this the gas passes through a water separator into a gas-holder of the familiar inverted water-sealed type, whence it is delivered, through sawdust "scrubbers", to the gas engines and works furnaces. This somewhat lengthy cleansing process is necessary owing to the difficulty in removing the dust and very objectionable tarry compounds contained in the gas, and also to cool and dry it sufficiently before delivery to the engines. Pressure producer tar is always particularly difficult to eradicate and dispose of, as it usually contains anything up to 40 per cent of water; about 150 lb. of this tar are obtained per ton of coal gasified, and in this installation it is burned in the furnaces of two Lancashire boilers, being blown by steam pressure over incandescent grate surfaces through a "Kermode" sprayer.

Coaling Arrangements.—The coal is delivered by railway trucks to a bucket-type elevator, whence it passes on a band conveyor to the 30-ton hoppers over the producers. A second band conveyor also carries coal to a 1200-ton ferro-concrete storage bunker comprising six 200-ton pockets elevated on columns high enough to permit 5-cwt. trucks to pass beneath them. Owing to war conditions it was at first impossible to obtain coal of uniform quality, and in January, 1918, nearly 800 tons of nine different qualities of coal were gasified; by December, 1918, conditions had somewhat improved but even then the coal supplied was of five different sorts; this want of uniformity adversely affected production costs.

The ashes and clinker from the producers are loaded into hand-pushed, 5-cwt., narrow-gauge trucks, whence they are finally tipped into railway

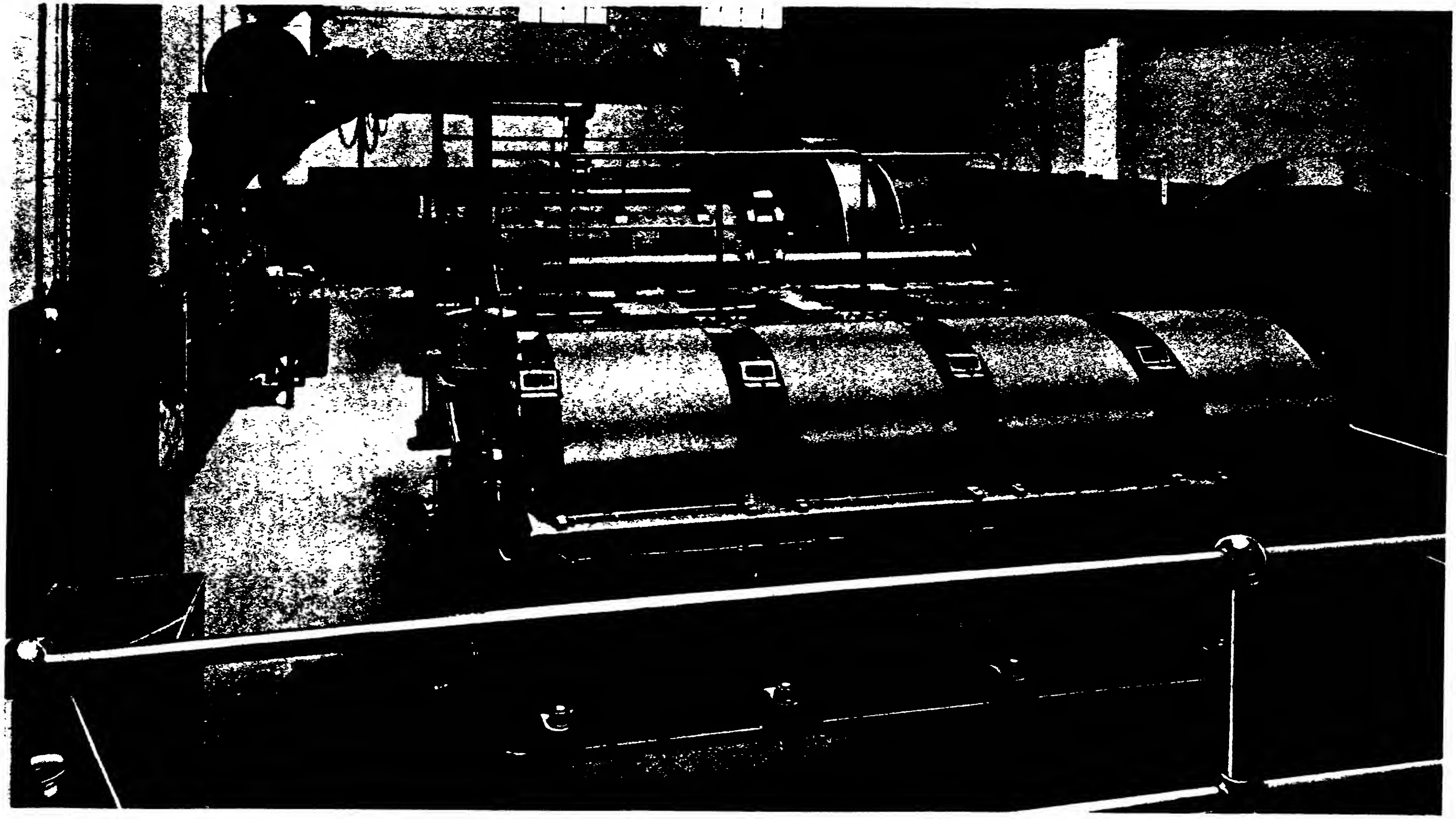

Fig. 3.—Installation of 500-b.h.p. Premier Engines working on Pressure-producer Gas with Recovery (at Chelmsford)

trucks or carts as required. The yield of sulphate of ammonia is about 90 lb. per ton of coal gasified.

Results in Ordinary Running.—A very large amount of steam is needed in installations of this type: (*a*) for the producers, to the extent of 2 to 2½ lb. per pound of coal gasified; (*b*) for evaporating the ammonia sulphate liquor; (*c*) for heating tar tanks and troughs to maintain it in a sufficiently fluid state for use; and (*d*) for various incidental purposes in connection with the plant. To obtain an idea of the aggregate quantity of steam required for these purposes one Lancashire boiler was isolated for one week in early summer and used to supply all the steam needed by the gas plant alone; it was found that the coal and tar (expressed in coal equivalent) burned during the week by this boiler amounted to 22¼ per cent of the coal gasified; as heat losses would be greater in winter it was considered that, supplied in this way, the amount of coal needed for steam raising should be taken in cost estimates at, roundly, 25 per cent of the coal gasified.

In this installation, however, much of this expenditure of coal is avoided by the provision of exhaust-heated boilers, and by burning the tar, produced in the gas-making, in the furnaces of the two Lancashire boilers; the result, in this case, is that the actual coal required to provide the balance of the gas-plant steam is reduced to only 6¼ per cent of the coal gasified.

The following figures are given by Mr. Patchell from six months' operation of one 30-ton gas plant under ordinary commercial conditions—the gas was supplied to two engines and sundry furnaces. The figures given below are adjusted to show the efficiency that would have been realized had all the gas made been used for power production The average calorific value of the coal was 11,333 B.Th.U. per pound whence the overall thermal efficiency (or overall "electro-thermal" efficiency, as Mr. Patchell conveniently terms it) is:

$$\frac{3410}{11{,}333 \times 1\cdot51} = 0\cdot199; \text{ i.e. } 19\cdot9 \text{ per cent.}$$

Fuel Consumption of one 30-ton Plant in Six Months
(W. H. Patchell, M.I.E.E.)

Coal Gasified.		Coal if Required for Providing all Steam, 25 %.	Coal Gasified. plus 25 % if required for Steam.		Tons of Coal Saved.		Surplus Steam used for Manufacturing Purposes.	Coal to be Debited to Power Plant		Engine Load Factor.	Overall Thermal Efficiency.
Tons.	Lb. per Kw -hr.	Tons.	Total Tons.	Lb per Kw -hr.	By Exhaust Boilers.	By Tar Burnt.	Tons.	Total Tons.	Lb. per Kw.-hr.		
1390	1·7	347·5	1737·5	2·12	379·75	114·7	146·95	1243·05	1·51	0·736	0·199
					Total saved, 494·45 tons.						

During the period considered, the two engines generated 1,834,375 units, the corresponding engine load factor being 0·736 on the actual running hours.

Mr. Patchell points out that in this recovery plant, working on a good load factor, the exhaust-heated boilers alone provided more steam than was required to make the gas fuel for the engines.

Quantity and Quality of Gas.—An average of about 135,000 c. ft. of gas was obtained per ton of coal gasified, and from samples taken over an interval of three months the average composition was:

Combustible ..	H	0·2630
	CH_4..	0·0256
	CO	0 1054
Incombustible ..	N	0·4352
	CO_2..	0·1560
	O	0·0148
	Total	1·0000 c. ft.

The average calorific value of this gas was roundly 140 B.Th.U per cubic foot at 32° F. and atmospheric pressure. The compression pressure employed in the engines was 120 lb. per square inch.

Capital Costs.—As this plant was installed during the war period, not only was the cost of the plant much above that in 1914, but the shortage of material and of skilled labour also delayed progress and still further increased capital outlay. The following table shows the outlay in £ per kilowatt installed; the first installation included one complete Lymn gas plant to gasify 30 tons of coal in 24 hr., ammonia sulphate plant, two 500-b h p. Premier-Crompton generating sets, Lancashire boiler, superheater, economizer, chimney, pumps, pipes, 600-ton coal bunker, coal-handling plant, &c. The second installation was a duplicate of the first plus two additional 500-b.h.p. Premier-Crompton generating sets; in this case the gas and electric supply had to be carried over a greater distance than in the case of the first installation:

CAPITAL COST PER KILOWATT OF LYMN PLANT
(W. H. Patchell, M.I.E.E.)

Item.	Installation. First. 1916	Installation. Second, 1917.	Average.
	£	£	£
Lymn gas producer plant, only	12·20	14·26	13·230
Foundation and buildings for Lymn plant	2·45	2·23	2·340
Coal-storage and handling plant (600 tons each) ..	2·76	2·69	2·725
Power-house buildings A, B, C, engine foundations, and cranes	7·30	9·05	8·175
Gas engines, gas, water, and air pipes, and compressors	7·75	12·20	9·975
Exhaust boilers, with steam, water, and gas piping and connections	1·14	1·99	1·565
Generators, switchboards, and connections	5·70	5·98	5·840
Lancashire boilers, chimney, boiler-house, and coal-handling plant	1·68	1·68	1·640
Total capital cost per kilowatt installed, ..	40·98	50·08	45·49

The table following gives the cost, in pence per unit generated, from the actual cost sheets covering six months normal running in 1918. It will be observed that a charge of 10 per cent on capital outlay is included; the figures given include the cost of sulphuric acid, and are credited with the return from sale of the sulphate of ammonia produced. The average prices per ton, during this period, were: coal, 28*s.* 11*d.*; sulphuric acid, 93*s.*; ammonia sulphate, 342*s.* Total number of units generated = 1,834,375; load factor, 0·736, as stated above

RUNNING COSTS OF LYMN PLANT PER KILOWATT-HOUR

(W H. Patchell, M.I E.E.)

Item.	Cost in Pence per Kilowatt-hour.
Fuel	0·166
10-per-cent charge on capital	0·207
Supervision and labour	0·159
Repairs and renewals	0·130
Lubrication	0·058
Total cost, pence per kilowatt-hour ..	0·72

During this period two of the engines were fitted with an uneconomical forced-lubrication system, and lubricating costs accordingly appear high; later a different arrangement was made, resulting in a reduction of 46 per cent in this item The item of 10 per cent charge on capital is also unduly large, for a reason already mentioned. And it is finally to be remembered that this plant was installed under war conditions.

It will have been observed that in the 6000-kw. installation at Kamata (see p. 17) the power is supplied by four horizontal tandem engines, or eight cylinders in all, the revolution speed being 94 per minute, whereas in the much smaller 2160-kw installation of the Hoffmann Company at Chelmsford, just described, the power is derived from six four-cylindered horizontal engines running at 190 revolutions, comprising in all twenty-four cylinders The output at Kamata per cylinder is thus 750 kw., but at Chelmsford only 90 kw.; the cylinders are double-acting in the first case and single-acting in the second.

So far, the great majority of high-powered gas engines built have been of the large, horizontal, few-cylindered, slow-speed type, but in recent years an increasing tendency is observable towards the production of quicker-running, many-cylindered types, both horizontal and vertical

This is especially noticeable among British gas-engine builders who have always favoured the single-acting, medium-speed engine with uncooled pistons, which limits the maximum practicable diameter of cylinder to about 26 in.

The National Gas Engine Co , Ltd., of Ashton-under-Lyne, have taken a leading position in the development of the many-cylindered vertical engine, and an illustration is given in fig. 4 of their standard six-crank, twelve-cylinder, tandem, single-acting, inverted-vertical, 1500-b.h.p. engine direct-coupled to an electric generator. The mean cylinder diameter is $22\frac{1}{2}$ in., stroke 24 in., and speed 200 r.p.m. The net weight, including fly-wheel, but excluding piping, air compressor, and silencers, is stated to be 149 tons, or 223 lb. per rated brake horse-power. It is well understood that the weight per brake horse-power of engines increases with their dimensions, and that the many-cylindered engine is accordingly lighter per unit of power output than the large few-cylindered slower engine. Thus this figure of 223 lb. per brake horse-power may be compared with the 410 lb. of the engines at the Kamata station, though this latter figure appears unusually large, probably on account of the enormous fly-wheel; a more usual figure is from 275 to 300 lb. per brake horse-power for this type and size

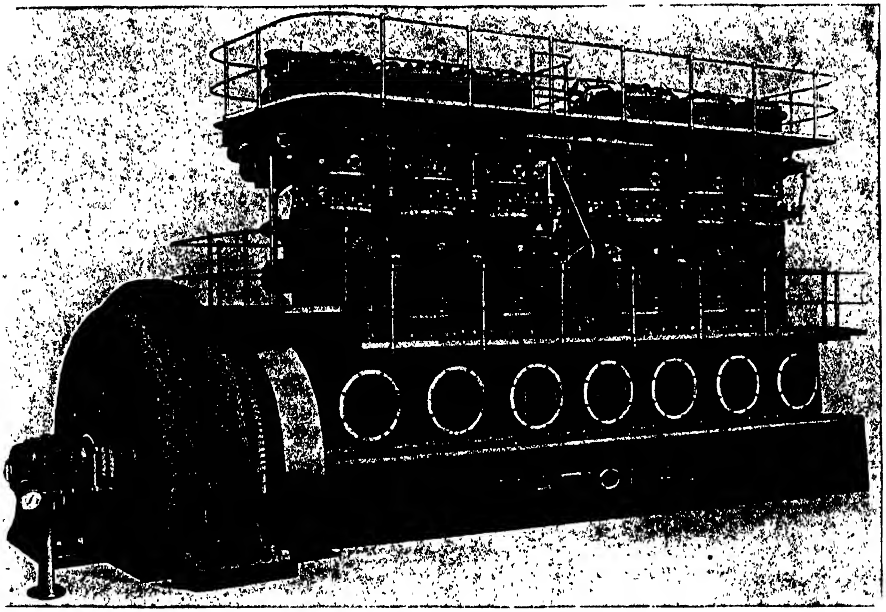

Fig 4.—1500-b.h.p. Six-crank National Gas Engine

The many-cylindered engine, especially of the tandem inverted-vertical type, requires much less floor space than the large few-cylindered horizontal, and this is frequently an important consideration; building and foundation costs are also correspondingly reduced. Again, the single-crank, double-acting, tandem, horizontal engine gives two impulses per revolution, whereas the four-crank, eight-cylinder, single-acting engine gives four impulses per revolution; the turning effort is thus more uniform in the latter case. With the many-cylindered type also the weights of component parts are lower, and this results in reduced cost in carriage and facility in handling.

The following is an estimate * of cost of an installation including one 1000-b.h.p., four-crank, eight-cylinder, vertical "National" engine of the

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* Prepared by the National Gas Engine Co., Ltd.

type as illustrated in fig. 4, supplied with gas from a suction producer, and running during 50 hr. per week, and also continuously, i.e. 168 hr. per week, respectively. Costs are given for 1913, 1921, and 1924 for comparison:

CAPITAL EXPENDITURE

Item.	In 1913.	In 1921.	In 1924.	Remarks.
	£	£	£	
One 1000-b.h.p. engine	5500	12,500	8100	For 50 working hours per week. For continuous running additional producer capacity is necessary (*v. infra*).
One 1000-b.h.p. suction gas plant	1600	3,750	3650*	
One 700-kw. generator	1450	5,000	2300†	
One compressed-air starter ..	150	450	350	
Total	8700	21,700	14,400	

This estimate does not include the cost of foundations, buildings, cooling tower, and pumps.

WEEKLY PERFORMANCE 1000-B.H.P. NATIONAL ENGINE AND SUCTION PRODUCER (RUNNING 50 HOURS PER WEEK)

Item.	
B.H.P.-hours per week at 100 per cent load factor ..	50,000
Kilowatt-hours per week at 100 per cent load factor ..	34,750
Fuel consumption (anthracite) per week; tons	28
Fuel consumption per b.h.p.-hour; lb.	1·25

RUNNING COSTS PER WEEK (50 HR.)

Item.	In 1913.	In 1921.	In 1924.
	£	£	£
Insurance, Interest, Depreciation, and Maintenance at 15 per cent per annum on capital cost	25·00	62·75	41·60
Fuel (28*s*. per ton in 1913; 56*s*. 8*d*. per ton in 1921; 39*s*. per ton in 1924)	39·20	79·33	54·60
Labour	6·00	14·00	8·75
Oil, waste, general stores, &c.	1·50	4·50	4·30
Total per week	71·70	160·58	109·25
Running cost, pence per b.h.p.-hour	0·344	0·770	0·524
Running cost, pence per kilowatt-hour ..	0·495	1·109	0·753

These running costs per brake horse-power hour, and per kilowatt-hour are clearly less than the costs that would be actually incurred, since (*a*) a 100-per-cent load factor is assumed, and (*b*) the statement of capital expenditure is incomplete.

For continuous running (i.e. 168 hr. per week) of a similar installation

* Including coal handling plant. † 750 kw. generator.

of one 1000-b.h.p. engine, the capital expenditure, estimated as above, is increased to £9250, £22,950, and £15,150, for 1913, 1921, and 1924 respectively, due to the additional producer capacity required. On the other hand, absence of starting and stand-by losses is considered to reduce the fuel expenditure to 1⅛ lb. of anthracite per brake horse-power hour. Accordingly the running cost estimate becomes in this case:

RUNNING COSTS PER WEEK FOR CONTINUOUS RUNNING (168 HOURS)

Item.	In 1913.	In 1921.	In 1924
	£	£	£
Insurance, interest, maintenance, and depreciation, at 30 per cent * per annum on capital cost	53·35	132·4	87·3
Fuel (28*s*. per ton in 1913; 56*s*. 8*d*. per ton in 1921; 39*s*. per ton in 1924)	117·60	238·0	164·6
Labour	22·50	50·0	28·0
Oil, waste, general stores, &c.	4·50	13·5	12·9
Total per week	197·95	433·9	292·8
Running cost, pence per brake horse-power hour (100-per-cent load factor)	0·281	0·621	0·418
Running cost, pence per kilowatt-hour (100-per-cent load factor)	0·406	0·892	0·597

These costs per brake horse-power hour and per kilowatt-hour are again subject to the considerations that a 100-per-cent load factor has been assumed, and that no cost of foundations, buildings, &c , has been included in the estimate.

The following estimate, prepared by the National Gas Engine Company, relates to an installation consisting of five 1000-b.h.p. engines (one being spare) operated by Mond producer gas with and without recovery, for continuous running at full load:

CAPITAL EXPENDITURE

FIVE 1000-B.H.P. ENGINES, AND NON-RECOVERY MOND GAS PLANT

Item.	1913.	1921.	1924.
	£	£	£
Five 1000-b.h.p. gas engines	27,500	62,500	40,500
One 5000-b.h.p. Mond gas plant (non-recovery)	12,000	18,000	18,000
Five 700-kilowatt electrical generators	7,250	25,000	11,500
Compressed air starting arrangement	250	650	450
	47,000	106,150	70,450

Not including buildings, foundations, cooling-tower pumps, &c.

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* This figure is the Author's.

Tar recovery plant is now (1924) usually supplied with Mond gas plants whether with or without ammonia recovery, the yield being practically the same in both cases. Early in 1924 the National Gas Engine Co. carried out a test by gasifying 38·5 tons of coal in a Mond producer plant. The cost of the coal was £40, 18*s*.; they say:

	£	*s.*	*d.*
" 1½ tons of pitch were recovered and sold at £6, 10*s*. per ton	9	15	0
180 gall. of tar oil at 8½*d*. gall. were sold for which was obtained	6	7	6

" Hence a saving of £16, 2*s* 6*d*., or 39 per cent upon the cost of the fuel was made.

" Thus allowing for the labour to obtain it, the net saving is ⅓ the cost of the fuel.

" This is obtained with the new design Mond producers, and the yield of tar is practically the same whether the sulphate is recovered or not."

WEEKLY PERFORMANCE

Item.	1913.	1921.	1924.
Running hours per week.. ..	168	168	168
Normal load	4000 b.h.p.	4000 b.h.p.	4000 b.h.p.
Brake horse-power hours per week	672,000	672,000	672,000
Kilowatt-hours per week ..	467,000	467,000	467,000
Fuel consumption per b.h.p.-hour	1¼ lb.	1¼ lb.	1¼ lb.
Fuel consumption per week ..	375 tons	375 tons	375 tons
Fuel cost per ton	£0·625	£1·875	1·187

The running costs per week, when without recovery of sulphate of ammonia, are given as follows:

RUNNING COSTS PER WEEK, WITHOUT RECOVERY

Item	In 1913.	In 1921.	In 1924.
	£	£	£
Interest, depreciation, maintenance, and insurance aggregating 15 per cent per annum on capital cost	135·575	306·200	203·00
Fuel	234·375	703·125	445·50*
Labour	60·000	140·000	56·44
Oil, waste, grease, &c...	18·000	54·000	45·00
Total weekly running costs, without recovery	447·95	1203·325	749·94
Running cost per brake horse-power hour; pence	0·159	0·429	0·216 †
Running cost per kilowatt hour; pence	0·230	0·618	0·310 †

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* At 23*s*. 9*d*. per ton.

† In arriving at these figures one-third of the cost of the fuel has been credited to the engines from the sale of the tar oil recovered.

When the sulphate of ammonia is recovered, although additional plant is necessary, the cost per unit per hour is reduced by the sale of (approximately) 70 lb. of sulphate obtained per ton of coal gasified. The sulphate sold at £14 per ton in 1913, £25 per ton in 1921, and £14 per ton in 1924.

ADDITIONAL CAPITAL OUTLAY FOR RECOVERY PLANT

	In 1913.	In 1921.	In 1924.
Cost of recovery plant, complete ..	£4000	£8000	£6750

WEEKLY RUNNING EXPENSES WITH RECOVERY

Item.	In 1913.	In 1921.	In 1924.
	£	£	£
Insurance, depreciation, &c., as above, at 15 per cent	11·500	23·000	19·50
Sulphuric acid, 1 ton per ton sulphate at £2·25 in 1913, £7 in 1921, and £6 in 1924, per ton	25·875	80·500	69·00
Packing of sulphate at £0·25 (1913), £0·50 (1921), and £0·40 per ton in 1924 ..	2·875	5·750	4·60
Extra labour	—	—	8·40
Total increase in weekly running expenses	40·25	109·25	101·50
Add total net weekly running expenses without recovery	447·95	1203·325	601·44*
Gross total weekly running cost with recovery	488·20	1312·575	702·94
Credit 11½ tons sulphate of ammonia.. ..	161·00	287·50	161·00
Net weekly running cost, with recovery	327·20	1025·075	541·94
Net running cost, with recovery, per b.h.p.; pence	0·116	0·366	0·194
Net running cost, with recovery, per kilowatt; pence	0·168	0·526	0·280

Estimated on a load factor of 100 per cent, and with no allowance for buildings and foundations.

Diesel-engined Stations.—In a valuable paper presented to the Diesel Engine Users' Association, 1916, Mr. G. Porter gives interesting data relating to three steam-power stations whose capacities have been increased by the addition of Diesel engines. Such " mixed " stations are now not uncommon, but it is to be remarked that in general in such cases the capital cost per kilowatt of added internal-combustion engine plant is unduly high owing to the grudging extent to which it is usually installed. Mr. Porter points out that station engineers, loaded with the burden of annual payments of principal and interest, are compelled to provide extensions of plant in such manner that the increased charges shall as far as possible keep pace with increases in income; thus, although, taking the long view, it would usually be better to increase plant to a degree sufficient to cope with the

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* This is £749·94 less one-third of £445·50

TABLE VII

TOTAL CAPITAL OUTLAY ON GENERATING PLANT FOR THE THREE "MIXED" STATIONS A, B, AND C

Item.	Station A.		Station B.		Station C.	
	Last Completed Financial Year before starting Diesel Engines.	Last Completed Financial Year.	Last Completed Financial Year before starting Diesel Engines.	Last Completed Financial Year.	Last Completed Financial Year before starting Diesel Engines.	Last Completed Financial Year.
Steam Plant:	£	£	£	£	£	£
Capital cost of engines, boilers, foundations, and accessories ..	15,698	15,698	87,100	87,100	34,292	34,292
Capacity of steam plant in kilowatts	538	538	3,500	3,100	860	860
Capital cost of steam plant per kilowatt	29·2	29·2	24·9	28·1	39·9	39·9
Diesel Plant:						
Capital cost of Diesel engines and dynamos	—	8301	—	12,300	—	8,450
Cost of foundations	—	200	—	2,500	—	1,277
Cost of accessories	—	747	—	1,200	—	506
Total capital cost of Diesel plant, with dynamos	—	9248	—	16,000	—	10,233
Capacity of Diesel plant in kilowatts	—	510	—	600	—	540
Capital cost of Diesel plant per kilowatt	—	18·1	—	26·7	—	19·0
Combined Plant:						
Total capital cost of combined plant	—	24,946	—	103,100	—	44,525
Total capacity of combined plant in kilowatts	—	1,048	—	3,700	—	1,400
Capital cost of combined plant per kilowatt	—	23·8	—	27·9	—	31·8

TABLE VIII

Annual Performance and Running Costs of the Three "Mixed" Stations A, B, and C

Item.	Station A.		Station B.		Station C.	
	Last Completed Financial Year before starting Diesel Engines.	Last Completed Financial Year.	Last Completed Financial Year before starting Diesel Engines.	Last Completed Financial Year.	Last Completed Financial Year before starting Diesel Engines.	Last Completed Financial Year.
Steam Plant:						
Total possible annual output in kilowatt-hours . .	4,712,880	4,712,880	30,660,000	27,156,000	7,533,600	7,533,600
Actual annual output in kilowatt-hours	609,609	11,312	5,024,127	2,133,214	1,332,851	403,431
Annual load factor	0·129	0·0024	0·164	0·079	0·177	0·054
Coal used per unit (kilowatt-hour) generated; lb. . .	5·8	12·8	4·0	4·05	10·1	14·9
Units generated per ton of coal burned	388	176	560	553	—	150
Overall thermal efficiency $\left(\frac{3410}{\text{lb. coal per unit} \times 12{,}000}\right)$	0·049	0·022	0·071	0·070	0·028	0·019
Running plant load factor	0·662	0·694	—	—	—	—
Average price of coal; shillings per ton	18·25	29·67	23·75	30·75	16·2	17·0
Cost of coal in pence per unit generated	0·567	2·04	0·51	0·667	0·875	1·36
Diesel Plant:						
Total possible annual output in kilowatt-hours . .	—	4,467,600	—	5,256,000	—	4,730,400
Actual annual output in kilowatt-hours	—	591,584	—	2,429,148	—	1,127,557
Annual load factor	—	0·132	—	0·462	—	0·238
Fuel oil used per kilowatt-hour generated; lb . . .	—	0·67	—	0·62	—	0·92
Units generated per ton of oil used	—	3200	—	3615	—	2435

Overall thermal efficiency $\left(\dfrac{3410}{\text{lb. oil per unit} \times 17{,}500}\right)$	—	0·291	—	0·314	—	0·212
Running plant load factor	—	0·569	—	—	—	—
Average price of fuel oil; shillings per ton	—	64·0	—	67·17	—	65·0
Cost of oil in pence per unit generated	—	0·230	—	0·223	—	0·320
Combined Plant:						
Annual combined output in kilowatt-hours	609,609	602,896	5,024,127	4,562,362	1,332,851	1,530,988
Annual combined load factor	—	0·0657	—	0·141	—	0·125
Per cent of total output generated by steam plant ..	100	1·88	100	46·8	100	26·3
Per cent of total output generated by Diesel plant ..	0	98·12	0	53·2	0	73·7
Cost of fuel in pence per unit generated; combined plant	0·567	0·264	0·510	0·433	0·875	0·594
Cost in pence per unit generated, of lubricating oil, water, waste, and general stores	0·092	0·106	0·028	0·032	0·048	0·075
Wages cost, per unit generated (running staff)* ..	0·206	0·139	0·150	0·194	0·199	0·204
Salaries, per unit generated (proportion)	0·068	0·069	—	—	—	—
Repairs and maintenance of generating plant (proportion)	0·105	0·073	0·106	0·090	0·060	0·068
Total running charges, in pence per unit generated ..	1·038	0·651	0·794	0·749	1·182	0·941
Breakdown insurance, in pence per unit generated; steam plant	0·110	0·110	0·033	0·033	—	—
Breakdown insurance, in pence per unit generated; Diesel plant	—	0·150	—	0·240	—	—
Annual interest and redemption, in pence per unit generated	2·230	1·950	—	—	—	—
Total of fixed and running charges in pence per unit generated	3·378	2·861	—	—	—	—

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* For Stations B and C, " Wages Cost " includes proportions of Salaries.

probable demand several years ahead, pressing financial conditions do not in general permit this larger policy to be adopted.

The data following are taken from Mr. Porter's paper *; three " mixed " stations, referred to as A, B, and C, are discussed. A is a station of 1048-kw. combined capacity, on the South Coast; B is a station of 3700 kw. combined capacity in London; C is a provincial riverside station of 1400-kw. combined capacity. Table VII (p. 33) gives figures relating to the capital outlay. In A and C the exhaust steam is condensed; B is a non-condensing station; excepting only one two-stroke Diesel in Station C, all the Diesel engines were of the four-stroke cycle type.

In Station B local circumstances necessitated a very heavy expense for foundations for the Diesel engines and prices generally were then also high; hence the capital cost of installing 600 kw. in B appears as £26·7 per kilowatt, as compared with only £18·1 per kilowatt for 510 kw. installed in Station A.

As the comparison instituted is between the two methods of power generation, no account is taken of the costs of storage batteries, boosters, &c.

Table VIII (p. 34) exhibits the figures of annual output and costs in the three cases. The total possible annual output is the capacity in kilowatts × 24 × 365; the average calorific value of the coal used is taken roundly at 12,000 B.Th.U. per pound; and for the fuel oil used by the Diesel engines an average value of 17,500 B.Th.U. per pound is assumed. From this table it appears that in all three cases economy has resulted from the addition of the Diesel engines, the reductions in total running charges being for:

Station A ..	.. 0·387*d*.,
Station B ..	.. 0·045*d*.,
Station C ..	.. 0·241*d*.,

per unit generated.

For Station A in particular Mr. Porter gives the following valuable figures, obtained by him from actual running experience over the period 1910–16:

STATION A.—REVENUE AND GROSS PROFITS 1910–16
(Geoff. Porter, A.M.I.C.E.)

Year.	Revenue per Kilowatt of Maximum Load, £.	Gross Profit per Kilowatt of Maximum Load, £.	Conditions of Running.
1910–1	21·2	11·3	Steam plant only.
1911–2	20·4	10·4	Part Diesel for about two months.
1912–3	19·1	11·1	Diesel plant, 82·2 per cent of output.
1913–4	20	11·8	Diesel plant 80 per cent of output.
1914–5	27·3	14·9	Diesel plant, 91·7 per cent of output.
1915–6	23·2	14·1	Diesel plant, 98 per cent of output.

A steady increase in gross profit is manifested with increased use of the Diesel plant. He observes that examination of the above three cases, A,

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* Reproduced by kind permission of the Diesel Engine Users' Association.

B, and C, shows that the lower cost of operating a Diesel-engined plant quickly extinguishes the higher annual capital charges incurred.

Table IX, exhibiting figures obtained from eight "mixed" steam and Diesel generating stations, shows that in each case an increased gross profit per kilowatt of maximum load was realized after the installation of the Diesel plant.

TABLE IX

(Geoff. Porter, A.M.I.C.E.)

Station No.	Reduction in Fuel Cost in Pence per Unit Sold.	Gross Profit in £ per Kilowatt of Maximum Load before Diesel Engines.	Gross Profit in £ per Kilowatt of Maximum Load after Diesel Engines.
1	0·31	11·3	14·1
2	0·23	9·9	10·5
3	0·20	8·8	14·3
4	0·18	11·1	15·2
5	0·20	3·37	6·9
6	0·21	8·4	10·2
7	0·11	9·8	11·5
8	0·06	13·4	15·1

An illustration of a standard type inverted-vertical, four-cylindered, 500-b.h.p. Diesel engine by Mirrlees, Bickerton, & Day, Ltd., is shown in fig. 5. This engine runs normally at 200 r p.m. on "Diesel engine oil" as supplied by The Anglo-American Company, Shell Mexican Company, &c., the consumption being about 0·45 lb. per brake horse-power from about ¾ load to full load; in 1914 this oil was obtainable at 65*s.* per ton; in 1921 the price had risen to 135*s.* per ton; by 1924 it had fallen to 110*s.* per ton at London depots. Shale oils. gas oils, and ordinary kerosenes are also suitable fuels, while tar oils may be successfully used by the addition of a special pilot fuel jet.

The capital cost of this type of engine increased from about £10 per brake horse-power in 1913 to fully £22 in 1921; by 1924 it had fallen to about £15. Depreciation may be assumed, according to circumstances, at from 5 per cent to 10 per cent per annum. The quantity of lubricating oil necessary is about 1½ per cent of that of the fuel oil; the cost of suitable lubricating oil increased from 2*s.* 6*d.* per gallon in 1913 to 5*s.* 3*d.* per gallon in 1921; in 1924 it had fallen to 3*s.* per gallon.

GROUP II.—POWER FOR USE IN FACTORIES AND MILLS

Diesel Engine.—Of plants for the production of power for use in factories and mills the first case selected for illustration is that of an 80-b.h.p. Diesel engine which ran regularly, with short periodical stoppages for overhauls only, from the autumn of 1911 until the end of 1917. The Diesel engine was of the usual vertical type with two cylinders, fitted with a two-stage air compressor on each cylinder for charging the reservoir used for starting and fuel injection; the normal power output was 80 b.h.p. at 200 r.p.m. The engine was run on Texas fuel oil, costing from 44*s*. to 47*s*. per ton before the war; at the end of 1917 the price of this oil fuel had risen to 135*s*. per ton.

During the six years this engine was in use it was worked continuously 24 hr. per day during six days per week, and 18 hr. on the seventh day; the remaining 6 hr. of the week were devoted to minor adjustments; the normal working week thus consisted of 162 hr.

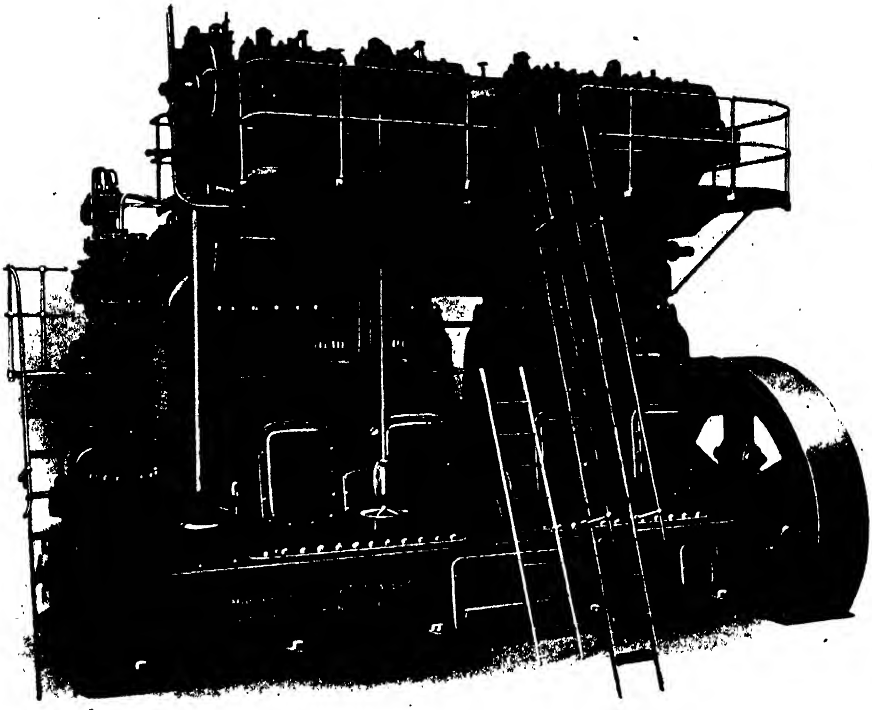

Fig 5.—500-b h.p Four-cylinder Diesel Engine by the Mirrlees Company

In addition to the weekly overhaul, at intervals alternately of about 6 months and 10 months respectively the engine was dismantled and overhauled, new pistons and new cylinder liners being fitted at the end of each complete period of about 16 months. The only other items found to require occasional renewal were the piston rings and valves. The main bearings, &c., required taking up from time to time, but were in good condition at the end of the service. Cessation of running arose through the owning company acquiring a much larger factory elsewhere, equipped throughout with electrical driving.

The soil was marshy, and the foundations accordingly somewhat large and costly, consisting of a tunnelled concrete block enabling the engine holding-down belts to be removed without disturbing the concrete; access to the tunnel was obtained from the fly-wheel pit. The cost of the engine foundations, including that for the outer bearing, and small foundations for the starting vessels, amounted in all to £350.

CAPITAL OUTLAY (1911)

	£
One 80-b.h.p. Diesel engine, erected and complete, with starting vessels, connections, and belt-driving drum	1206
Foundations	350
Buildings (estimated cost)	400
Total	1956

ANNUAL PERFORMANCE (1911–7)

162 hr. per week for 52 wk., less 424 hr. for overhauls = 8000 working hours per year. 80 b.h.p. for 8000 hr. = 640,000 b.h.p.-hr per year.

AVERAGE OPERATING COSTS PER YEAR

	£
Interest on capital outlay at 5 per cent	97·8
Depreciation at 7½ per cent (as actually taken)	146·7
Labour (including supervision) and material for annual overhauling, excluding the 6 hours per week	128
Weekly adjustments; 1 fitter at 1*s*. 1*d*., and 1 mate at 10*d*.; 6 hours ..	29·9
Running attendants at 1*s*. per hour (3 shifts)	400
Fuel oil, 648 gall. per working week, at 3·3*d*. per gallon *	440·2
Lubricating oil; 20 gall. per working week, at 1*s*. 6*d*. per gallon ..	74·1
Cooling water; 56,700 gall. per working week, at 7*d*. per 1000 gall. ..	81·7
Total	1398·4

OPERATING COST PER BRAKE HORSE-POWER HOUR

640,000 b.h.p.-hr. per year for £1398·4 = 0·5244*d* per b.h.p.-hour.

This case is of special interest both on account of the continuous heavy duty satisfactorily performed by the engine, and from the fact that the costs given are from actual experience in prolonged running under commercial conditions.

Ruston-Hornsby Gas Engine.—The second case selected as an illustration in Group II is that of a horizontal, four-stroke, single-acting, two-cylindered Ruston-Hornsby gas engine developing a normal maximum of 220 b.h.p. at 200 r.p.m., using gas from a Hornsby-Stockport anthracite suction producer (fig. 6). The figures given on pp. 42–3 are from actual experience: the engine ran 50 hr. per week for 52 wk. per year, and developed an average estimated at 170 b.h.p.; the load factor was thus, roundly, 0·8. Small adjustments, valve cleaning, &c., were carried out after working hours.

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* This price corresponds to about 65*s*. per ton.

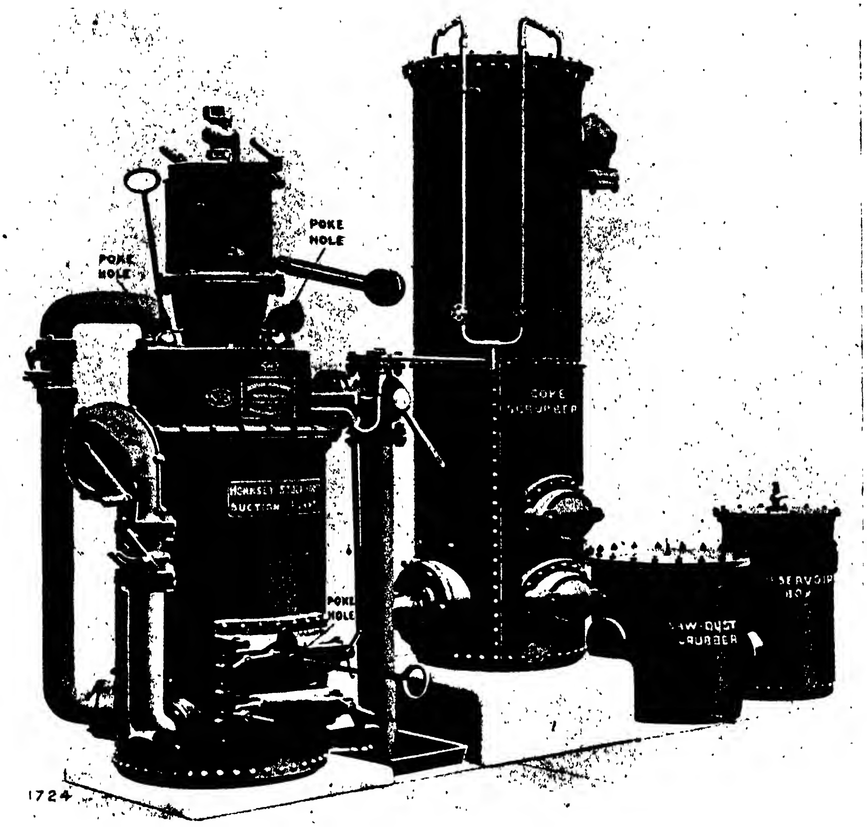

Fig. 6.—View of Hornsby-Stockport Suction Gas Producer and Scrubber

CAPITAL OUTLAY

Item.	In 1913.	In 1921.	In 1924.
	£	£	£
One 220-b.h.p. engine and gas producer, with all accessories, including erection	1440	4660	2300
Foundations for same	30	100	90
Buildings, complete	400	1500	1000
Total capital outlay	1870	6260	3390
Capital outlay in £ per maximum brake horse-power installed	8·5	28·5	15·4

ANNUAL PERFORMANCE

170 b.h.p. for 50 hr. per week and 52 wk. per year = 170 × 50 × 52
= 442,000 b.h.p.-hr. per year.

Operating Costs per Year

Item.	In 1913.	In 1921.	In 1924.
	£	£	£
Interest on capital outlay: 5 per cent, 1913; 8 per cent, 1921; 6 per cent, 1924	93·5	500·8	203·4
Depreciation at 8 per cent on power plant	115·2	372·8	184·0
Insurance at 1½ per cent on capital outlay	28·1	93·9	50·9
Repairs and maintenance at 3 per cent per annum ..	56·1	187·8	101·7
Wages of 1 driver and 2 stokers, averaging 32*s*. 6*d*. per week in 1913, 65*s*. per week in 1921, and 50*s*. in 1924 ..	253·5	507·0	390·0
Anthracite, 200 tons at 28*s*., 1913, 56*s*. 8*d*., 1921, and 42*s*., 1924	280·0	566·7	420·0
Lubricating oil, 16 gall. per week at 1*s*. 6*d*. per gallon in 1913, 4*s*. 6*d*. per gallon in 1921, and 3*s*. 9*d*. in 1924 ..	62·4	187·2	156·0
Washing and cooling water at 10 gall. per b.h.p. hour and 6*d*. per 1000 gall. in 1913, 1*s*., 1921, and 9*d*., 1924 ..	110·5	221·0	165·7
Total operating costs per year	999·3	2637·2	1671·7
Operating cost in pence per brake horse-power hour ..	0·5426	1·432	0·908

In this case the cost of water used for washing and cooling the gas and engine is included. Whenever possible, however, producer power plants are located near a river, and the water is thence obtained free of cost.

A favourable case of this kind is that of a 220-b.h.p. Ruston-Hornsby gas engine, as just described, installed in a large timber works in north-east Hertfordshire, adjacent to a river; here not only is all the water required obtained free of cost, but the fuel also, as the Ruston " Refuse " suction producer burns saw-dust only. The costs in this case are reduced to 0·331*d* (1913 prices), 1·004*d*. (1921 prices), and 0·590*d*. (1924 prices), per brake horse-power hour.

Between three and four tons of saw-dust are burned per day, and the producer hopper is charged at intervals of about fifteen minutes during running hours. The producer charge is prevented from burning into holes by the usual poking arrangements The installation gives complete satisfaction.

The gas produced is heavily burdened with tarry impurities and passes finally through a saw-dust " scrubber " containing trays of saw-dust about 6 in. in thickness before being received by the engine; this scrubber requires cleaning out at three-monthly intervals.

About twice as much water as in the anthracite case is here found necessary in order to cleanse and cool adequately the gas from the saw-dust, and this water becomes much befouled with tarry vesicles, &c.; it is here allowed to run to waste into a lengthy ditch, and soaks away into the subsoil, but in some localities its disposal might present difficulties. An illustration of the 220-b.h.p. Hornsby gas engine is shown in fig. 7.

Crossley Heavy Oil Engine.—The third type selected to illustrate Group II is that of the heavy oil engines of Messrs. Crossley Bros., Ltd. The figures given on p. 43 for 1913 and 1921 relate to their then standard horizontal twin-cylindered 16 in. bore × 26 in. stroke single-acting four-stroke " crude oil " engine of 170 b.h.p. normal maximum output at 190

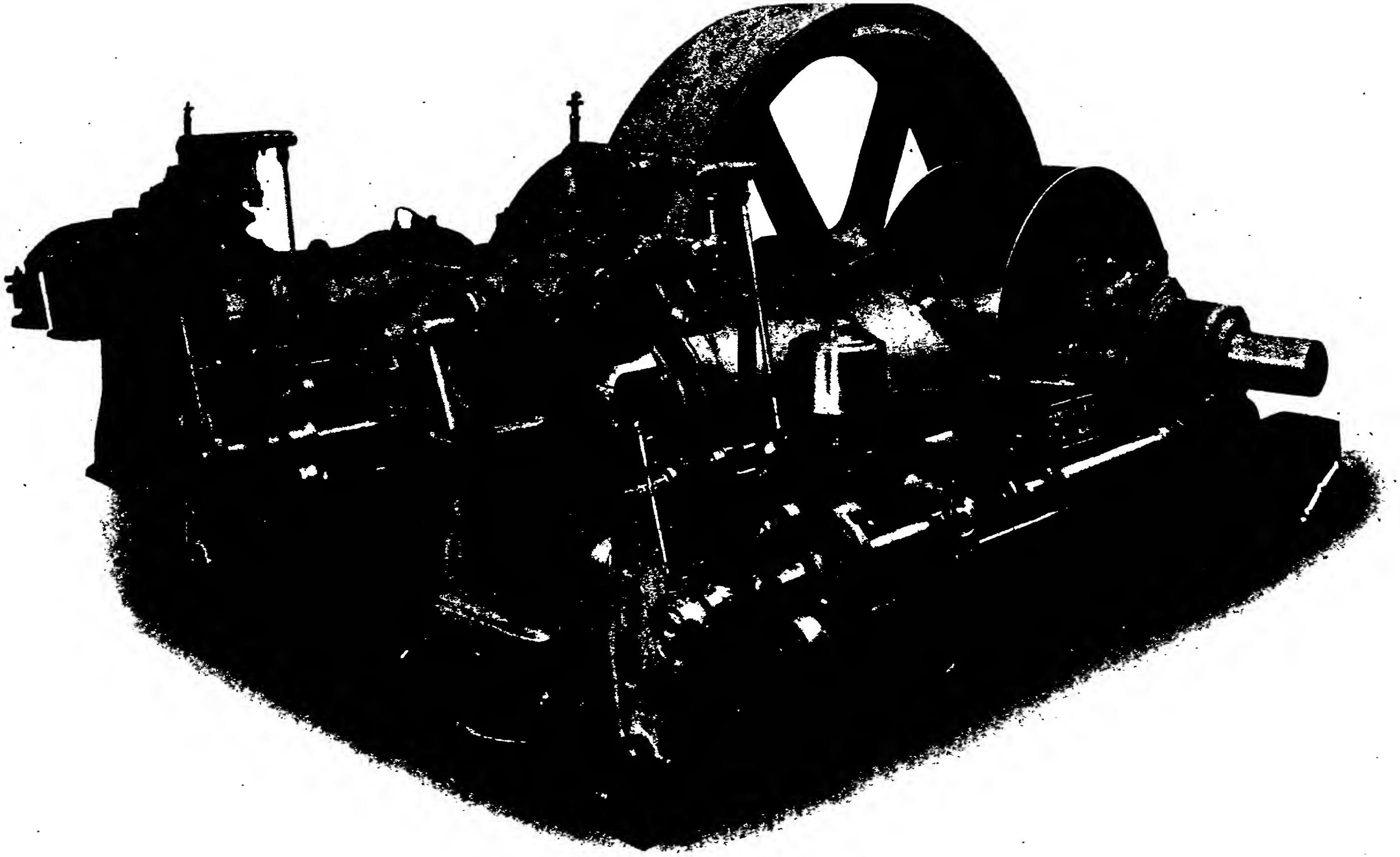

Fig. 7.—200-b.h.p. Ruston-Hornsby Twin-cylinder Gas Engine

r.p.m., using as fuel light crude oils ranging in specific gravity from 0·86 to 0·89. By 1924 this type had been superseded by the " cold starting " crude oil type, and the figures given for 1924 refer to their standard cold starting engine of 188–208 b.h.p. normal maximum output at 210 r.p.m., using as fuel residual oils or " furnace oils " of specific gravity ranging from 0·89 to 0·92. The fuel consumption at full load is stated to be about 0·44 lb. per brake horse-power hour.

Costs based on information supplied by the makers, but arranged in the manner herein adopted, are as under:

CAPITAL OUTLAY

Item.	In 1913.	In 1921.	In 1924.
	£	£	£
Engine, all complete, and erected in London district	1260	3720	1800
Foundations (estimated)	200	600	300
Buildings (estimated)	250	750	350
Total	1710	5070	2450
Capital outlay per brake horse-power installed	10·06	29·82	13·03

The figures for 1913 and 1921 relate to a 170-b.h.p. "crude oil" engine, those for 1924 to a 188–208-b.h.p. "cold starting" crude oil engine.

ASSUMED ANNUAL PERFORMANCE

Taking a load factor at 0·8, as in the preceding case, we have, say, 135 b.h.p for 50 hours per week, and 52 weeks per year = 135 × 50 × 52 = 351,000 b.h.p.-hours per year for 1913 and 1921; and, say, 150 b.h.p. corresponding to 390,000 b.h.p. hours per year for 1924.

OPERATING COSTS PER YEAR

Item	In 1913.	In 1921.	In 1924.
	£	£	£
Interest on capital outlay, 5 per cent (1913), 8 per cent (1921) and 6 per cent (1924)	85·5	405·6	147·0
Depreciation at 5 per cent per annum on power plant ..	63·0	297·6	108·0
Insurance at 1 per cent per annum	17·1	50·7	24·5
Adjustments and repairs at 3 per cent per annum on power plant	37·8	111·6	54·0
Attendance: half one man's time at £2 (1913), £4 (1921), £3 (1924)	52·0	104·0	78·0
Fuel oil at £3 (1913), £6 (1921). and £5 (1924) per ton. 80 tons..	240·0	480·0	400·0
Lubricating oil at 1*s*. 3*d*. (1913), 5*s*. (1921), and 3*s*. (1924) per gallon. 180 gall.	11·3	45·0	27·0
Water at 7 gall. per brake horse-power hour; 2½ per cent loss by evaporation at 6*d*. per 1000 gall. (1913) and 1*s*. (1921 and 1924). 64,000 gall.	1·6	3·2	3·2
Total	508·3	1497·7	841·7
Operating cost in pence per brake horse-power hour, on rate of working as assumed..	0·3476	1·024	0·518

In this costs statement only the cost of water required to make up evaporation loss is included, which implies that cooling tanks must be provided, the cost of which does not appear among the above items. To make the case more directly comparable with that discussed on p. 41, the whole of the water required must be charged for; if this be done, the operating costs per brake horse-power hour become 0·3884*d.* (1913), 1·106*d.* (1921), and 0·56*d.* (1924), respectively. The absence of a gas producer with its several bulky washing and cooling adjuncts materially reduces the costs of foundations, buildings, attendance, and water, with resulting reduction in the total operating cost per brake horse-power hour.

GROUP III.—TRANSPORT POWER

For the varied purposes of transport by land, water, and air, the petrol motor is almost universally used. In Great Britain no fewer than 853,900 licences were issued in the first six months of 1921 in respect of motor vehicles only, horse-drawn vehicle licences within the same period totalling only 261,000 *. Of this immense total of motor vehicles about 226,000 were privately owned motor-cars, 370,000 motor-cycles, and the balance of 257,900 was made up of commercial lorries, motor-omnibuses, " hackney carriages ", motor tractors, ploughs, &c. For transport by water also the internal-combustion engine is making rapid headway, many large ocean-going steamships being propelled by Diesel engines in 1924, together with a great number of smaller coastal craft and trawlers equipped with simple engines of the " hot-bulb Diesel " type, one case of which is given later herein.

For aircraft, up to 1924, the petrol engine was the only practicable means of propulsion, though experiments with heavy-oil aero engines were being prosecuted. In an address delivered in August, 1924, Air Vice-Marshal Brancker claimed that aeroplanes could then be operated at 100 miles per hour for " about 4*s.* to 4*s.* 6*d.* per ton-mile ", and that it was impossible with the number of passengers and weight of cargo obtainable to make European air transport pay its way without Governmental financial aid.

With transport vehicles it is customary to estimate running costs in pence per ton-mile, or per passenger-mile The first case selected for illustration is that of the ordinary motor-omnibus At the beginning of 1913 in greater London alone about 300 miles of streets were traversed daily by some 2450 petrol-engined motor-omnibuses, with a daily mileage ranging from 100 to 120, a total running cost ranging from 7¼*d.* to 8*d.* per mile, and receipts averaging from 10½*d.* to 11*d.* per mile. In the whole of Great Britain there were at that date about 4500 motor-omnibuses in service; in many country districts, however, the daily mileage was only about 75, due to poor roads and hills, and the total running costs in such cases ranged from 9*d.* to 1*s.* per mile.

Total running costs for 1909, 1912, and 1924 are given in the table

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* See *The Autocar*, 25th June, 1921.

hereunder; it will be observed that enlarged experience and improved organization resulted in a reduction of no less than 2·23*d.* per mile being achieved at the end of 1912; the increased cost per mile in 1924 resulted partly from the larger size of recent omnibuses and partly from the general increase in post-war costs of all kinds.

LONDON MOTOR-OMNIBUSES; TOTAL RUNNING COSTS PER MILE (1909–24)

Item.	For 1909.	For 1912.	For 1924.*
Interest on capital outlay	0·50	0·31	0·43
Depreciation	1·00	0·50	2·30
Running and maintenance	3·28	2·44	2·40
Traffic expenses	2·65	2·43	3·07
Tyres	1·33	1·02	0·95
General expenses	0·79	0·62	0·70
Total running cost per mile; pence	9·55	7·32	9·85

The report of the Manchester Corporation Tramways for 1916 showed that the Corporation motor-omnibuses during that year ran 180,956 miles, and carried 1,416,760 passengers, at a running cost per mile estimated at 9½*d.*, the receipts per mile averaging about 9¾*d.* From 1920 onwards the Corporation of Aberdeen operated a fleet of motor omnibuses; during 1923 these vehicles are stated to have earned a profit of 20 per cent on the capital outlay, the working expenses having been rather under one shilling per vehicle mile.

Petrol Lorries.—As examples of this type of vehicle the "Thornycroft" standard 4-ton and 2-ton lorries are selected.

The Thornycroft "Type J" petrol lorry, designed to carry useful loads of 3½–4 tons, had a length of 21 ft., width 7 ft., and height, unladen, 6¾ ft., with a flat loading platform 13½ × 6½ ft. The approximate weight unladen was 3 tons, and the vehicle was driven by a four-cylindered vertical petrol engine of 4½-in. bore and 5-in. stroke. The transmission was by geared wheels, with final overhead worm drive to the rear axle; four forward speeds and a reverse were provided, giving 2¾, 5¼, 8¾, and 13½ miles per hour respectively, the reverse speed being 2¼ miles per hour, at normal engine speed; the vehicle was capable of turning in a circle of 50 ft. in diameter. Costs are estimated as follows:

CAPITAL OUTLAY

	In 1913.	In 1921.	In 1924.
One "Type J" Thornycroft petrol lorry	£695	£1300	£925

ANNUAL PERFORMANCE

The annual performance is taken as 60 miles per day on 300 days per annum, i.e. 18,000 vehicle-miles per annum.

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* *The Commercial Motor*, 1st April, 1924.

RUNNING COSTS PER YEAR

Item.	In 1913.	In 1921.	In 1924.
	£	£	£
Interest on capital outlay, 5 per cent (1913), 8 per cent (1921), and 6 per cent (1924)	34·75	104·0	55·5
Depreciation at 15 per cent	104·25	195·0	138·8
Maintenance and repairs at 10 per cent	69·5	130·0	92·5
Oil, grease, and general stores	18·0	54·0	49·0
Insurance; special fire and accident policy ..	15·0	28·0	28·0
Tyres at 1½*d.* per mile	112·5	112·5	112·5
Driver at 30*s.* (1913), £4 (1921 and 1924), and boy, 7*s.* 6*d.* (1913), £1 (1921 and 1924) ..	97·5	260·0	260·0
Petrol, 1*s.* 4½*d.* per gallon (1913), 3*s.* 1*d.* per gallon (1921). Average of 5 miles per gallon and 1*s.* 6*d.* per gallon (1924)	247·5	555·0	270·0
Taxation	—	33·0	33·0
Total running costs	699·0	1471·5	1039·3
Total running cost in pence per vehicle-mile, on assumed annual mileage..	9·32	19·62	13·86

The cost per net ton-mile is obviously dependent upon the average net load carried; for example, in the case of a brewery store supplied from a brewery, the lorry returning with a half-load of empty barrels, crates of bottles, &c., there is a full load on the outward journey and a half-load on the return, or an average of 0·75 of full load, i.e. 3 tons. Hence in such a case we should have:

	In 1913	In 1921.	In 1924.
Running cost per ton-mile of load, in pence, for an average of ¾ths full load	3·11	6·54	4·62

Cost estimates for a standard 2-ton Thornycroft petrol lorry are given hereunder:

CAPITAL OUTLAY

	In 1913.	In 1921.	In 1924.
One 2-ton vehicle with lorry platform body	£540	£1070	£717

ANNUAL PERFORMANCE

As in the preceding case, a vehicle-mileage of 60 per day for 300 days per year is assumed, or an annual vehicle-mileage of 18,000.

RUNNING COSTS PER YEAR

Item.	In 1913.	In 1921.	In 1924.
	£	£	£
Interest on capital outlay, 5 per cent (1913), 8 per cent (1921), and 6 per cent (1924)	27·0	85·6	43·0
Depreciation at 15 per cent	81·0	160·5	107·6
Maintenance and repairs at 10 per cent	54·0	107·0	71·7
Oil, grease, and general stores	15·0	45·0	40·0
Insurance	11·0	20·0	25·0
Tyres at 0·75*d*. per mile	56·5	56·5	56·5
Driver at 30*s*. (1913), £4 (1921 and 1924), and boy, 7*s*. 6*d* (1913), £1 (1921 and 1924) ..	97·5	260·0	260·0
Petrol at 1*s*. 4½*d*. per gallon (1913), 3*s*. 1*d*. per gallon (1921), and 1*s*. 6*d*. per gallon (1924); average of 8½ miles per gallon	145·6	326·5	158·5
Taxation	—	25·0	25·0
Total running costs per year	487·6	1086·1	787·3
Total running cost in pence per vehicle-mile on assumed annual mileage of 18,000	6·5	14·5	10·5
Total running cost in pence per ton-mile of load for an average of ¾ths of full load	4·34	9·67	7·0

These may be regarded as typical instances of goods transport by motor vehicles; running costs are frequently in excess of those given herein, particularly in cases where vehicles necessarily run light over a considerable part of their total mileage; the reader, however, can readily make suitable modifications in the several items of cost to render them applicable to any specific case.

Farm Tractors.—A post-war development of great importance is the rapidly extending use in Great Britain of the internal-combustion-engined farm tractor, which is proving invaluable to the farmer in ploughing, mowing, cultivating, cutting and binding, rolling and harrowing; and as a "stationary" engine for threshing, stacking, hay-baling, chaff-cutting, grinding, sawing, pumping, &c. The normal design comprises a stoutly-built four-cylindered, water-cooled, four-stroke vertical engine of the motor-car type, foot-operated clutch and brake, and 2-, 3-, or 4-speed gear-box, with reverse, from which the rear wheels are driven either by chains or gearing. A typical illustration is shown in fig. 8.

The tractor usually hauls the plough, cultivator, cutter and binder, or other implement over the land, while for stationary work a belt pulley is fitted. Engines are usually started on petrol, and turned on to paraffin as soon as they are warmed up; " impulse " starters are frequently fitted to the ignition magnetos, to facilitate starting in cold weather. The tractors of 1924 were, generally, specified as capable of:

1. Ploughing three 10-in. furrows 6 in. deep in medium land on low gear; or two furrows in heavy clay land.

2. Hauling a load of 4 tons at 5 miles per hour and climbing a gradient of 1 : 12 therewith on ordinary hard road surfaces.

3. Driving a 54-in. threshing machine or other stationary farming machinery from an 18-in. to 20-in. pulley running at 450 to 650 r.p.m., by means of a 5-in. or 6-in. belt.

The leading particulars of four typical tractors are given on p. 50.

An average daily performance is as follows:

Ploughing.—4 to 4½ ac., using 2½ to 3½ gall. of paraffin per acre, dependent upon the nature and condition of the land.

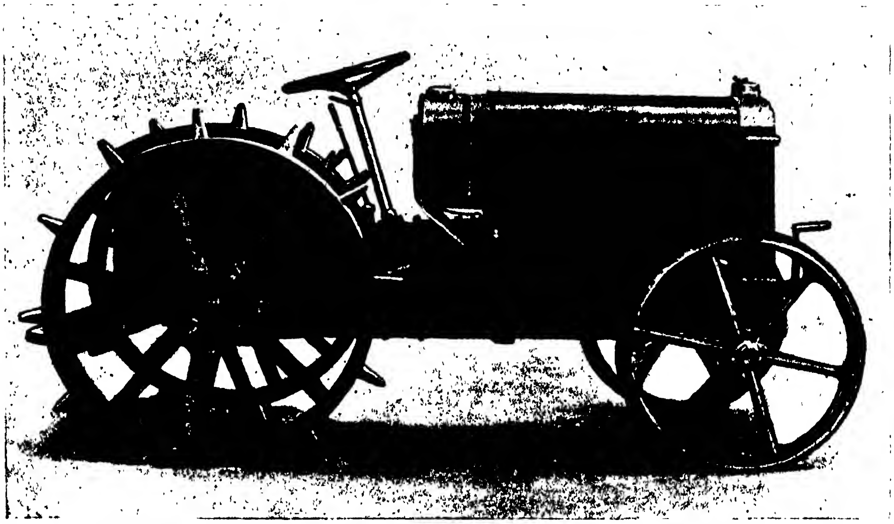

Fig. 8 —Illustration of Typical Farm Tractor

Cutting and Binding.—16 to 24 ac. per day with 6-ft. or 7-ft. binder, using about ¾ gall. of paraffin per acre.

Threshing.—With a 4-ft.-6-in. thresher, about 2 gall. of paraffin per hour

Lubricating-oil consumption in good cases is from ½ to ¾ pt per acre in ploughing.

The following is a verbatim copy of a report by an owner, of actual performance in the normal daily work on a Lincolnshire farm:

". . . The tractor started work on March 18th, 1920, and was worked every weekday up to December 10th, 1920, without a stop. You can go to the tractor in the morning and she will start with the second pull-up of starting-handle.

" During the 236 working days the tractor has ploughed 424 acres and dragged 304 acres, two days' threshing and 12 days' sawing with 30-in. circular saw. It also cut with self-binder 160 acres of corn. For the ploughing and dragging of the 728 acres it has used 2⅞ gallons of paraffin per acre, and 3 pints of oil per day; sawing and threshing, 7 gallons of paraffin and 3 pints of oil per day."

Running Costs.—The very varied nature of the services these tractors are called upon to render makes it impossible to give more than a somewhat general estimate of running costs. A useful statement, deduced from experience, of the approximate work that is ordinarily obtained per brake horse-power hour with small plants is given as follows:

APPROXIMATE WORK OF ONE BRAKE HORSE-POWER HOUR WITH SMALL PLANTS

1. Raise 1000 gall. of water, or sewage, 100 ft.
2. Cut 75 ft. of 9-in. deal.
3. Grind 1¼ bushels of corn to fine meal.
4. Crack or "kebble" 8 bushels of corn.
5. Cut 4 cwt. of straw to ½-in. chaff.
6. Separate 180 gall. of milk.
7. Make 12 lb. of ice with a refrigerator.
8. Maintain 200 c. ft. air at a temperature of 32° F.
9. Cool 80 gall. of milk to 25°.
10. Churn 40 to 50 gall. of cream.
11. Break 8 cwt. of stone.
12. Hoist 3 tons 200 ft. vertically.
13. Maintain a 1000-candle-power arc lamp.

Figures furnished by a farmer-owner for a two years' use of a tractor have enabled the author to compile the following as a typical costs statement:

FARM TRACTOR: ESTIMATED AVERAGE RUNNING EXPENSES, 1921 AND 1924. 285 WORKING DAYS PER YEAR

	1921.	1924.
	£	£
Interest on capital cost of tractor at 8 per cent (1921), and 6 per cent (1924)	0·100	0·048
Depreciation at 20 per cent per annum	0·246	0·154
Adjustments and repairs at £40 per annum	0·140	0·140
Petrol at 3*s*. 1*d*. (1921), and 1*s*. 6*d*. (1924), per gallon; about ⅓ gall. per day	0·051	0·025
Paraffin at 1*s*. 6*d*. (1921), and 10*d*. (1924), per gallon; average 10 gall. per day	0·750	0·417
Lubricating oil at 6*s*. (1921), and 3*s*. (1924), per gallon; average 3 pt. per day	0·113	0·057
Driver at 60*s*. per week (1921); 40*s*. per week (1924)	0·500	0·333
Total running cost per working day	1·900	1·174

Thus, on a liberal estimate, the total running cost fell from 38*s*. per average working day in 1921 to 23*s*. 6*d*. in 1924, for a 5-years' life of the machine. The year of 285 working days is obtained by deduction from the whole year of 52 Sundays and 28 days for holidays and time for overhauls and repairs. Tractors of the type here discussed are found to replace about six horses; they can be driven and tended by any intelligent labourer or boy; and the farmer enjoys the advantage of getting his work done on the land quickly and well immediately favourable conditions occur.

LEADING PARTICULARS OF FOUR TYPICAL FARM TRACTORS

Name.	Engine.		Forward Speeds in Miles per Hour.	Length × Width. Feet.	Total Weight (approx). Cwt.	Turning Radius in Feet.	Price in England,		Remarks.
	Bore × Stroke. Inches.	Revolutions per minute.					July, 1921.	July, 1924.	
							£	£	
British Wallis..	$4\frac{1}{4} \times 5\frac{3}{4}$	850	2·3 and 3·4	11 × 5·0	37·0	10	420	350	Fitted with Impulse Starter
Austin.. ..	$3\frac{3}{4} \times 5$	1200	$2\frac{1}{2}$ and $4\frac{1}{4}$	9·2 × 5·1	26·0	12	360	225	Price d/d Austin Works
New International Junior	$4\frac{1}{4} \times 5$	1000	$1\frac{3}{4}$, $2\frac{1}{2}$, and 4	10·25 × 5·0	32·2	15	350	260	Fitted with Impulse Starter
Fordson ..	4×5	—	3 forward speeds	8·5 × 5·2	26·0	—	235	136	Price includes belt pulley

The approximate brake horse-powers developed by the four engines, on paraffin, are 27, 25, 29, and 22, at the stated revolution speeds.

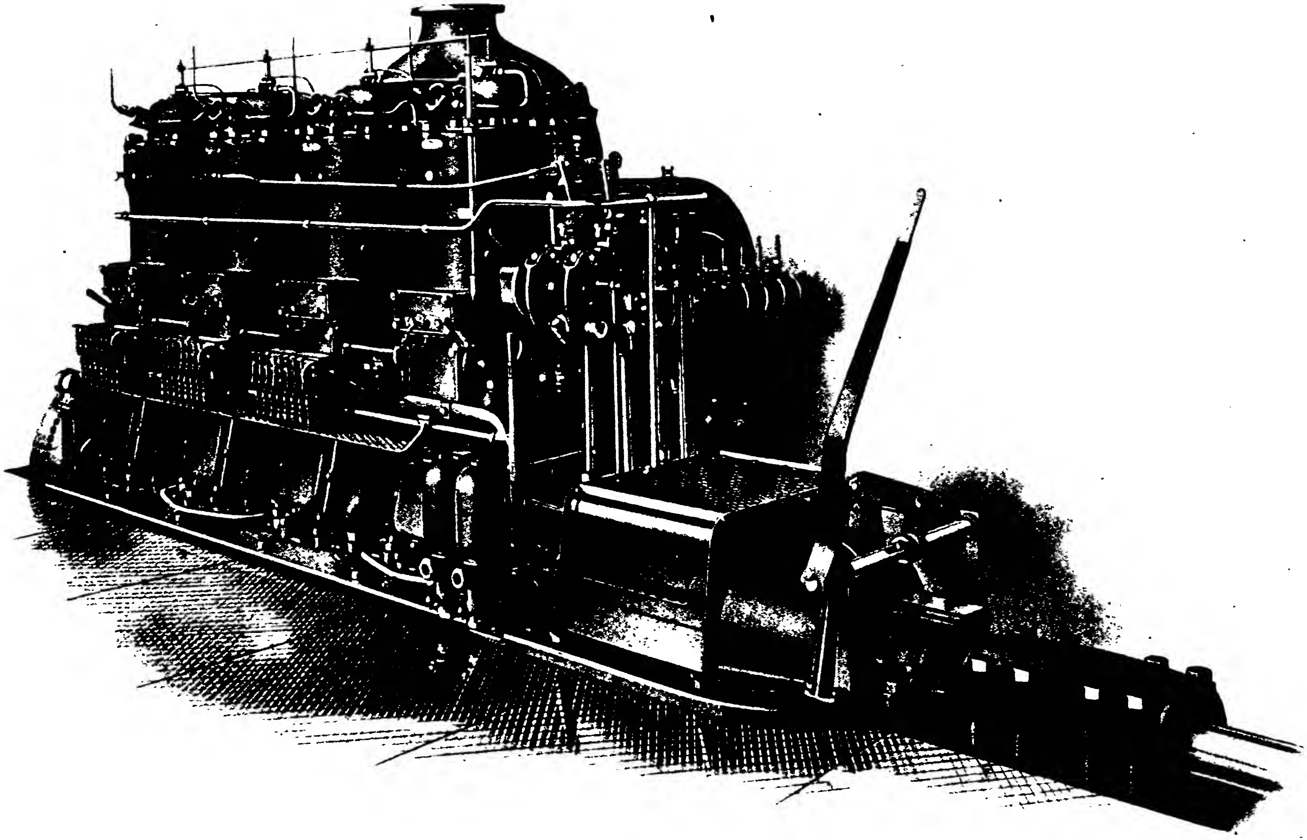

Fig 9.—View of Four-cylinder Bolinder Two-stroke Heavy Oil Marine Engine

Marine Applications.—In addition to many large steam-going vessels propelled by Diesel engines there is a great number of coasters and trawlers equipped with internal-combustion oil engines most commonly of the " hot-bulb " or " semi-Diesel " type. As an illustration of this class the case of a coasting vessel fitted with the well-known " Bolinder's " crude-oil engine is selected, costs being deduced from data furnished by Messrs. James Pollock, Ltd., of London. Operating costs are given per day's work of 24 hr., as the runs with vessels of this type are usually of short duration.

The engine referred to in the figures for 1913 and 1921 was the then standard four-cylinder four-crank vertical single-acting two-stroke Bolinder of 16½-in. bore and 18⅞-in. stroke, developing a normal maximum of 320 b.h.p. at 225 r.p.m.; this engine used air-blast injection with air furnished from the starting reservoir. The figures for 1924 relate to the improved 16½-in. × 18⅞-in. engine giving 350 b.h.p. maximum, at 225 r.p.m., using " solid " fuel injection, and accordingly requiring only a small two-stage compressor to maintain the starting air reservoir; this improved engine was fitted also with electric starting apparatus, rendering unnecessary any preliminary heating of the bulbs by blow lamps. An illustration showing this improved 350-b.h.p. engine is given in fig. 9. Capital and operating costs are estimated as follows:

CAPITAL OUTLAY

Item.	1913.	1921.	1924.
	£	£	£
One engine (320 h.p., 1913 and 1921, and 350 h.p., 1924) complete with all accessories, installed in ship	3040	8352	4500
∴ Total capital cost per B.H.P. installed	9·50	26·10	12·86

OPERATING COSTS PER DAY OF 24 HOURS.

320 B.H.P. (1913 and 1921). 350 B.H.P (1924)

Item.	In 1913.	In 1921.	In 1924.
	£	£	£
Interest on capital 5 per cent (1913), 8 per cent (1921), 6 per cent (1924)	0·42	1·83	0·74
Depreciation at 5 per cent per annum	0·42	1·14	0·62
Maintenance and repairs	0·62	4·10	1·85
Fuel oil, 4120 lb. per day. 34*s*. per ton (1913); 206*s*. per ton (1921); and 135*s*. per ton (1924)	3·14	19·00	13·00
Lubricating oil..	1·20	2·40	2·00
Attendance	0·68	1·64	1·50
Grease, waste, and general consumable stores ..	0·11	0·27	0·25
Total operating costs per day	6·59	30·38	19·96

It will be noted that the cost of the fuel oil is by far the largest item, amounting to 47·7 per cent of the total in 1913, 62·6 per cent in 1921, and

65 per cent in 1924. If the engine be assumed to average half its maximum power output there would be, for 1924, an average of 175 × 24 = 4200 b.h.p.-hr. per day, with a corresponding total operating cost of 1·14*d.* per brake horse-power.

5. CONCLUSION

Study of the cases herein discussed should enable a good general idea to be formed of the cost of power production by internal-combustion engines in selected typical instances. Circumstances vary so very greatly in different cases as to render impracticable any general conclusions; it becomes necessary, therefore, to examine in detail each case that arises in order to decide what type of power plant will best fulfil the requirements.

It is apparent that within the present century the applications of the internal-combustion engine have become enormously extended, and its distribution is now world-wide; it has profoundly affected the conditions of human life in recent years both in peace and war. The great variety of fuels utilized—many until quite lately absolutely waste products—the high economy of fuel consumption in even the smallest engines, their compactness, relative lightness, safety, and universality of application united render the internal-combustion engine one of the greatest of the many boons conferred upon the community by the modern engineer.

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