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THE DIESEL ENGINE AND SOME OF ITS APPLICATIONS.

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The Diesel engine is an internal combustion engine, primarily intended to work with liquid or solid fuels, being radically different in working principles and method of carrying out combustion to all other types of internal combustion engines. It was thought that it might be of interest if these differences were not only duly noted, but that the evolution of the principles of the cycle, together with their practical development in the engine, should be carefully considered. The author, however, is fully aware that these aspects are of use only in understanding the bases of operation, and that probably the most important factors to the members of this Institution and those whom they serve, viz., the Australian public, are the possibilities of application and their economic value, together with present and future development therein.

Herr Rudolph Diesel, the eminent scientist who enunciated the theory and working principles of the engines which bear his name, after a most exhaustive examination of the method of combustion and cycle of operations of the existing types of heat engines, as compared with the ideal of the Carnot cycle, came to the conclusion that their underlying principles were wrong, and that if any material improvement in efficiency were to be obtained new methods of combustion and operation would have to be adopted. In coming to this conclusion Herr Diesel, no doubt, was influenced by the works of Beau de Roches, who in 1862 first drew attention to the fact that to attain high economy of operation the maximum pressures should be at the beginning of the stroke and obtained by compression of the air. He further pointed out that this high compression might be utilised to ignite the charge, owing to the consequent heat. Brayton also in 1873 first drew attention to the advantages of combustion at constant pressure with compression in a separate cylinder, and several attempts were made to utilise this cycle, notably by Simon, of Nottingham, Hennig and Co., in Germany, and Foulis, of Glasgow, who, however, failed, chiefly apparently because their attention was expended in recovering the waste heat of the cooling jackets and exhaust gases, instead of perfecting the efficiency of combustion. The difference in the results obtained by these experimenters and Diesel, who first theoretically constructed his cycle, and then attempted to construct an engine to operate on it, is perhaps noteworthy of attention in emphasising the need of scientific training for success in engineering. With these precedents, and the result of his own theoretical analysis, Diesel formulated the following conclusions as necessary for the cycle of the ideal motor:—

(1) The highest temperature in the cycle of operations must be produced by isothermal and adiabatic compression of the air alone, and should be as high as is attainable.

(2) The combustible must be gradually introduced in the highly-compressed and, therefore, heated air in so fine a state of atomic separation that spontaneous combustion is set up, thereby supplying the heat necessary to maintain the gases at constant temperature—i.e., that of the compression during the whole period of fuel admission.

(3) That the air supplied during combustion must be greatly in excess of the theoretical quantity required, and must be definitely proportioned to the heat value of the fuel, in order that the maximum temperature of compression may be maintained, which temperature must be predetermined, so that the engine may be lubricated and worked without the use of a water jacket, resulting in a complete cycle, as follows:—(1) Isothermal and adiabatic compression to the maximum pressure and temperature; (2) isothermal combustion; and finally, adiabatic expansion to atmosphere.

Fig. 1, illustrates the cycle which could be as follows in a single-cylinder 4-stroke engine:—

(1) Forward stroke of piston; drawing in atmospheric air to volume a.

(2) Return stroke of piston; isothermal compression to volume b—i.e., with water injection, and thence on to volume c without water injection (adiabatic compression).

(3) Second forward stroke; isothermal combustion of a small quantity of fuel gradually injected, the piston being driven out to d, followed by adiabatic expansion without combustion.

(4) Second return stroke; discharge of gases.

In passing, it is interesting to note the pressures and temperatures. Combustion takes place from volume c—0.8 litres (=4.87 Cu inches) to volume d —2.24 litres. From thence to the final volume a of 19.1 litres the gases expand to atmospheric pressure expansion, ratio 23.9. The temperatures are 800 deg. C.=1472° F. during combustion, to 223° C.=473° F. exhaust. On these "theses" an experimental engine was built in 1893 to burn coal dust; the high pressures and expansion ratios adopted necessitated the use of three cylinders without water jackets, and most valuable experience and data were obtained, especially with regard to how far materials and method of construction at present in use allow of the ideal being carried out in practice. After two years' of experiment and discussion of results the following modifications were introduced as tending to greater ease of construction, whilst at the same time making only a very slight reduction in the thermal efficiency. The modifications were as follow:— (1) Adiabatic compression was solely used, thereby enabling the high temperature necessary being obtained at greatly decreased pressure, at the same time saving the complication attending water injection, but entailing increased loss through the higher temperature of the exhaust. (2) The expansion was not continued to atmospheric pressure, in order to reduce the cylinder dimensions and cost thereof for the output. The results of these changes are shown on Fig. 2, An engine was built and worked on this cycle; it had water jacket; the maximum compression temperature was 700° C, at a pressure of 64 atmospheres, or 910 lbs. per sq. inch, with a theoretically possible thermal efficiency of 64 per cent., and actually attained 26 per cent. on a mechanical efficiency of 71 per cent. It was afterwards found necessary for building large engines to still further reduce the pressure of combustion to from 30 to 40 atmosphere (450-570 lbs. per sq. inch)—i.e., at constant pressure—instead of isothermally, resulting in such increased temperatures that the water jacket became necessary, which is prac tically the existing type.

The result of these modifications from the theoretical ideal and the practically possible is shown on Fig. 2, and is further compared with an actual indicator card.

Description.—Adiabatic compression d h f, practically attainable; isothermal combustion f fl a, theoretically desirable; adiabatic expansion a b, practically attainable (broken line). The actual card for the 80 b.h.p. engine being d e h a c, the curve a c indicates the higher temperatures of the actual gases over what would be the case if the curve f a could be attained; at the same time the maximum pressure attained is lower and the mean pressure higher than the theoretical card gives. The thermal efficiency is, of course, lower, but still both the theoretically possible and the actually obtained thermal efficiencies are much higher than for any other type of engine.

The Diesel engine, as now made, has the following cycle of operations:—First stroke takes in air alone at atmospheric pressure and temperature. Second stroke compresses this air to a high pressure (35 atmospheres equals 500 lbs. per sq. inch), and to a temperature of about 1000° F. This compression is neither isothermal nor adiabatic, since the operations are conducted in a water-jacketed conducting cylinder. Third stroke is the working stroke, during the first part of which the combustion of the fuel is carried on at constant pressure for a period which is determined by the amount of oil to be sprayed in, which quantity is controlled by the governor. The second part of this stroke is approximately an adiabatic expansion. Fourth stroke exhausts the gases.

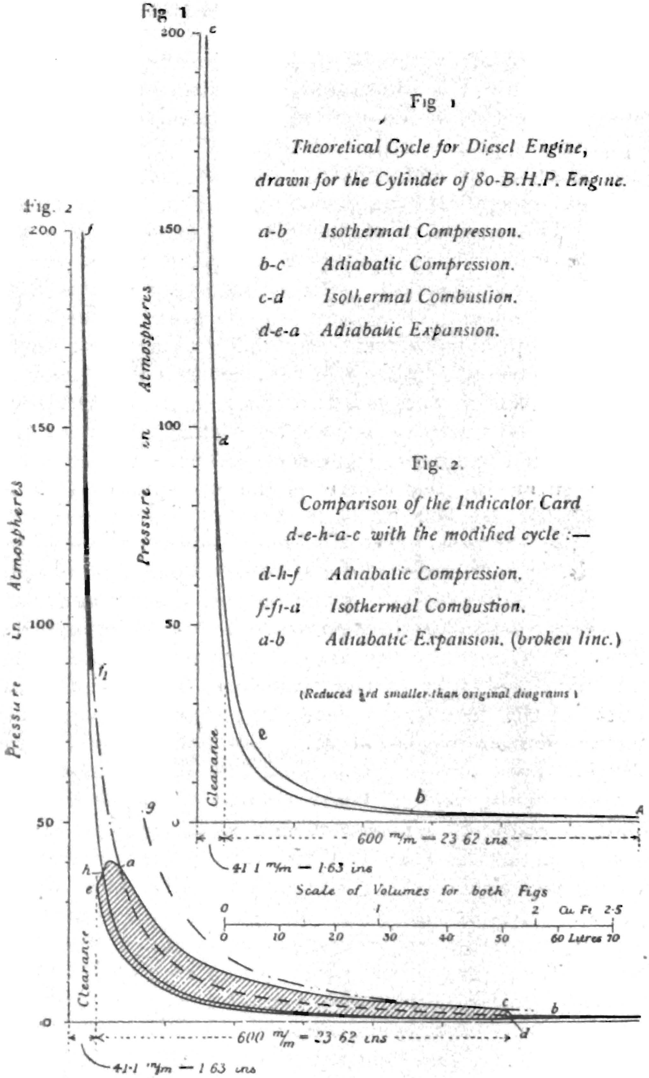


Fig 1

Theoretical Cycle for Diesel Engine, drawn for the Cylinder of 80-B.H.P. Engine.

a-b	*Isothermal Compression.*
b-c	*Adiabatic Compression.*
c-d	*Isothermal Combustion.*
d-e-a	*Adiabatic Expansion.*

Fig. 2.

Comparison of the Indicator Card d-e-h-a-c with the modified cycle :—

d-h-f	*Adiabatic Compression.*
f-f₁-a	*Isothermal Combustion.*
a-b	*Adiabatic Expansion. (broken line.)*

(Reduced ⅓rd smaller than original diagrams)

PRESENT DAY PRACTICE 80 B.H.P. ENGINE.

This size of engine is made by Carels Freres, Ghent. On Figs. 3 and 4 is illustrated a longitudinal section and a transverse section of the engine, with standard arrangements of piping for petroleum, lubricating oil, cooling water, air blast, starting air and exhaust; in fact, all the engine connections, except the water-cooling tanks, when such are used. The engine is of the vertical type, with a strong cast-iron frame, the upper part of which forms the outer wall of the water jacket. Into this upper part is fitted a cylinder of special close-grained cast-iron. The cylinder cover is deep and hollow, being thoroughly water-jacketed. In the transverse section will be seen two valves; the central one is the oil sprayer, the other is the starting valve, which may be made to act as the suction valve for the air pump. In the longitudinal section three valves are seen in the cover—in the centre is the oil sprayer (for detail see Fig. 6), on the right is the air inlet, and on the left is the exhaust valve. The oil-spraying valve opens upwards, or outwards, and the others open downwards, or inwards. All three are spring closed, the air and exhaust valve being kept closed by pressure inside the cylinder. All valves are opened by the action of the bent rocking levers seen upon the right in the transverse section; the movements of the levers are determined by the cams placed upon the horizontal cam shaft. The cam shaft is driven at half the speed of the crank shaft by means of the bevel gearing and the vertical shaft seen on the right in the longitudinal section. The governor is of the loaded centrifugal type, and is placed at the top of the vertical shaft; its action is explained in connection with the oil pump (Fig 5). The piston is of the usual open trunk type, directly connected to a connecting rod of the marine type. There are seven piston rings of the Ramsbottom type—six near the top, and one much lower, in order that it may pass the lubricating channels. The crank shaft is solid, and has three bearings fitted with ring lubricators. The flywheel is built in halves, and on the inner edge of the rim is a toothed ring, into which work two ratchet pawls, actuated by a rocking lever; this device is for bringing the engine into the starting position—that is, with the crank

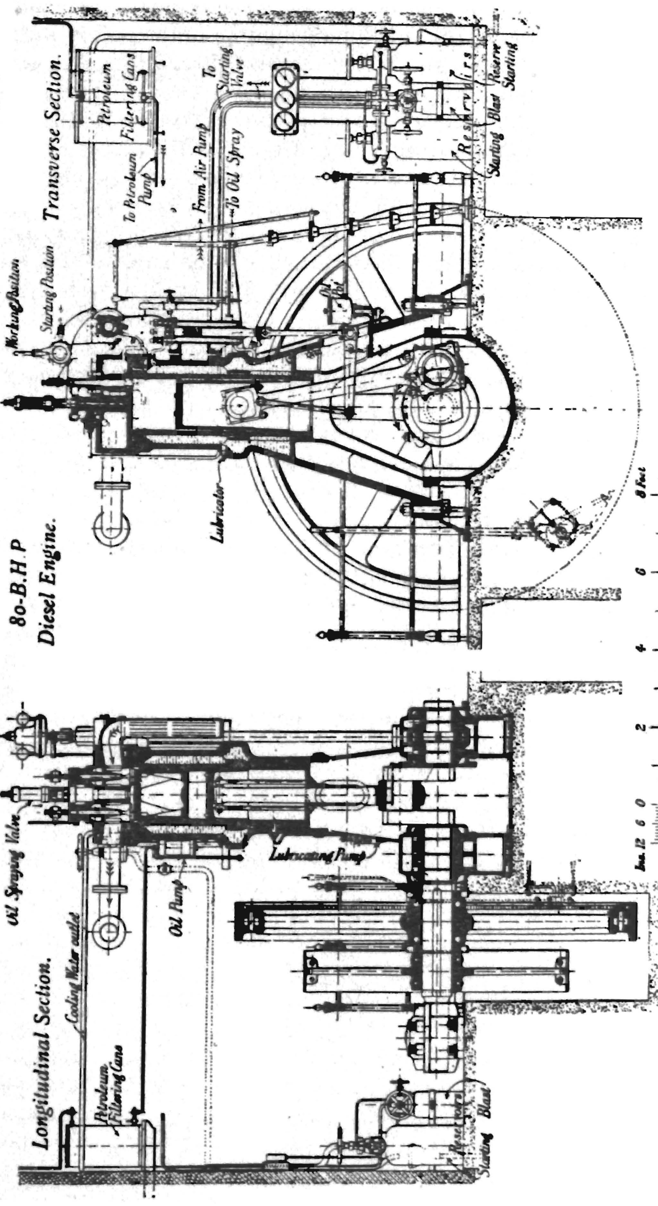


Fig. 3. Longitudinal Section.

80-B.H.P Diesel Engine.

Fig. 4 Transverse Section.

just above its top dead centre. On the left of the longitudinal section (Fig. 3) is the petroleum pump. This pump is connected by a pipe to the petroleum filtering tanks, and by a pipe of small bore to the oil-spraying valve. The plunger of this pump is driven by a crank pin placed in a disc at the end of the cam shaft and so has a constant stroke. On the right of the transverse section (Fig. 4) is the air pump. Its cylinder is thoroughly water-jacketed, and the plunger is driven by connecting rod, rocking levers, and connecting links from the small end of the connecting rod. This pump takes its air from the engine cylinder just before the end of the compression stroke, still further compresses this air and delivers it to the air-blast reservoir. In the earlier designs the pump took its air direct from the atmosphere, and was then much more bulky and less efficient. This practice has again been reverted to, as it reduces the wear and tear. The air-blast reservoir is the smaller one on the right of the cross section, and is connected to the oil-spraying valve for injecting the petroleum into the cylinder against the high pressure of 35 atmospheres, or 500 lbs. per sq. inch, already existing there. For this purpose the pump maintains a steady pressure in the reservoir of 5 to 15 atmospheres higher—that is, from 40 to 55 atmospheres, or from 580 to 880 lbs. per sq. inch. It is also connected by an overflow valve to the air-starting reservoir, this valve allowing air to pass from the blast to the starting reservoir when the pressure in the former exceeds a predetermined value.

The cylinder lubrication is forced by means of the pumps seen on the left of the engine in the longitudinal section, the lubricant entering at five or six points in a horizotal plane, below which one piston ring passes. The crank is lubricated by the ring and oil ways seen in the longitudinal section. The lubricant is forced to the small end of the rod inside the piston. The water jacket is very complete, as the section shows, entirely enveloping the engine cylinder walls and end, and also the air pump. The water enters at the bottom of the engine jacket, and passes upwards through this jacket and the air pump jacket, from the top to the cylinder cover, the outlet being close to the exhaust pipe. The oil-spraying or pulverising valve is

80-B.H.P. Diesel Engine.

Fig. 5. *Oil-fuel Pump.*

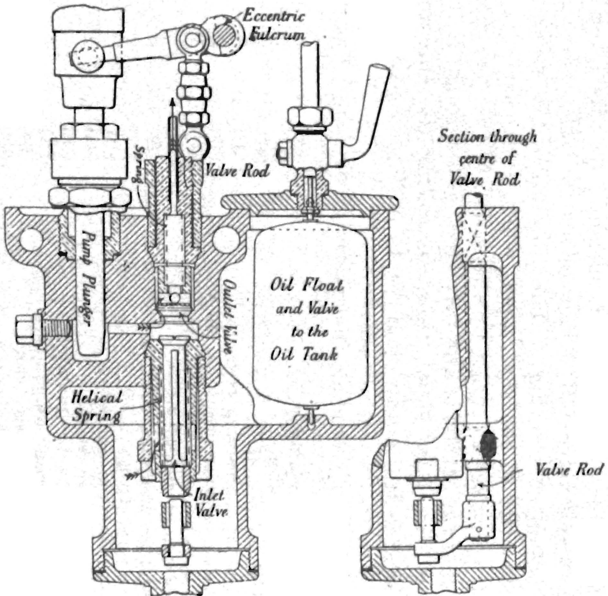
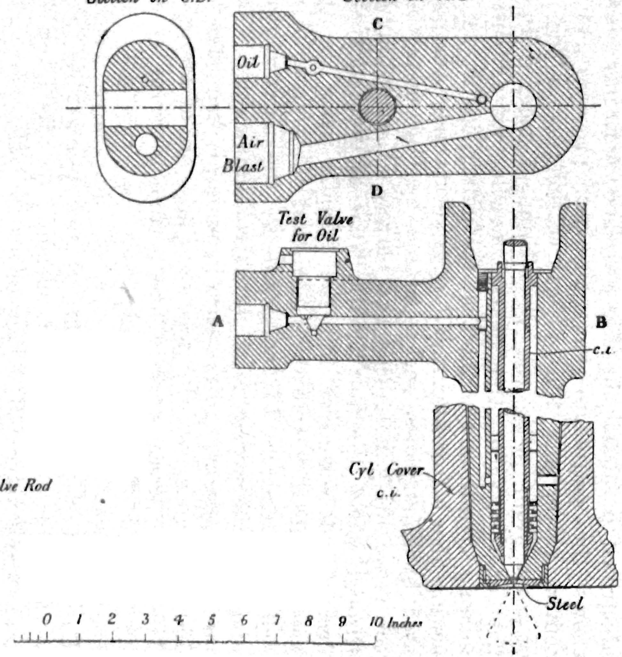


Fig. 6. *Oil-spraying Valve.*



illustrated in detail in Fig 6. The horizontal section shows the petroleum and air-blast passages to the central valve, and the vertical section shows the body of cast iron, with the petroleum passage and overflow or test valve, the central needle valve, with its guiding sheath, and at the base the pulverising device, consisting of a set of four metal rings of special form, perforated by small holes and separated by four metal bands; the terminating nosepiece has narrow channels cut in it, through which the pulverised oil passes to the expanding orifice, and is sprayed into the cylinder when the needle valve is raised. It will be seen that the petroleum pump delivers petroleum to the nozzle by the narrow passage, and that the nozzle is in direct communication with the airblast reservoir, the pressure in which is kept steadily at 150 lbs. higher than the maximum pressure of compression. The device works well. The petroleum pump is shown in Fig. 5. The plunger has a constant stroke, being driven from the end of the valve cam-shaft. Passing through the head of the plunger is a lever working upon an eccentric fulcrum; to this lever is attached the valve rod, which opens the inlet valve against the action of a spring. The fulcrum of the rocking lever is eccentric to the shaft upon which it is placed, and this shaft is caused to rotate by the action of the governor, thus altering the stroke of the valve rod, and through it the opening of the inlet valve, thus controlling the amount of oil passing to the pump chamber to be forced past the outlet valve to the injecting valve.

Table 1.—Leading Dimensions of 80 b.h.p. Engine.

	Mm.	Ft.	In.
Diameter of cylinder	400	1	3.75
Stroke of piston	600	1	11.62
Length of piston	905	2	11.65
Length of connecting rod	1610	5	3.4
Distance between crank bearings	920	2	7.5
Distance between flywheel bearings	1440	4	8.7
Diameter of flywheel	3400	11	1.8
Air pump diameter	60	0	2.36
Air pump stroke	140	0	5.5
Blast reservoir diameter	204	0	8.03
Blast reservoir length	900	2	11.42
Starting reservoir diameter	340	1	1.38
Starting reservoir length	1785	5	10.27
Petroleum filters' diameter	330	1	1
Petroleum filters' length	600	1	11.62

Table 1.—Leading Dimensions of 80 b h.p. Engine —*Continued.*

	Mm.	Ft.	In.
Over-all length of engine (including railing.)	3900	13	2.6
Over-all width of engine (including railing.)	3900	13	2.6
Over-all height of engine (including railing.)	3900	13	2.6
Depth below floor of engine	1500	4	11.1
Depth of foundations	2400	7	10.6
Height required for erection	5900	19	4

There is a controlling device shown, by which the inlet valve can be held open, thus allowing the plunger to pump back the oil to the pump reservoir tank, instead of passing it on to the engine by way of the outlet valve. The tappet of this device encircles the valve rod foot tappet.

STARTING AND RUNNING OF THE ENGINE.

The engine is started by compressed air, which is stored in the starting reservoir under a pressure of about 55 atmospheres, or 800 lbs. per sq. inch, by the air pump during the previous run of the engine; or, in the case of a new engine, the makers send out these reservoirs ready charged. There is little or no danger of these vessels losing a charge. Engines of this type have been started up on air stored as long as 8-9 months before the engine was started from them. Assuming the engine to be left standing from the previous days run, the procedure for starting would be:—(1) See that all lubricators are in order; (2) see that the pretroleum tanks are charged; (3) open the test cock on the oil-spraying valve, using the oil pump as a hand pump, and, if necessary, charge oil-spraying valve with petroleum; (4) by means of the hand lever rack the engine over till the crank is just past its top dead centre; (5) pull over the lever which puts the starting lever into connection with the starting cam (see starting position on transverse section, Fig. 4); (6) open the screw down valves of the blast reservoir and the starting reservoir. The engine now starts off as an air-driven engine. Allow it to make five or six revolutions under this condition, and then throw back the lever; the engine will then start on its normal cycle, as an oil engine. Fig. 8 shows the starting card.

The actual starting of the engine is very simple and quite certain, and the author has seen this operation successfully performed on all occasions, whether the engine has been stopped for a few minutes or for days, and can be easily carried out by one man. The normal running of this engine is on the ordinary four-stroke cycle, with the following distinguishing characteristics:—

(1) Very high compression of the air, to about 500 lbs. per sq. inch, and a temperature of 1000 deg. F., so that the fuel burns at once on being injected, needing no igniting device whatever, and, further, making preignition impossible.

(2) The gradual injection of the fuel into this volume of highly-heated air, by means of a blast of air at about 100 to 150 lbs. per sq. inch higher pressure than is already in the cylinder.

(3) The gradual and complete combustion of the fuel, as distinguished from the explosive combustion of the ordinary type of gas or oil engine.

TABLE 2.—80 B.H.P. DIESEL ENGINE.

Test of Single-Cylinder Diesel Engine at Carels Freres', Ghent, on 7th February, 1903.

This trial was run by Professor Ade Clark in response to the request of Mr. A. J. Lawson (engineer to the British Electric Traction Co.), Mr. H. W. Anderson (London), and the author, when on a visit of inspection to Messrs. Carels Freres' works at Ghent. Preparations for running this trial not having been made, it is not so complete as some others.

SUMMARY OF RESULTS.

1. Load	0.25	0.5	0.75	Full
2. Duration in Minutes	30.5	30.1	32	30.75
3. Total revolutions	4.890	4.863	4.800	4.797
4. Revolutions per minute	163	161	160	160
5. Mean effective pressures	48.5	68.4	89.1	109.4
6. Indicated horse-power	46.8	67.0	82.8	101.5
7. Effective	24.8	45	60.8	79.5
8. Electrical	17.3	35.6	52.1	68.8
9. Mechanical efficiency	53	67.0	73.5	78.3
10. Total oil in pounds	8.38	10.73	Lost	17.63
11. Oil per I.H.P. hour	0.352	0.320	—	0.339
12. Oil per effective H.P. hour	0.664	0.477	—	0.434
13. Oil per electrical H.P. hour	0.952	0.601	—	0.500
14. B.Th.U'S per 1 H.P. minute	114	104	—	111
15. Thermal efficiency on the 1 H.P., per cent.	37.2	40.8	—	39.9
16. Thermal efficiency on the B.H.P. per cent.	19.7	23.3	—	31.2

The transmission to the dynamo consisted of a belt to a line shaft, and a belt from the shaft to the dynamo.

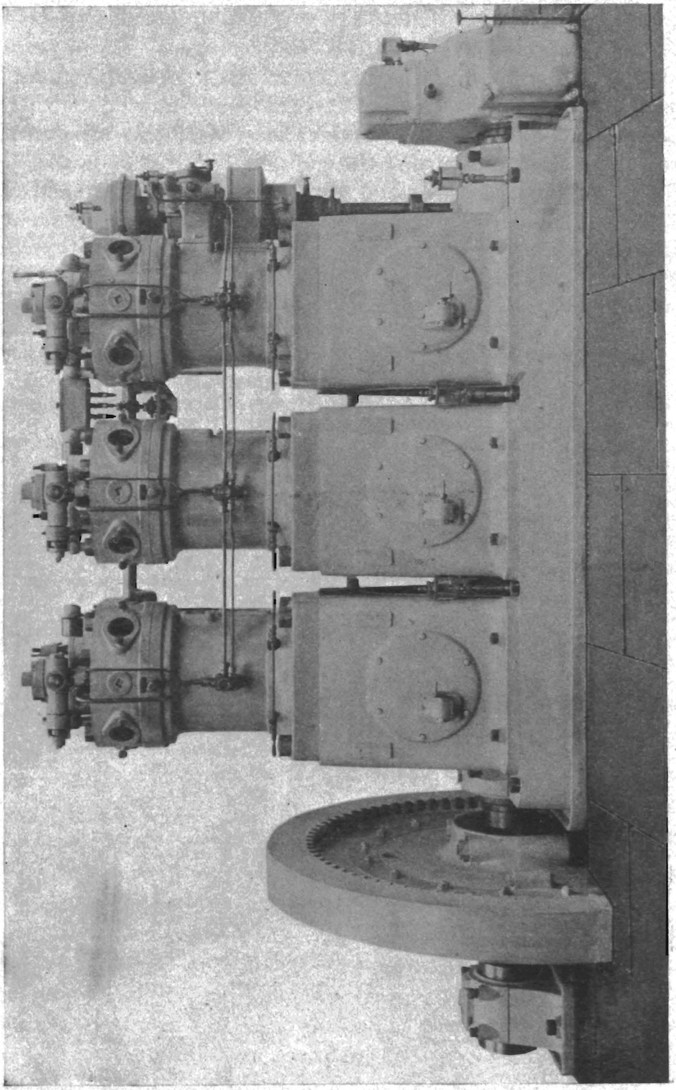


Fig. 5A.

There was also belted to the shaft a motor which was running light.

Fig. 9, which is omitted, showed a card taken from the air pump supplying the air reservoirs. Various modifications have been made by different manufacturing firms; nearly all have now done away with the air-pump drive by rocking lever from the gadgeon pin, as it is much more simply arranged driven direct from the crankshaft. Fig. No. 5A shows an engine of the four-stroke type (recent design), arranged to run at 300 r.p.m., having three cylinders. The air pump, it will be noted, is mounted direct on the crankshaft end, and all the gear is more simply arranged.

TABLE 3.

160-B H.P. Diesel Engine.

Test of Two Cylinder Diesel Engine at Messrs. Carels Fréres, Ghent, on 7th March, 1903.

SUMMARY OF RESULTS.

1. Load	Full	0.53	0.375	0.25	None
2. Duration in minutes	60	60	61	60	30
3. Total revolutions	9,258	9,424	9,639	9,476	4,770
4. Revolutions per minute	154.5	157	158	158	159
5. Mean effective pressures, L	113.4	64.7	51.9	38.2	46.2
,, ,, R	114.5	74.1	60.7	46.2	39.7
6. I.H.P. cylinder, 4L	101.0	59.1	46.6	34.4	42.6
,, ,, 5R	103.4	67.7	53.4	40.5	36.7
7. ,, total or mean	204.4	126.8	100.0	74.9	39.64
8. ,, or air-pump	3.6	3.25	3.0	2.97	2.98
9. Net I.H.P. from the oil	201.1	123.6	97.0	71.93	36.66
10. Effective horse-power	164.8	87.2	60.4	35.4	—
11. Mechanical efficiency	80.7	68.8	60.4	49.2	—
12. Total oil in pounds	67.0	40.58	30.45	25.6	7.6
13. Oil per net I.H.P. hour	0.333	0.329	0.309	0.356	0.415
14. ,, ,, effective H.P. hour	0.408	0.465	0.505	0.724	—
15. Cooling water per minute	49.6	43.0	26.25	16.1	—
lbs .. inlet	9.5	9.5	9.5	9.5	10.0
16. Temperatures of water C outlet	62.0	52.5	60.5	65.5	67.0
17. Change of temperature	52.5	43.0	51.0	56.0	57.0
18. Temperature of exhaust C	384.0	239.0	197.0	158.0	—
19. B.Th.U. per net I.H.P. minute	108.0	106.0	102.0	114.0	154.5
20. ,, converted to work	42.4	42.4	42.4	42.4	42.4
21. ,, rejected in cooling water	22.9	26.3	24.3	21.7	—
22. B.Th.U. reject in exhaust gases	32.1	28.3	14.4	13.5	—
23. Thermal efficiency on net I.H.P., per cent.	39.25	40.0	41.5	37.2	—
24. Thermal efficiency on Eff. H.P., per cent.	32.3	28.3	26.1	18.3	—
Exhaust gas analysis:					
25. Carbon dioxide Vol., per cent.	7.0	4.1	3.1	2.9	—
Carbon monoxide Vol., per cent	—	—	Trace?	0.1?	—
Oxygen, per cent	11.3	15.0	16.6	17.6	—
Nitrogen by difference, per cent	81.7	80.9	80.3	80.3	—

Note.—The tap of the carbon dioxide bottle was not quite gas-tight, but was well smeared with vaseline to prevent serious leakage.

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Before passing to discuss the economic possibilities of the Diesel engine, it was thought that figures of actual tests might be of interest. Table No. 3 gives the summary of results of tests taken by Mr. H. Ade. Clark, of the Yorkshire College, Leeds, of a 160 b.h.p. 2-cylinder engine made by Messrs. Carels Freres, of Ghent, Belgium, in which it is interesting to note the fuel consumption and thermo-dynamic efficiency, which is a fair average for engines of this size. Fig. No. 8 shows indicator starting and running card, taken during the carrying out of the above test. The author has witnessed tests which were quite as good as the above, but had not such complete re-

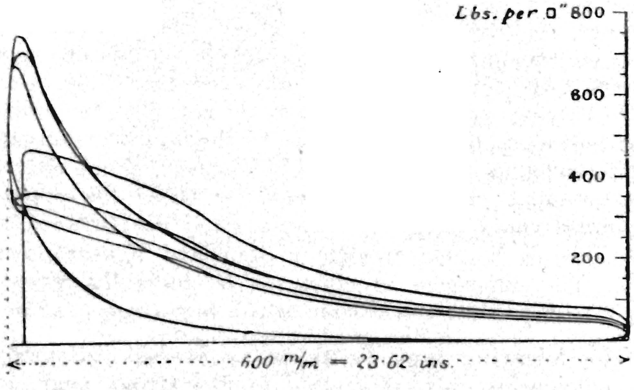

Fig. 8.—Full size Indicator Diagram from 160 B.H.P. Diesel Engine. Starting Card.

cords as they are. Engines for large powers are now being designed and built to operate on both the four-stroke and two-stroke cycles. The operations of the two-stroke cycle are as follows:—

First Stroke.—When the piston is at the bottom of the stroke the cylinder is full of pure air at atmospheric pressure, which air has just been admitted through scavenge valve. During the up stroke the air is compressed up to 500 lbs. pressure per sq. inch, as in the compression stroke of the four-cycle engine.

Second Stroke.—As in the third stroke of the four-cycle engine, fuel is injected into the cylinder, and combustion takes place at constant pressure, followed by adiabatic expansion, till the bottom of the stroke is nearly reached, when the piston uncovers the exhaust valves in the cylinder walls, and shortly after this occurs the scavenge valve is opened, admitting the scavenge air, which sweeps out the remaining gases, leaving the cylinder filled with pure air ready for compression on the up stroke. Various arrangements are adopted by different makers for the scavenge valve, some using an air valve in the cylinder cover, others using scavenge inlets in the cylinder bottom, which are controlled by external valves, or simply have ports in the cylinders, which are uncovered by the piston external valves, and are direct connected to an air pump operated by rocking lever. In either case a separate air pump is used to supply the scavenge air, as this only needs to be at a low pressure, usually not exceeding 6 lbs. per sq. inch. The two-stroke type is usually not quite so efficient in fuel consumption, chiefly due to the extra compression of the scavenge air. One would, however, think that the slight amount of work consumed by these low-pressure air pumps would have been compensated by the decreased losses due to the far smaller pistons and lighter moving parts. The difference in efficiency is generally given as from 6 to 8 per cent. in favour of the four-stroke engine.

The following may be taken as average thermodynamic efficiencies in good up-to-date four-stroke engines at full load:—

	Per Cent.
Calorific value of fuel	100
Loss in exhaust, cooling and radiation	55
I.H.P.	45
Loss—Engine friction and air pump	11
B.H.P.	34

These figures vary a good deal with the size of engine. The moderate speed engine with large cylinder dimensions easily achieves these figures. In practically all engines 31 per cent, thermodynamic efficiency should be attained. The heaviest losses are, of course, those accounted for under heading exhaust, cooling and radiation of which the exhaust gases account for from 22 to 26 per cent., and cooling water 20 to 25 per cent. These are referred to later on.

The sizes of oil engines working on the Diesel principle have rapidly increased of late. Four or five years ago a 4-cylinder engine, developing 500 h.p., was considered big, but nowadays engines developing 250 h.p. per cylinder are rapidly coming into regular use for land purposes, and more important developments are now taking place, which will be referred to later on.

The most usual application of the Diesel engine is as prime mover for electrical power generation, but a great number of Diesel engines are supplied for direct driving in industrial establishments. The trend of events, however, appears likely to still further develop in conjunction with electrical operation for both public and private power supply. The first point in the economic side which has to be tackled, however, is the question of oil supply. As is now well known, the Diesel type of engine will operate satisfactorily on nearly all the crude oils quite as well as on the residual oil which is left after the distillation of the lighter products of natural crude oil and oils distilled from coal and shales. However, on this point we cannot do better than quote Mr. Paul Rieppel, of Nurnberg, who is probably the greatest authority on the subject.

Extracted from Mr. Milton's Paper, Institution of Naval Architects, April, 1911:—

The various hydrocarbon oils which occur, either as natural products or as the result of distillation, either of brown coal, ordinary coal or crude oils, may be divided into two classes, which differ very much in their behaviour when raised to a high temperature. Those of one class, when raised to such a temperature as is obtained by the compression in Diesel engines, readily decompose into free hydrogen and heavier hydrocarbons; those of the other class at first only vaporise, or partially vaporise, and require much higher temperatures than that due to the compression for their decomposition. In those of the first class the hydrogen, because of its easy ignition, burns first, and the resulting heat enables the remainder of the hydrocarbons to become completely burnt, the total combustion taking an appreciable though small, amount of time.