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The Origin and Development of Heavy Oil Engines.

(Akroyd Stuart Award Prize Paper, 1929—Abridged.)

BY ARTHUR F. EVANS (Member).

READ

Tuesday, November 26, 1929, *at* 6.30 *p.m.*

CHAIRMAN: Mr. H. J. VOSE (Vice-Chairman of Council).

The CHAIRMAN: The paper to be presented to-night has been selected as the prize winning paper under the terms of the Akroyd Stuart Award, which was founded by Will of the late Herbert Akroyd Stuart, who was a member of this Institute and, as we all know, a pioneer of the heavy oil engine*. He bequeathed the sum of £700 to the Institute, the interest on which sum is offered every two years as a prize for the best essay on "The Origin and Development of Heavy Oil Engines" read before the Institute. The award for the first competition will be made to Mr. Evans at our Annual Meeting on March 21st next. The second competition is now open, papers for which may be submitted before April 30th, 1931. Particulars of the competition will be found in the Awards circulars which have been issued with the Transactions from time to time, and further copies may be obtained from the Honorary Secretary.

* Akroyd Crude Oil Automatic Ignition Engine. Patent 7146. May 8th, 1890.—J.A.

Mr. Evans, the author of this paper, has been associated with the introduction and development of the oil engine from the Priestman and its contemporaries; he was the proud owner of a 2 H.P. Benz motor car in 1896. He was the first to make it his exclusive business to supply marine motors and launches, and was associated with the first motor propelled fishing boat. He was responsible for the first British racing motorboat. He carried out a good deal of research work on injection and Diesel engines in the early days. For twelve years, until a few years ago, he was Chief Mechanical Engineer of the Royal National Lifeboat Institution, and was in consequence responsible for the building up of their fleet of motor lifeboats.

The rapid increase of interest in the light Diesel engine which is now taking place is very gratifying. Apparently all those who are users of this class of engine are considering the possibilities. It is rather a pity, however, that while these possibilities have been offered for some years past from British sources, they took neither action nor interest until the offer came from foreign sources.

I will now call upon Mr. Evans to read his paper.

In the introduction to the paper submitted for the Akroyd Stuart Award the author endeavoured to analyse and follow the trend of thought that had been applied to the development of the internal combustion engine from its inception; he apologised for the element of criticism that such a review must contain, and submitted the question as to what value such a review or history could assume.

In this very short abridgment of the paper, the need for an answer to this question is not so apparent, but the answer given was to the effect that, to the expert, history is somewhat prone to act as a drogue on development, though to the student, such a history, if fully developed and detailed, can form a medium for both ideas and warnings, and it was pointed out that the paper in question might form an index to these studies.

The present paper can hardly assume such functions, as it is but a brief review of some of the leading features and incidents of the life of the internal combustion engine, for it should be understood that any definite line of demarcation between gas, spirit, paraffin, or heavy oil engines cannot be drawn from the historical point of view; it is as vague as is the definition of the Diesel engine itself, but an attempt will be made to concentrate on those incidents or examples that deal with, or lead more directly towards the heavy oil engine as it now is.

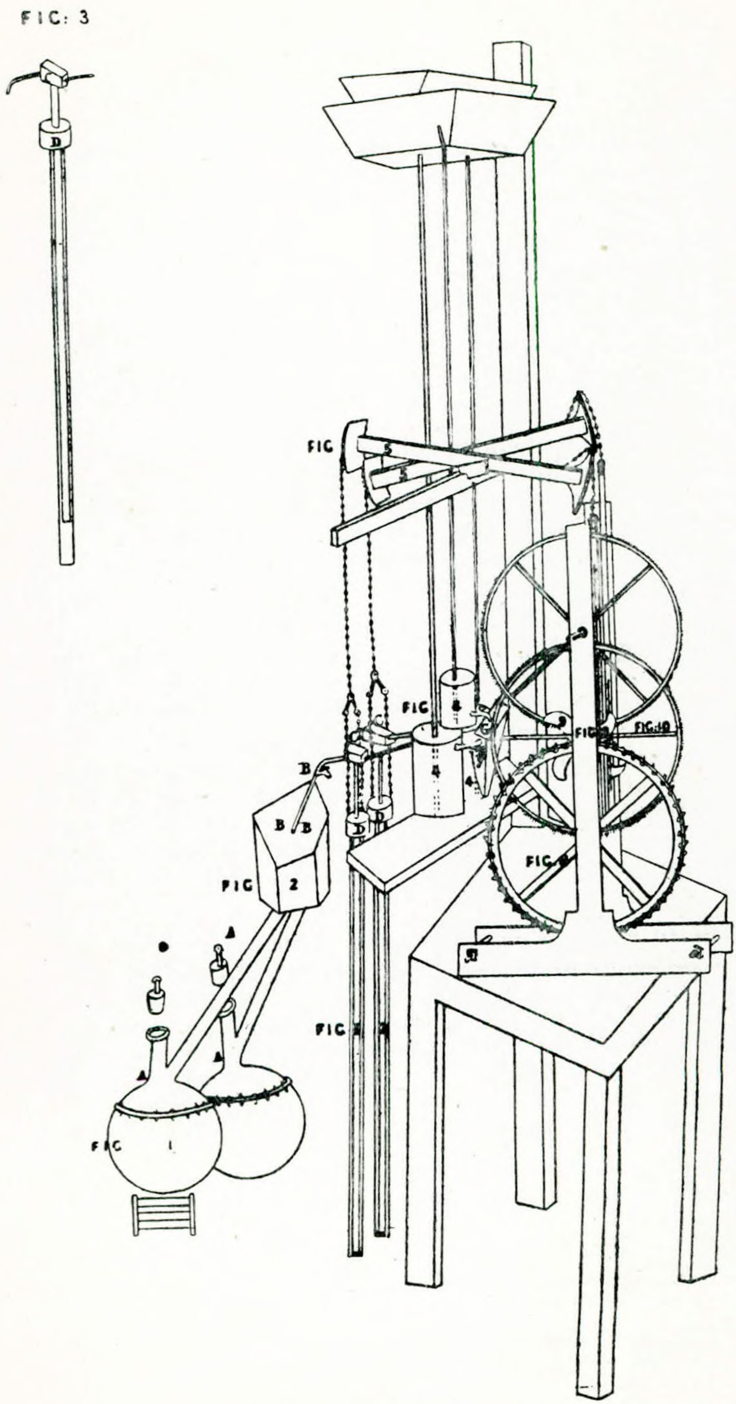
The oil or gas engine is an internally fired hot air engine, and it had its beginnings in the furnace gas engine that was to the fore in the middle of last century. In these engines air was pumped through an enclosed coal furnace, and the resultant products, heated and expanded by the furnace itself, were employed to drive a piston. What was the Brayton but an internally fired furnace gas engine? and what is the Diesel but a high pressure Brayton?

The author also pointed out that the term "Heavy Oil" for the purpose of this history could have no value, and in support of this he quoted the Griffin engine where heavy residues were distilled in a gas heated retort, the vapour being used as if it were a gas, while the tar was at intervals drawn from the retort.

However, the genesis of the oil engine is to be found in the explosive powder engine, perhaps in the firearm itself, where a piston is actuated in a cylinder by a pressure difference, the firearm by the way being quite an efficient heat engine. This is as it should be, as it has all the elements of efficiency, high pressure difference, minimum heat losses and high piston speed. Huyghens, in 1680, found many difficulties with his gunpowder engine, but Papin a few years later substituted metal valves for the flat, wet leather tubes that were employed by Huyghens, and made some improvement, just as to-day the employment of a more suitable valve steel may nearly double the possible output of an engine.

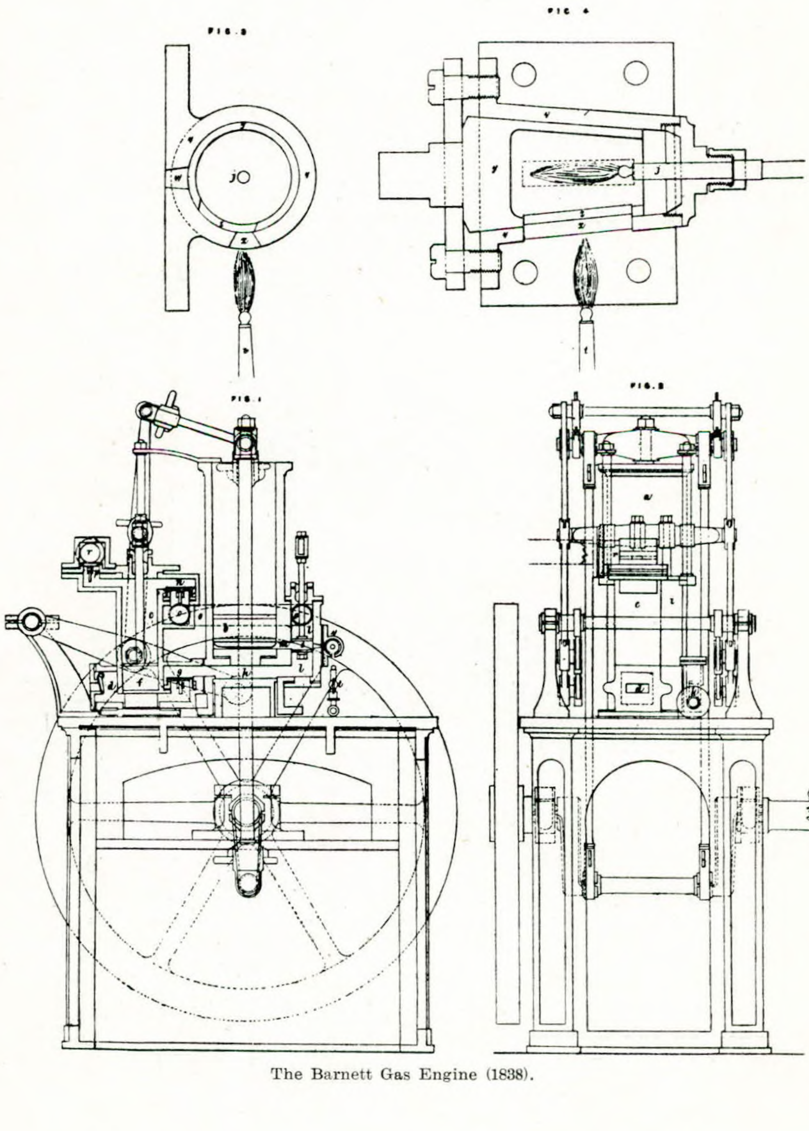
The furnace gas engine is not quite dead; it can be found in the torpedo, where the compressed air on its way to the air engine passes through an oil furnace, where it is heated and augmented by the products of combustion. Neither do any of these ideas actually die; they occur time after time, in a different guise and under different circumstances, and this is really the author's meaning in his reference to the possible value of history to the student.

In the year 1687 Hautefeuille made a gunpowder pump; in this he foreshadowed the Humphrey pump, but we must proceed and refer to the first oil engine. It was invented by John Barber in 1791; he produced gas from oil, burned the gas in a retort, and directed the products on to a Pelton wheel. Thus the oil engine came into being as did the steam engine, and we can but wonder whether the cycle will be completed.



Barber Oil Engine (1791).

The gas engine proper made it appearance in 1794, as Robert Street then introduced what may be termed the "half stroke" system where a charge was drawn in during the first half stroke, ignited by an indrawn flame at mid stroke, and expanded during

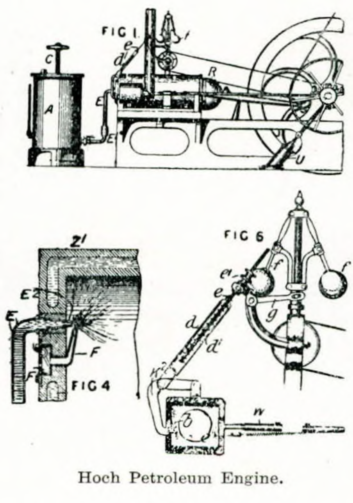


The Barnett Gas Engine (1838).

the remainder, the return stroke scavenging the cylinder. This engine of Street's was an oil engine, for gas had not then been invented. He injected some turpentine into the cylinder which impinged on to a hot plate, so the first oil engine was of the internal vaporiser variety. In this case the engine was atmospheric, and the work was transmitted direct to a pump.

Julius Hock of Vienna soon followed; he had the "infinite capacity for taking pains" and we had a far better example.

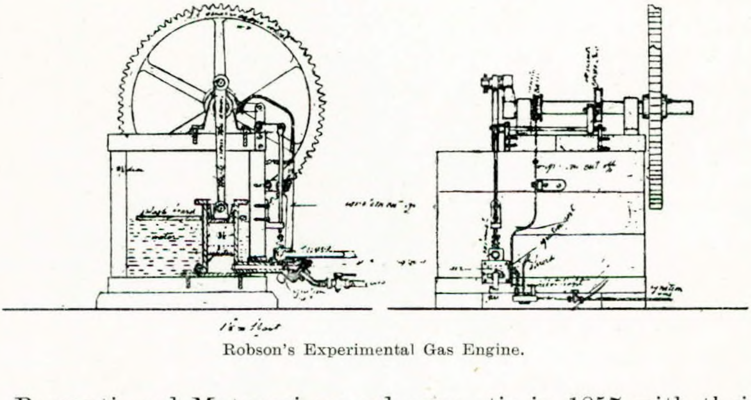
Phillipe Lebon, a French engineer, in 1801 produced an engine that was double-acting, pressure charged and electrically ignited. He was assassinated in 1804, otherwise there is no doubt that history would tell another story. Twenty years passed before anything further was done, the next step being taken by Samuel Brown, who reverted to the atmospheric engine with internal jet cooling, a cycle that can be found embodied in the German water cart now on the market.



Hoch Petroleum Engine.

In 1817 the first motor vessel, designed by Claude Niepse, of Frith Street, Soho, was produced. The motor was on the lines of the Humphrey pump, the column of water being driven astern.

Numerous other devices were tried; sometimes they were placed on the market, and the advertising matter that accompanied these efforts whetted the public appetite for such an engine as was described, and in 1838 William Barnett responded with a very important engine. He allowed an exhaust valve to remain open till half stroke, mixture was then introduced under pressure, and this was further compressed till at dead centre it was ignited by a flame enclosed in a hollow rotating cock, when expansion took place over the whole outward stroke. Here we had compression before ignition; ignition at dead centre, full stroke expansion, and the retention of some of the exhaust products, the latter feature being the subject of considerable discussion at a much later period.



Robson's Experimental Gas Engine.

Barsanti and Mateucci caused some stir in 1857 with their free piston atmospheric engine with electric ignition, but it was in this year that James Robson of North Shields, a man who was afterwards to become famous in the gas engine world, brought out his first engine, a horizontal example of the half stroke system so well exemplified by the Bischop and the Lenoir engines.

The latter engine appeared in Paris in 1860; it was a double-acting half stroke cycle engine on steam engine lines, and it was provided with electric ignition. Lenoir had many incorrect theories, stratification being one of them, and the consumption was about 100 feet per h.p. hour. On the other hand he was backed by manufacturing facilities, and by 1865 there were over 300 of these engines at work in Paris alone. Also at this time Johnson made an engine such as the Lenoir with slide valves and sparking plugs, but this was an oil engine, for the fuel was vaporised in an outside exhaust heated vaporiser, thus showing how difficult it is to differentiate between the oil and gas engine.

In this year also the Spaniard, Jacques Arbos, designed a producer gas engine, and he employed the steam generated in the cylinder jacket to do work in a steam cylinder. This, however, is but incidental; what is of importance is the advent of Beau de Rochas, who by logic, by reasoning, and by his knowledge of physics, established the creed of the internal combustion engineer. In 1862 he read a paper before a learned society and in this he advocated his cycle, the four-stroke cycle as we know it, and he gave the following as the conditions necessary for a successful engine:—

(*a.*) The greatest possible cylinder volume with the least possible cooling surface.

(*b.*) The greatest possible rapidity of expansion.

(*c.*) The greatest possible expansion.

(*d.*) The greatest possible pressure at the commencement of expansion.

As we go on we shall see how we are penalised when we depart from these laws and how we gain by their whole-hearted acceptance.

For fourteen years nothing was done and then came Dr. Otto who accepted de Rochas' cycle, but not his physics, and Sir William Siemens, who had much to say on these matters and the theories that then existed.

At this time also was introduced the pistonless water pump, the elements of the Beula boiler, and the persistent error that the injection of water had some actual thermal value. Otto and Langden brought out their free piston engine in 1867, the ratchet of which was a jambing roller, and by means of good work and strict attention to business they sold several thousands of these noisy, inefficient little engines. Everything possible was done by them and by their licensees, Messrs. Crossley Bros., to improve the engine, but as Gillies of Cologne proved to be somewhat formidable prospective rivals they turned their attention to a new cycle, a new theory, and a new epoch. This was ushered in by the Gas Motoren Fabrik with whom Dr. Otto was associated. Their engine was almost identical with the early Crossley engines, well within our own memory. It was on the four-stroke system but as before mentioned, Dr. Otto refused to accept the theory of Beau de Rochas and he substituted that of stratification, claiming this as the basis of the success of his engine, despite the proofs to the contrary that were put forward. Crossleys carried on with their representation, and there appears to have been a full exchange of ideas throughout.

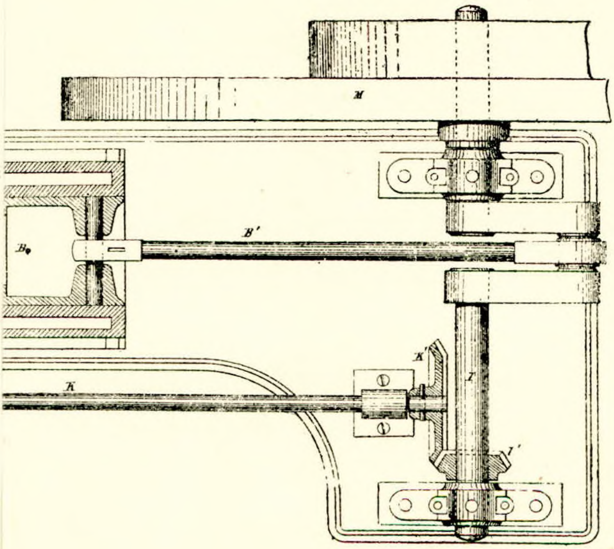


FIG 12

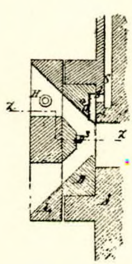


FIG 13

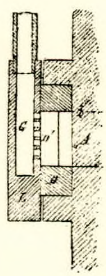


FIG. 7.

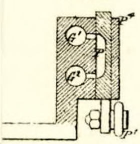


FIG.9.

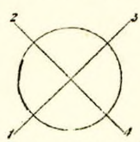


FIG.10.

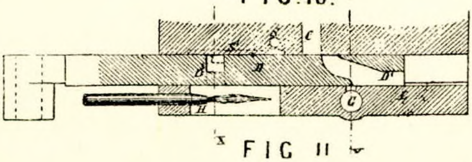
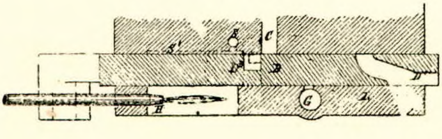


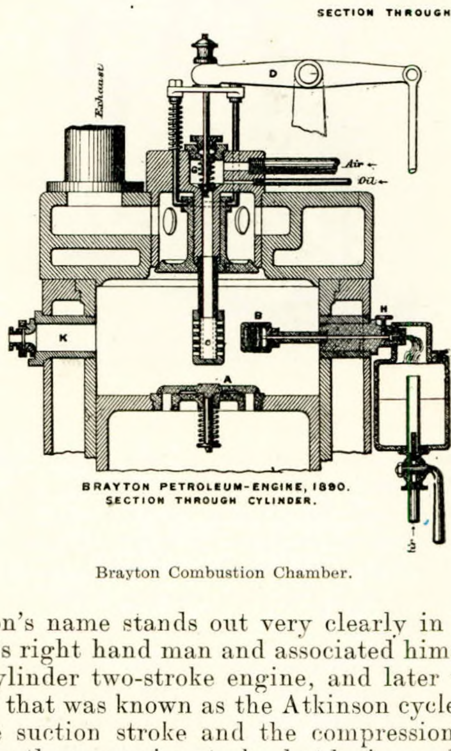
FIG 11



son engine was made by Tangyes and a considerable quantity were produced as gas engines, though no attempt appears to have been made to employ oil as a fuel.

The idea of a gas Diesel has always been fascinating, and at this time Lambart endeavoured to pump gas into the combustion chamber of a four-cycle engine with electric ignition, but the loss in high-pressure pumping negatived the good results.

We first hear of Daimler in 1875 and again in 1877 in connection with a compound engine, a subject of such fascination that it recurs again and again, right up to modern times.



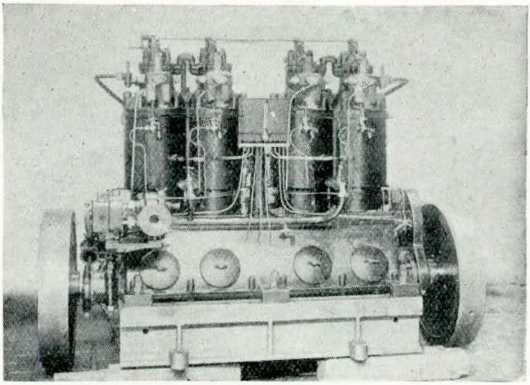
Brayton Combustion Chamber.

J. Atkinson's name stands out very clearly in history. He was Crossley's right hand man and associated himself first with a separate cylinder two-stroke engine, and later with the bell crank engine that was known as the Atkinson cycle engine. In this case the suction stroke and the compression stroke were much less than the expansion stroke, but he ignored the fact that the cost of an engine, all other things being equal, varies inversely as the piston speed and the brake mean effective pressure. We have, however, to thank Atkinson for the introduction of tube ignition and many other interesting features.

As the years went on proposals were made, somewhat tentative in most cases, which covered nearly all the ground we now traverse. For instance, in 1878 Linford proposed two pistons working in opposition in one cylinder coupled to the crankshaft by rocker arms, and this mechanism occurs time after time till at last we have the Junkers engine.

In 1880 Giesenberger used part of his cylinder jacket to vaporise hydrocarbons, and he also endeavoured to produce ignition by means of the magneto.

The Stockport Co. introduced two opposed cylinders and one crank, one of the cylinders being employed for scavenging, and the author would like to take this opportunity to re-introduce



Tolsch Paraffin Engines.

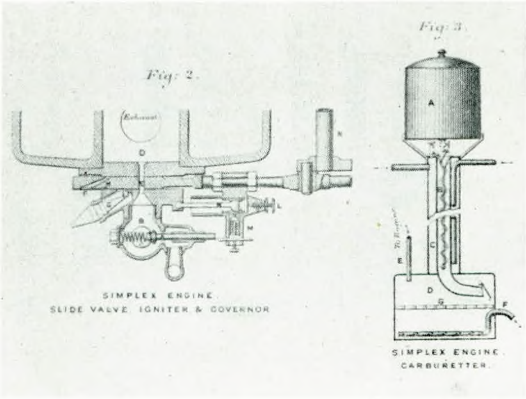
an axiom which even to this day appears, now and then, to be lost sight of. There is a credit and debit balance on every engine, the power stroke is on the credit side and the compression on the debit. These two strokes we must have, but what, in any given engine, are we paying for the scavenging? In the four-stroke cycle it is obviously 50% of the cost of the engine. In the Stockport engine, if the scavenge cylinder is in accordance with requirements, the proportion is no doubt 50%, and we must make our comparison with a four-stroke engine on these lines. Robson, by making a double-acting engine and using only one half for power production again pays 50%, and as we proceed it will be as well to keep this axiom in view.

Crossleys had been engaged with the construction of the Otto four-cycle stratification engine before they discovered that this theory of stratification was ill founded, and they at once set about eliminating any tendency for the gases to stratify.

The six-stroke cycle was introduced by Linford, and in later years a good example of this was produced by Dick Kerr in the form of a horizontal steam engine with slide valves and all, and as this was double-acting it produced quite a reasonable machine.

In 1880 Wittig introduced the Junkers engine in its entirety, and Delamare was responsible for the beginnings of the spray carburettor for light oil.

In 1881 J. Fielding brought out the two-stroke cycle crank chamber scavenge engine with mechanically operated valves in the cylinder head, quite modern acute angled inlet ports around the cylinder, and with a deflector on the piston.



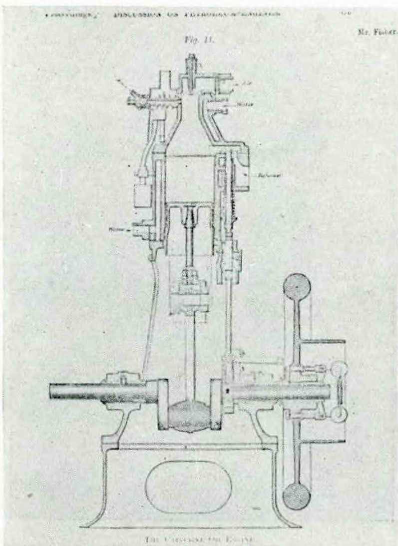
The Simplex Engine.

T. H. Lucas introduced the opposed piston two crankshaft engine, a form of mechanism that has been to the fore somewhat of late years.

Fielding of Gloucester re-introduced the internal make-and-break electrical ignition, but very little was done with it, and it was practically unknown when the author re-introduced the system in conjunction with an American engine in 1898.

J. J. R. Hulme is supposed to have placed on the London River the first marine engine in 1885, but unfortunately details are lacking. Campbell introduced a new system—the double-acting engine with the crosshead pin in the middle of the piston, this idea being followed by J. S. White some years back and by a contemporary production called the "Bega."

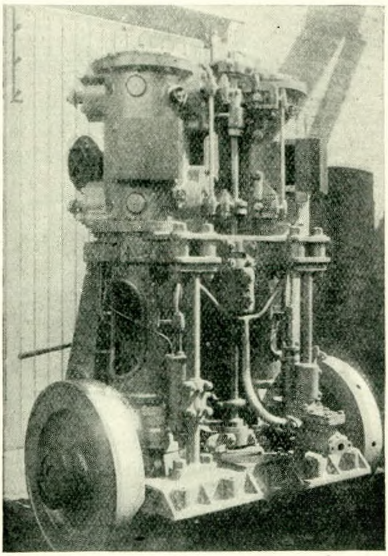
Weatherhogg was perhaps responsible for the introduction of the stepped piston engine on the two-stroke cycle, but he made the very common mistake of compressing the scavenge charge to too high a figure, perhaps because he conceived the idea of trapping this compressed charge for starting purposes.



The Capataine Oil Engine.

The name of Emil Capataine is one that now appears, and it is a name that will frequently occur and which bulks large in oil engine history. He starts by being somewhat ahead of his time, for he designed a closed crank chamber engine with opposed cylinders, two-stroke cycle with ports, and a hollow fixed crankshaft, the engine being rotary. Crossleys brought out their vertical engine with poppet valves instead of slides, a small engine that had a very strong commercial position.

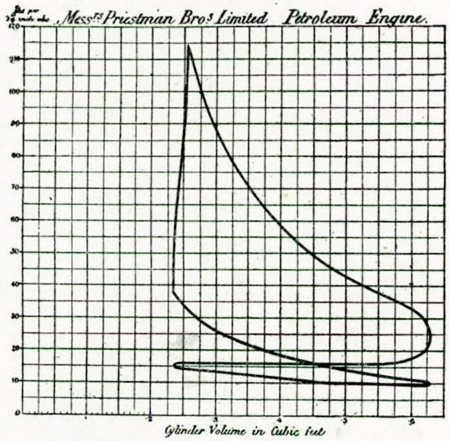
Priestman's first appearance in the year 1885 is somewhat disconcerting to the historian as they apparently are the inventors of the Diesel engine, or semi-Diesel, if this term may be allowed to indicate engines where the fuel is injected at maximum compression and ignition procured by some artificial means. Unfortunately they abandoned this idea, even though they had, in a way, incorporated with it the employment of blast air, and when we remember the excellence of their later production it is only logical to suggest that the development of the Diesel engine would have been greatly accelerated if they had persisted.



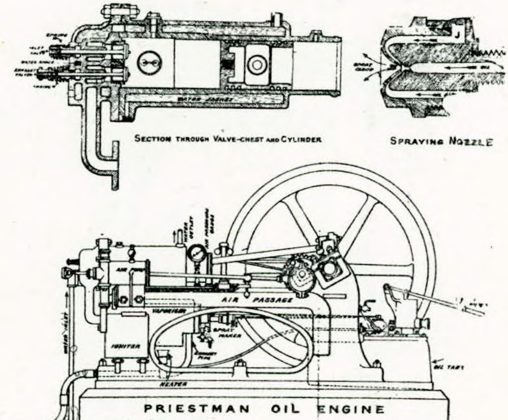
Priestman Marine Engine

Gottleib Daimler was now progressing towards the engine that brought his name forward; he had arrived at the engine with two flywheels enclosed in a crank case with built up crankshaft, on the four-stroke cycle with automatic inlet valve and push rod operated exhaust. An interesting feature of this engine was the governing by allowing the exhaust valve to remain closed, a system that might have been adopted for the vaporiser engine of later years with great advantage. This engine was mounted on a bicycle, and this dates the motor bicycle as being 44 years old.

In the year 1886 we begin to note some definite turning towards the oil engine proper. So far it has been but an after-thought, but Spiels bent a tube into the combustion chamber; the outside of this tube terminated in an automatic valve and a



Priestman Indicator Card.



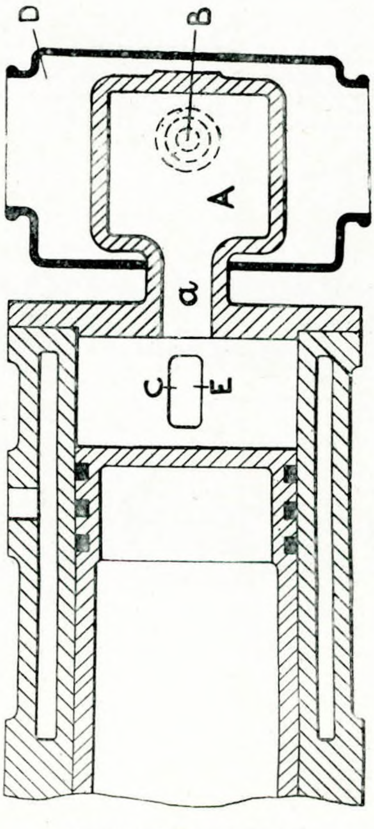
The Priestman Engine.

metering pump delivered oil to this valve, therefore giving us all the elements of the paraffin engine proper. He also employed an air pump and reservoir for starting.

Benz is another outstanding name of which we hear for the first time in 1886 in connection with a motor car engine with a surface vaporiser.

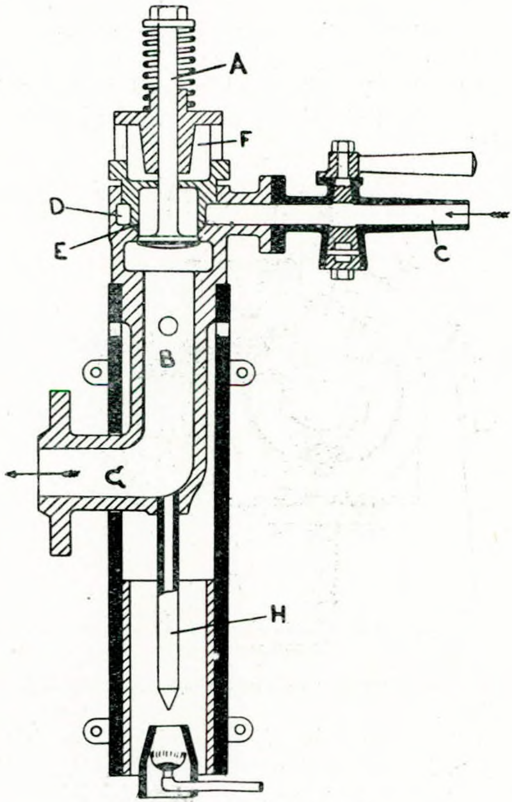
We first hear of the Priestman engine, as it was known, in 1886. Priestman was an idealist; he set out to produce a charge for his cylinder on academic lines, but the cylinder did not at all appreciate this fare, as will be shown when the subject is dealt with.

Akroyd Stuart appears for the first time with a vaporising engine where air and oil are passed through gauze filled chambers. He incorporated a separate hydraulically operated



The Akroyd Stuart Vaporiser.

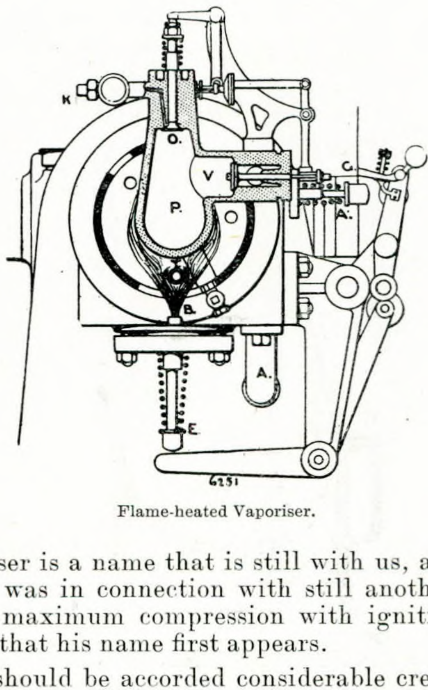
piston for the adjustment of compression, and he also employed air starting. There were other devices introduced at this time for the adjustment of compression which appeared then to be essential in order that an engine could comply with various requirements in speed or fuel.



The Campbell Internal Vaporiser.

In 1887 Hosack made an effort to produce a gas Diesel engine, Tellier designed a gas driven locomotive, and the Gas Motoren and Crossleys produced the timed ignition tube. The German firm took the initiative but Crossleys soon followed with a far better design. In this year, too, was seen the famous Butler tricycle, the engines for which were two-stroke cycle, direct connected with pressure admission on the lines of the Brayton.

In 1888 Crossleys definitely tried for the compound engine with an arrangement that should have proved a success if any compounding of the internal combustion engine could. There were two double-acting four-stroke cycle cylinders on conventional lines, and they were operated by crank pins in line. Each cylinder fired alternately, and the exhaust from each was turned into both of the front ends and then expanded to twice its volume. There certainly was a considerable gain in thermal efficiency, but the increase in cost per h.p. did not make this a commercial proposition. The author re-invented this system some ten years after this and was advised of these facts by Messrs. Crossley.



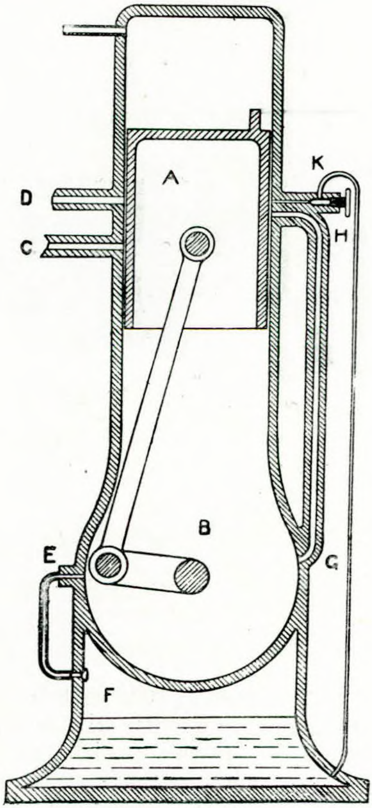
Flame-heated Vaporiser.

Oechelhaeuser is a name that is still with us, and it is significant that it was in connection with still another attempt to inject gas at maximum compression with ignition by a continuous spark that his name first appears.

J. C. Stitt should be accorded considerable credit as he provided the Lifeboat Institution with a specification that embodied practically all the leading features of the modern lifeboat installation.

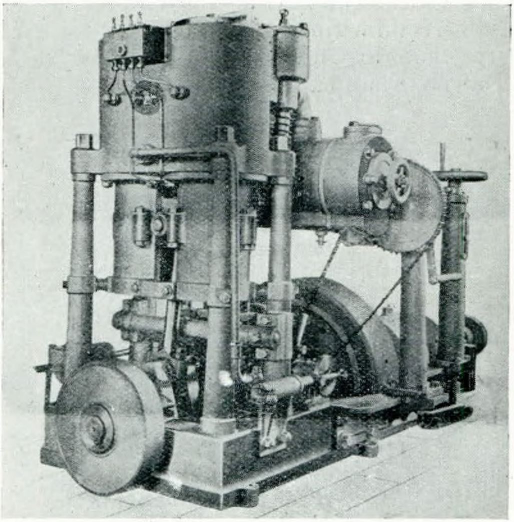
In 1889 J. Roots appears, that pioneer who did so much towards the introduction of the vaporiser engine. He very rightly stressed the importance of measuring the charge, but he was so obsessed with this factor that he entirely missed the royal road to the paraffin vaporiser, a path that has only just of late been picked up.

We again have heat conservation attempted by Hargreaves with his insulated combustion chamber and piston crown. This is a very logical thought which has, as we know, been accepted by Doxford, Sulzer, Krupp and others.



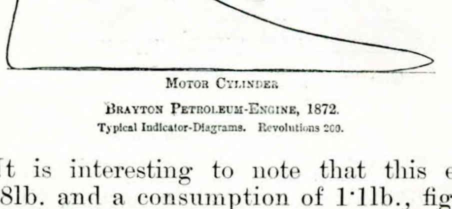
The Simplest Oil Engine—The "Day."

Emil Capataine fell into the same error as Priestman and Samuelson at first, as he directed his attention to the complete spraying and mixing of the oil and air charge and the heating of the same outside the cylinder, but he soon turned his attention to the internal vaporiser where very little air passed through the heating device. In 1889 he was well established with the design of this engine, which had a conical combustion chamber and leading into it a small vaporiser which was



The Griffin Engine.

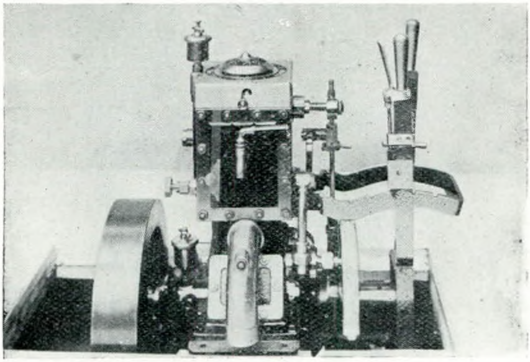
initially heated by a lamp and kept very hot by combustion. A very small quantity of air passed through this vaporiser, the main supply entering the combustion chamber by a valve in



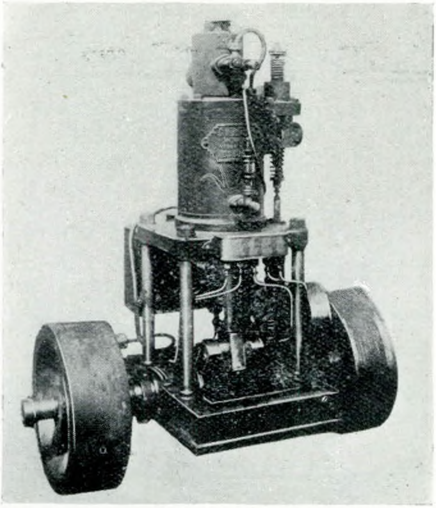
BRAYTON PETROLEUM-ENGINE, 1872.
Typical Indicator-Diagrams. Revolutions 200.

the apex. It is interesting to note that this engine had a b.m.e.p. of 48lb. and a consumption of 1·1lb., figures that are not far behind some of our contemporary petrol paraffin engines.

The Capataine engine differed from most others at that time inasmuch as there did not appear to be the definite condensation



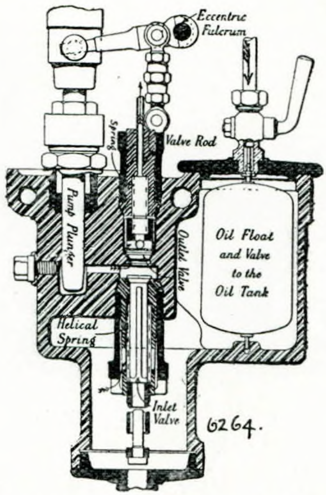
An English Two-Stroke Engine.



The "Mollerop"—a Danish Akroyd.

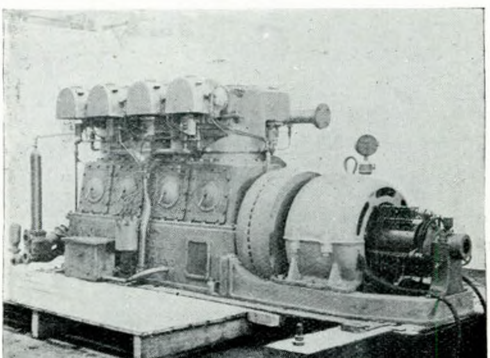
of fuel in the cylinder as in most of the other engines, in the Roots and Priestman engines for instance. This condensed paraffin formed the only piston lubricant.

The Daimler "V" type engine appeared; we hear of F. W. Lanchester, and the Trusty engine was introduced. In this



Dr. Diesel's Valve Regulated Fuel Pump.

case the jacket was used as a vaporiser. It gave quite fair results, but the mechanics were bad. There were numerous other attempts at solving the problem, and it appeared that the

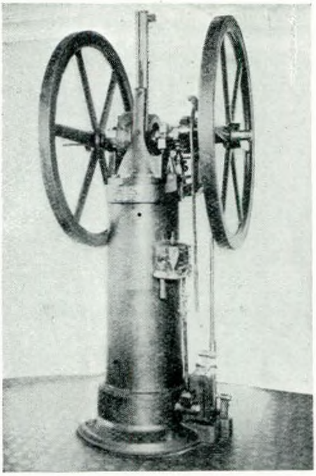


Hornsby Vertical Engine (1900).

Campbell system would dominate the field as it eventually did, but when modified to a very considerable extent.

Of some historical, but little technical interest is the Griffin engine as made by Palmers. Here we had a large outside vaporiser in which any form of fuel was delivered; the heat of the exhaust distilled off the more volatile products, and the residue was drawn off from time to time. It was announced as a residue-oil burning engine; but it is hard to see how this claim was justified.

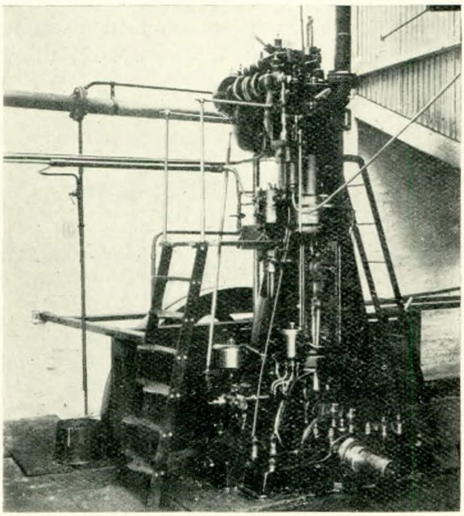
We are now able to turn to Patent No. 7146/1890 of Akroyd Stuart, which is generally considered to be an anticipation of the Diesel, inasmuch as he specifies and claims that the oil is pumped into the cylinder, in a fine spray, at the moment of maximum compression.



Crossley Free Piston Gas Engine.

The author feels that this is not such a clear anticipation as the Priestman suggestion; the combustion chamber complicates matters, and although Priestman procured ignition by a spark, Stuart relied upon the hot surfaces of the vaporiser. However, this point may stand over, together with details of the engine, till the type is specifically dealt with later in the paper. Weyman and Hitchcock did practically the same thing, but they employed a separate ignition tube and lamp.

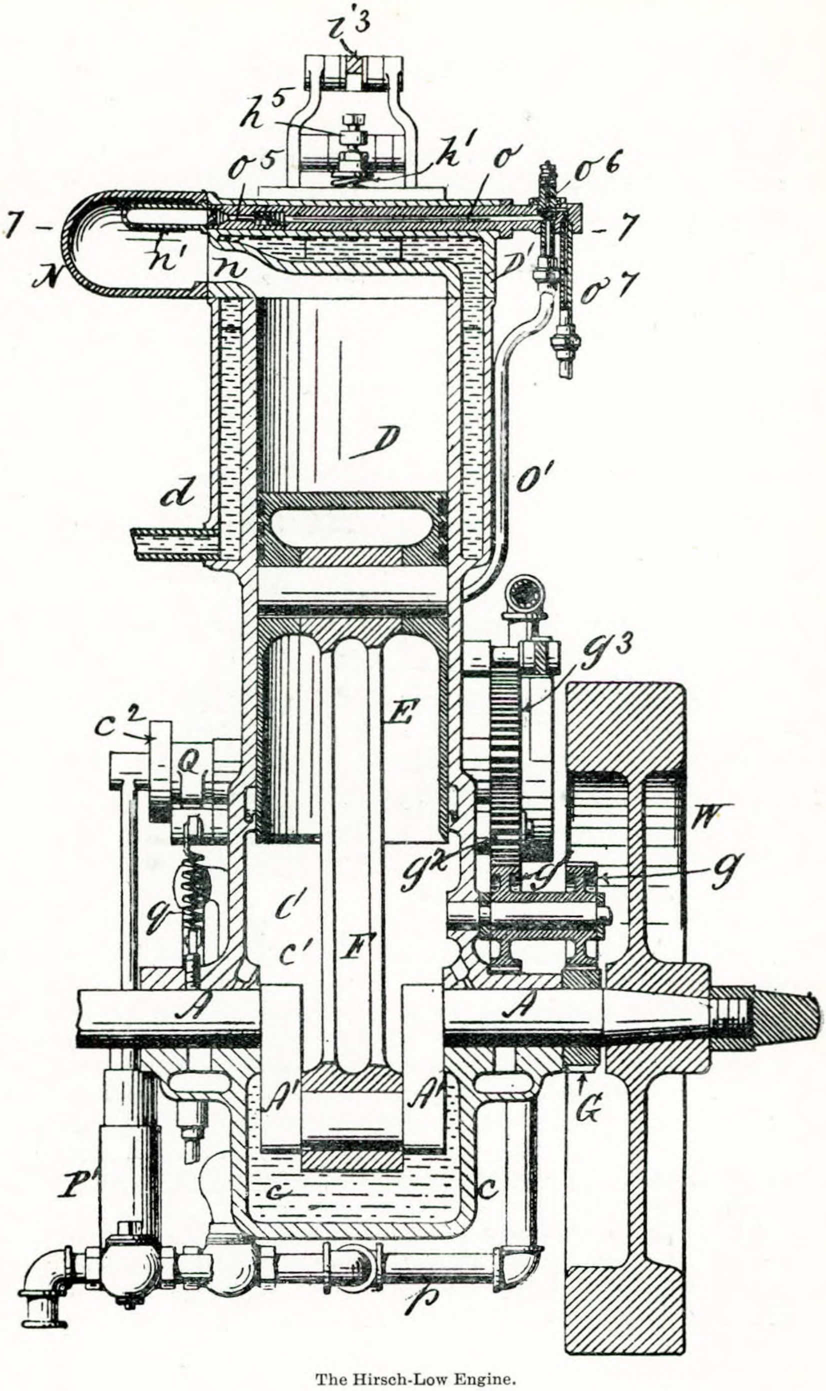
We must close the year with Akroyd Stuart's Patent No. 15,994/1890, in which he abandoned his Diesel system for the reason that he found that he could not pump the oil as he intended, *in a fine spray at the moment of maximum compression*, and he then reverted to the combustion chamber separated from the cylinder by a narrow neck, as he could then pump in the oil in an indifferent manner. In this device was the progenitor of all the pre-ignition chambers with which we are now surrounded, and which came into being for precisely the same reason, *the failure to pump the oil correctly*.



The First Diesel Engine made in England. (Mirrlees.)

We have in the year 1891 a gleam of inspiration from O. Weiss; he tapped some of the exhaust products under pressure during the combustion stroke and employed them to vaporise the paraffin and inject it into the air during the induction stroke—a somewhat complex valve arrangement, no doubt, and the metering would be a separate operation, but if Roots and Weiss had joined forces an excellent engine could have been produced.

J. Day has always been credited with the invention of the crankchamber scavenge engine. This was hardly the case, but he was perhaps the first to actually market such an engine. The type, however, did not properly materialise till the Americans, some six years later, adopted it for small gasoline launch engines.

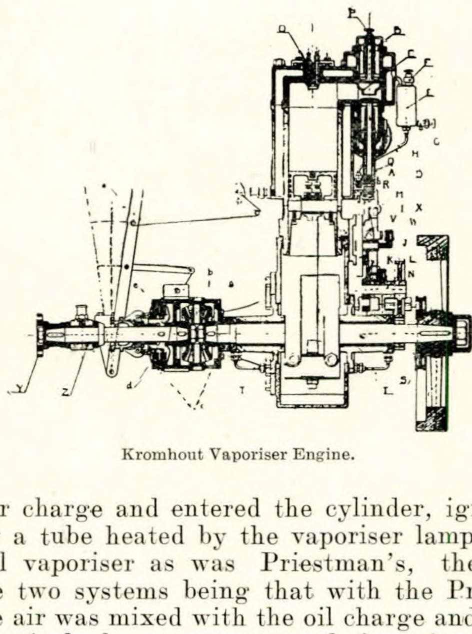


The Hirsch-Low Engine.

Still later they had a new and undeservedly long lease of life as the " Semi Diesel," the absence of fuel in the crank chamber and the glamour of simplicity overpowering the very many defects.

To revert to Day, he also suggested the crosshead scavenge engine, and even foreshadowed this engine with a separate scavenge pump.

Crossleys now introduced what may be termed the standard oil engine of the day. The oil was sprayed into a labyrinth passage heated by a lamp, and the vapour was then mixed with

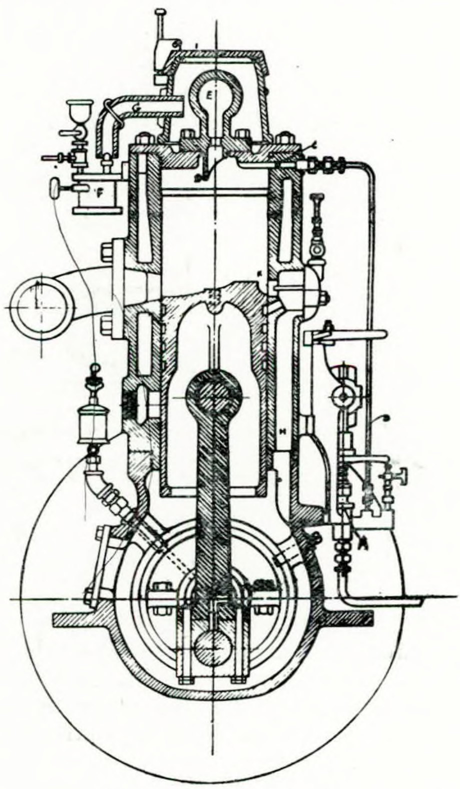


Kromhout Vaporiser Engine.

the main air charge and entered the cylinder, ignition being procured by a tube heated by the vaporiser lamp. This was the external vaporiser as was Priestman's, the difference between the two systems being that with the Priestman the whole of the air was mixed with the oil charge and brought up to a comparatively low temperature before it entered the cylinder, while with the Crossley system only a small part of the air was heated, and the temperature was much higher for the purpose of vaporising though the mean temperature of the charge was less.

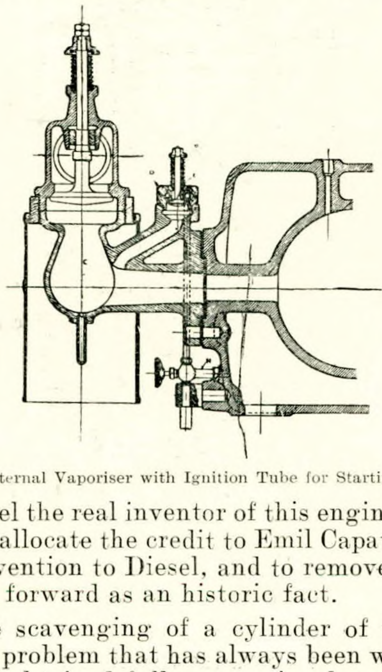
In the beginning of 1892 Skideski somewhat startled us by designing a combustion chamber that was hemispherical and provided with a dished piston crown. Into this combustion chamber were led two oil jets. They were diametrically opposite and they converged, somewhat on the lines of the Price Rathbone system of the Ingersoll Rand Co., and while the convergence of jets is undoubtedly incorrect the designer's objective was good, as he wished to prevent the impingement of the spray on the combustion chamber walls.

In this year of 1892, on April 14th, a Patent Specification, No. 7241, was lodged in the name of Rudolph Diesel. There



The Mietz and Weiss Engine.

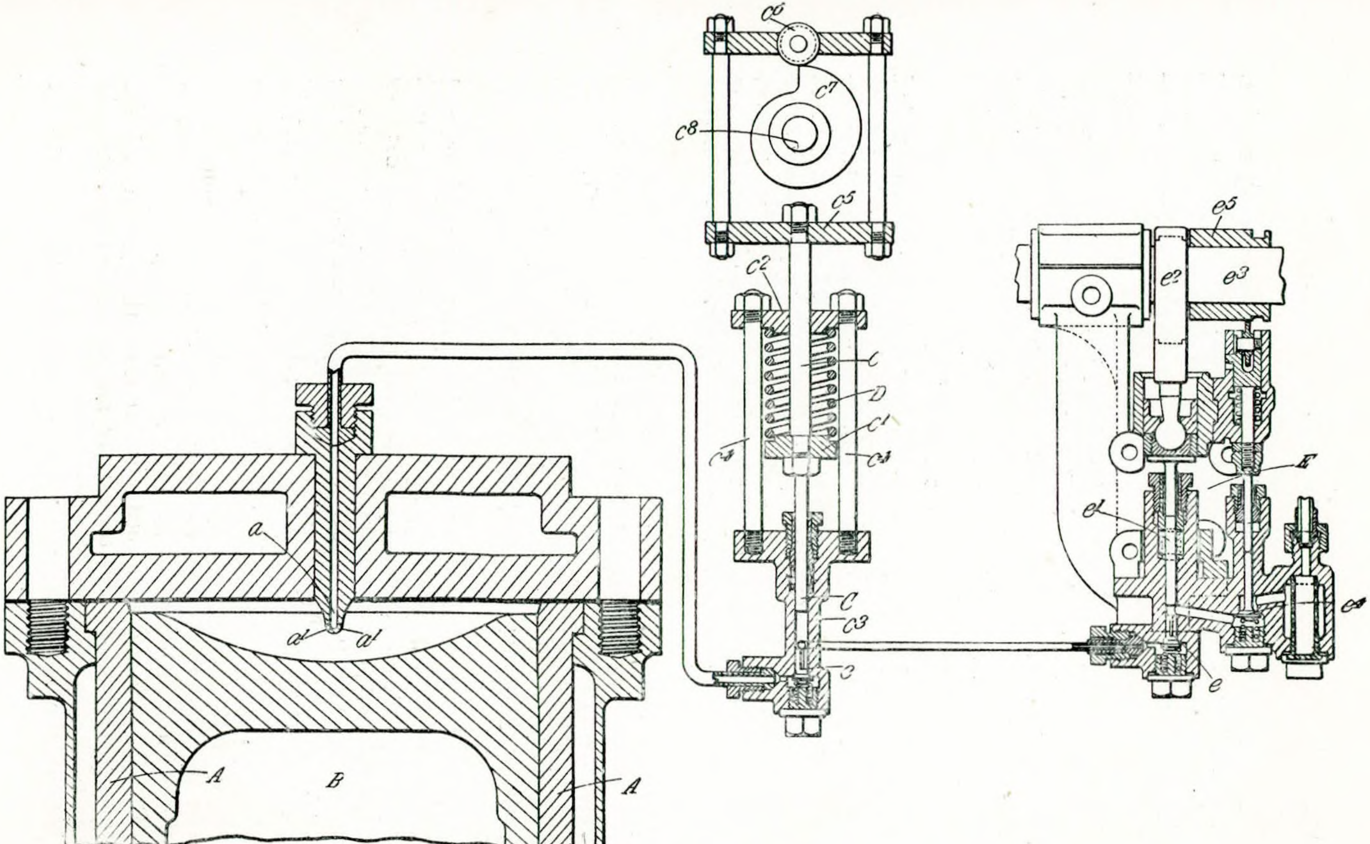
are two significant passages in this specification, although they are apt to be overlooked when Diesel nomenclature and characteristics are being discussed. First we have,—" air is drawn into the cylinder and compressed on the instroke until its temperature far exceeds that of the ignition point of the fuel employed." The next one is,—" the fuel, gaseous, pulverised, or liquid, is then gradually injected into the cylinder in a state of fine subdivision, and ignites." A third point is contained in the words that follow—" the expansion preventing the pressure and temperature from rising above that at the beginning of the stroke." The significance of these phrases we will not deal with, but we do know the difficulties that were encountered by Diesel; we know of his futile attempts to use coal dust, and his subsequent utilisation of the high pressure air compressing plant which he had to hand for the injection of oil, and we also know that very soon after his engine was launched and taken up by M.A.N., Mirrlees, and others he appeared to lose all interest, and from this time to the time of his death he accomplished little that was of interest or value.



Internal Vaporiser with Ignition Tube for Starting.

Was Dr. Diesel the real inventor of this engine? The author would prefer to allocate the credit to Emil Capataine, who probably sold his invention to Diesel, and to remove any ambiguity he will put this forward as an historic fact.

The complete scavenging of a cylinder of the products of combustion is a problem that has always been with us. Atkinson (Crossleys) obtained full scavenging by providing a long exhaust pipe and leaving the exhaust valve open for some time after the induction valve was opened, the inertia of the exhaust column causing a flow of air through the combustion chamber before the gas valve opened Büchi does the same thing today, with the exception that he employs an exhaust driven blower.



McKechnie Fuel Injection System.

The year 1894 was a very important one for the oil engine, as a great effort was made to secure awards at the Royal Show at Cambridge. The results of these trials were in favour of Hornsby, and the following table of the results is of interest:—

Name.		Piston Speed.	M.E.P.	Mech. Eff.	Lb. B.H.P.	Thermal Eff.
Hornsby	...	600	29·8	83·3	·977	13·1
Crossley	...	500	72·2	88	·82	15·6
Premier	...	400	49·6	88·6	1·04	12·3
Trusty	...	565	46·1	73	1·19	10·75
Britannia	...	520	47·3	74	1·68	7·6

The consumption figures for the three days trial were: Hornsby ·919 and Crossley ·9 lb. B.H.P. hour.

With these figures before us we should not hesitate to award the first prize to Crossleys, but the Committee no doubt viewed the matter more from the farmers' standpoint; the Hornsby appealed to them, and it was allocated the highest award. This clearly shows that the Akroyd Stuart system possessed some inherent value that was clearly recognised by the judges, though its acceptance by the experts was tempered by the difficulties experienced in the matter of pumping and spraying the oil.

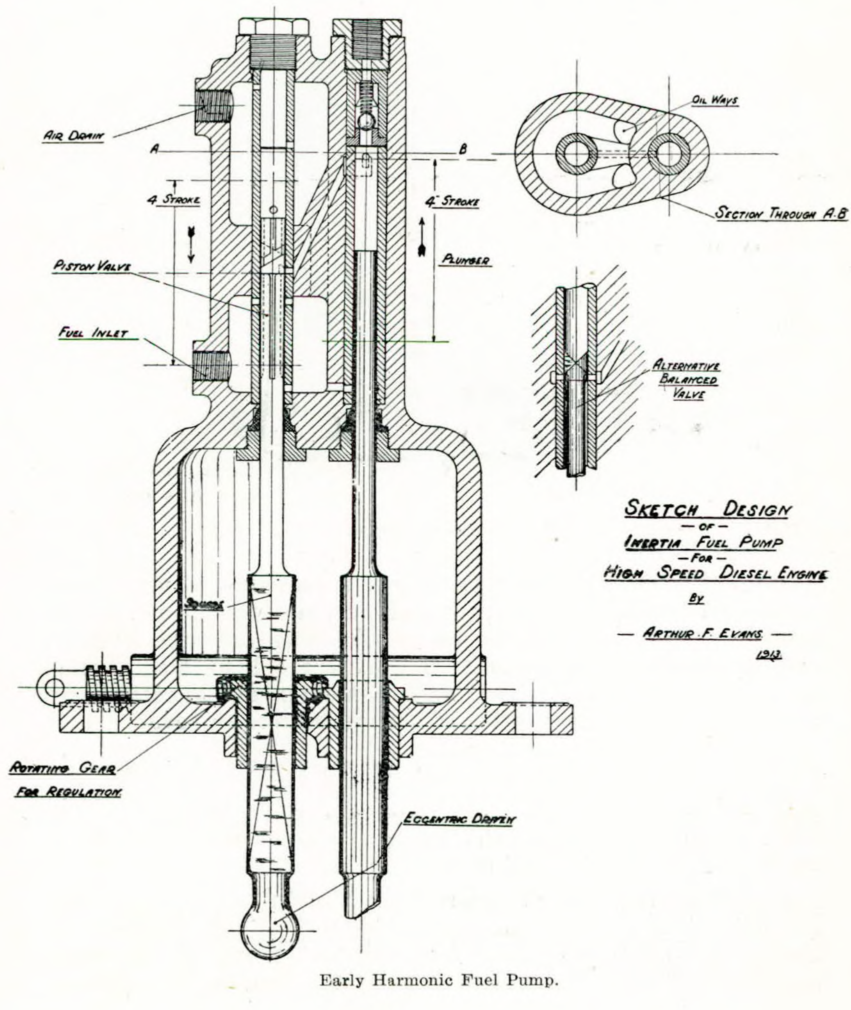
Tesla makes an interesting suggestion to the effect that if the pistons of an internal combustion engine could be operated against a spring and run at their natural periodicity, a very efficient engine could be obtained. There is a great deal in this, and it is to be wondered that some attempt has not been made in this direction, with the double-acting two-stroke for instance.

Singer invented the cuff valve, and a multitude of piston and other valves was tried out; Capitaine actually produced a pre-ignition chamber though he did not use it as such, but Brunler did, in construction, actually anticipate the first conventional pre-ignition chamber, the Hirsch. Brunler did not recognise the value of his invention. He was trying to evade pre-ignition, while Hirsch had the semi-Diesel clearly in view; one was a fugitive and the other a pioneer, but they both took the same path.

H. P. Holt introduced the use of pre-ignition for reversing an engine, as Rundlof did in later years.

It will perhaps be of interest to mention that a Mr. Houghton, in a discussion on the subject of oil engines in Australia, stated that he considered the raising of the compression the most important line of development for the oil engine, and he suggested that this would greatly increase the efficiency and simplify both ignition and vaporisation, but how reluctant have some designers been to follow this course, and even to-day low pressures are cited by vendors as virtues.

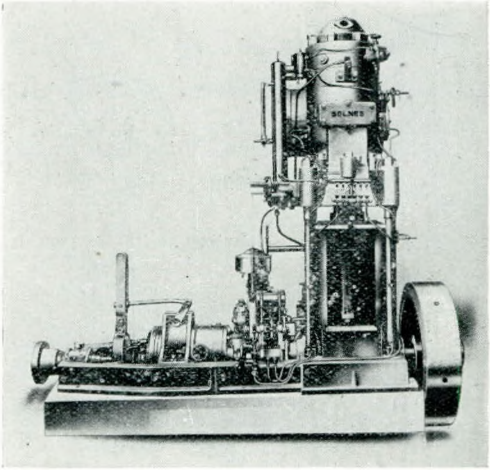
F. Withers, of the Brayton Co., applied injection at maximum compression to a two-stroke engine, and this suggestion would come naturally to an engineer associated with the



Early Harmonic Fuel Pump.

Brayton, while W. Lorenz made history by producing a conventional multicylinder vertical engine.

Grist had the elements of an excellent idea in an arrangement of cone and vortex chambers, whereby a vortex scrapes off a film of oil and pulverises it, while Smee carried out this idea a few years later in a very practical manner.



An Open Crosshead Scavenge Engine.

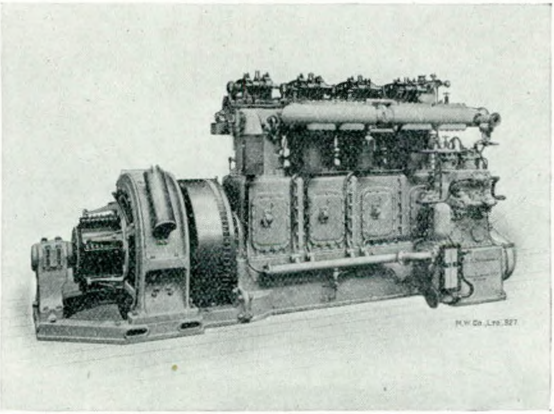
About this time Priestmans appear to have been in serious trouble through pre-ignition or detonation, a resultant of an increase in compression pressure. This was obviated by injecting water into the cylinder, but the avowed function of the water was the cooling of the combustion chamber; its retarding effect on inflammation did not appear to be recognised.

Gobron Brille brought out the petrol driven "Junkers" engine for car work. It soon died out, but it has been definitely reintroduced for small engines, for instance, as the Peugeot and the Junkers Aero itself.

The final year of this purely historical sketch, 1899, was an eventful one, and it saw the introduction of a number of definite, progressive steps as well as other comparatively unimportant detail improvements.

Hecht invented the conventional splash lubrication, Fleury varied the compression by telescoping the cylinder into the crank chamber in the same manner as in the Ricardo experimental engine, but with cams instead of a screw.

The displacer on the piston was tried by Haselwanda, and Bell and Warren came very near to the invention of the preignition chamber, but the author prefers to allocate this distinction to Hirsch. Grainger put forward the two-stroke Hornsby, which can be considered historic, and we also have

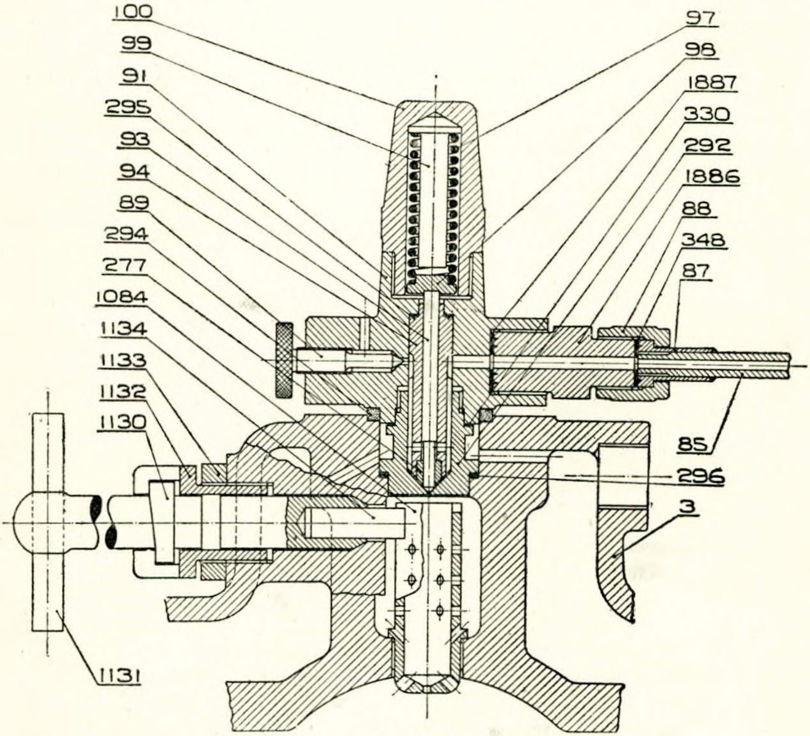


Mirrlees "Dreadnought" Type Engine.

the now famous name of Maybach introduced to us in connection with a turbulence scheme. The next two names, coupled with the former, bring us up to modern times, to airships and to engines weighing one pound per h.p., for Edge and Napier invented the inserted liner and the detachable head in their present form, as used in many modern petrol engines and practically every Diesel engine.

We will close the year, and this purely historical section with a reference to F. C. Hirsch, who the author claims was the first to design, produce, and commercially operate the preignition chamber in an engine injecting fuel at maximum compression. This engine has a very great claim to a position in history, for it was an engine of this make that only two years later was the first to propel a vessel across the Western Ocean to Falmouth. The Aibel Abbot Low was her name; she was only 45 feet long, and the trip was a tragedy for other reasons than the performance of the motor, which, according to the log, functioned excellently right through.

Several attempts have been made at classification, but the author feels that there is little to be gained in this. There is



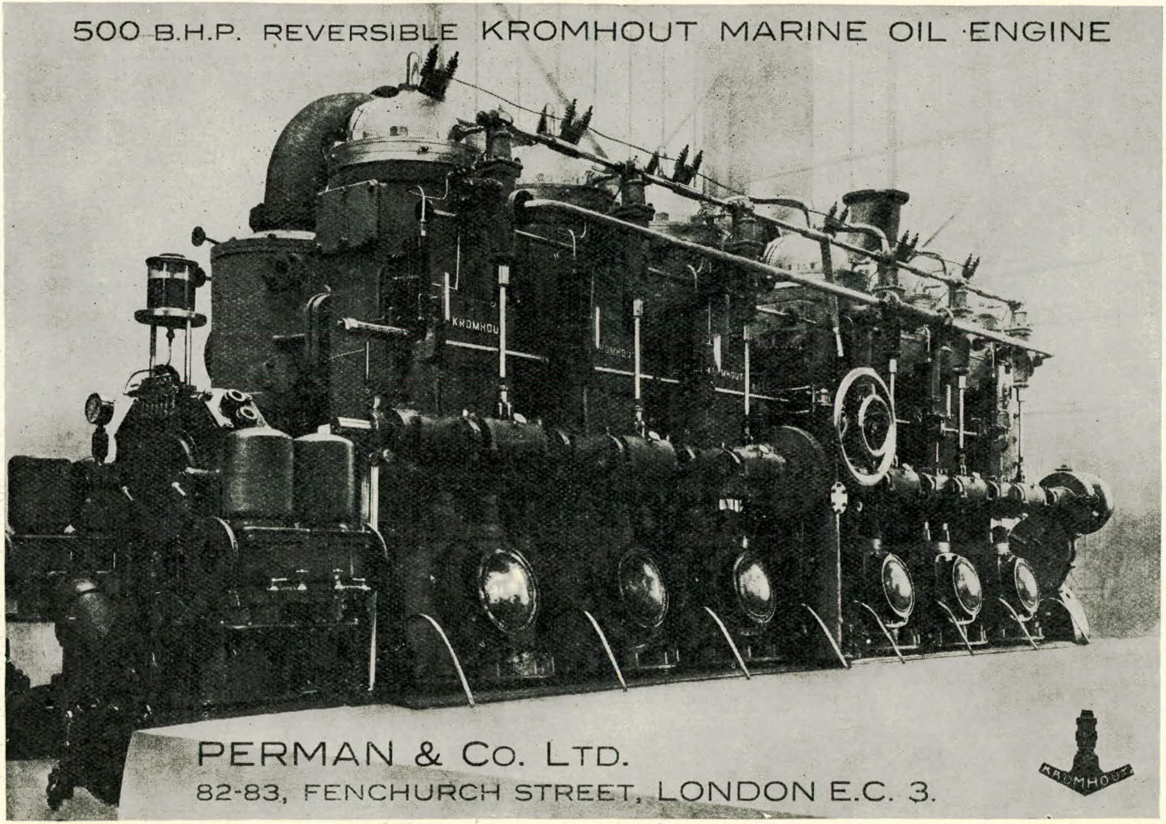
The "Elwee" Pre-Combustion Chamber and Capsule.

perhaps one classification that might be suggested; it is simple, and is as follows:—

(a) Engines in which the fuel enters the cylinder or combustion chamber at the moment when combustion is required.

(b) Engines in which the fuel enters previous to this.

Obviously this classification is of no practical value, as it brackets the Brayton and the Diesel, but if some new name could be found to include the Diesel, the semi-Diesel and the compression ignition engine, whatever they may be, it would

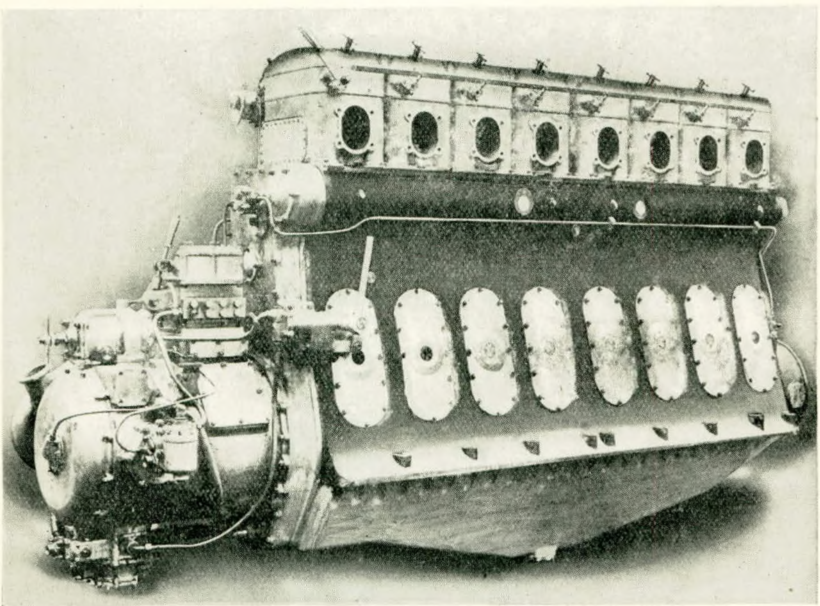


A Reversing Crank Chamber Scavenge Marine Engine.

be of value, and to this end the author will suggest the name "Injection Engine" for consideration.

Having brought up the purely historical side of this review to the year 1900, the author will now endeavour to trace the subsequent evolution of the oil engine, sometimes reverting to the historical period, but selecting definite lines of development.

Mechanism.—Mechanism, for instance, is one factor that can play an important part or be but purely incidental. There is



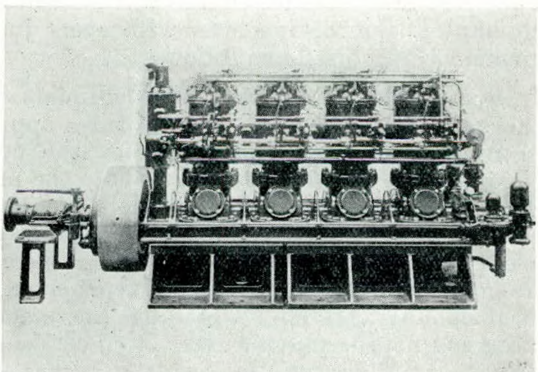
The Engine of the R101.

but little difference between a motor car engine and a small Diesel, as far as mechanism goes, yet the engines greatly differ, while we may have the horizontal gas engine mechanism applied to the principle of the said small vertical Diesel, though occasionally the mechanism is the dominating feature of the design.

As an instance the stepped piston may be cited. It was introduced by Baron in 1876, and there were various other instances till we had the M.A.N. submarine Diesel on these lines. It was an attractive scheme but it was never properly carried out, not excepting the said M.A.N. engine, and for this reason it fell into disrepute.

The crosshead scavenge engine, a double-acting construction where the lower half of the cylinder is employed for scavenging purposes has already been mentioned; it was hailed as an advance beyond the crank chamber scavenge engine, but it is illogical and uneconomical.

Many attempts were made at the swashplate system. Its first appearance was in 1860, but no progress was made till the scheme was revived by Michell a few years back, though we still have no knowledge of the results.



Gardner C.C.S. Engine.

The Humphrey pump was evolved in 1906, though this principle was suggested on many occasions in the very early days. The probability is that the civil engineering work connected with its construction is so costly that there is no real financial gain.

The opposed piston has already been dealt with, but there is a modification of this, the Fullagar; mechanically it is sound, but it hardly bears economical analysis

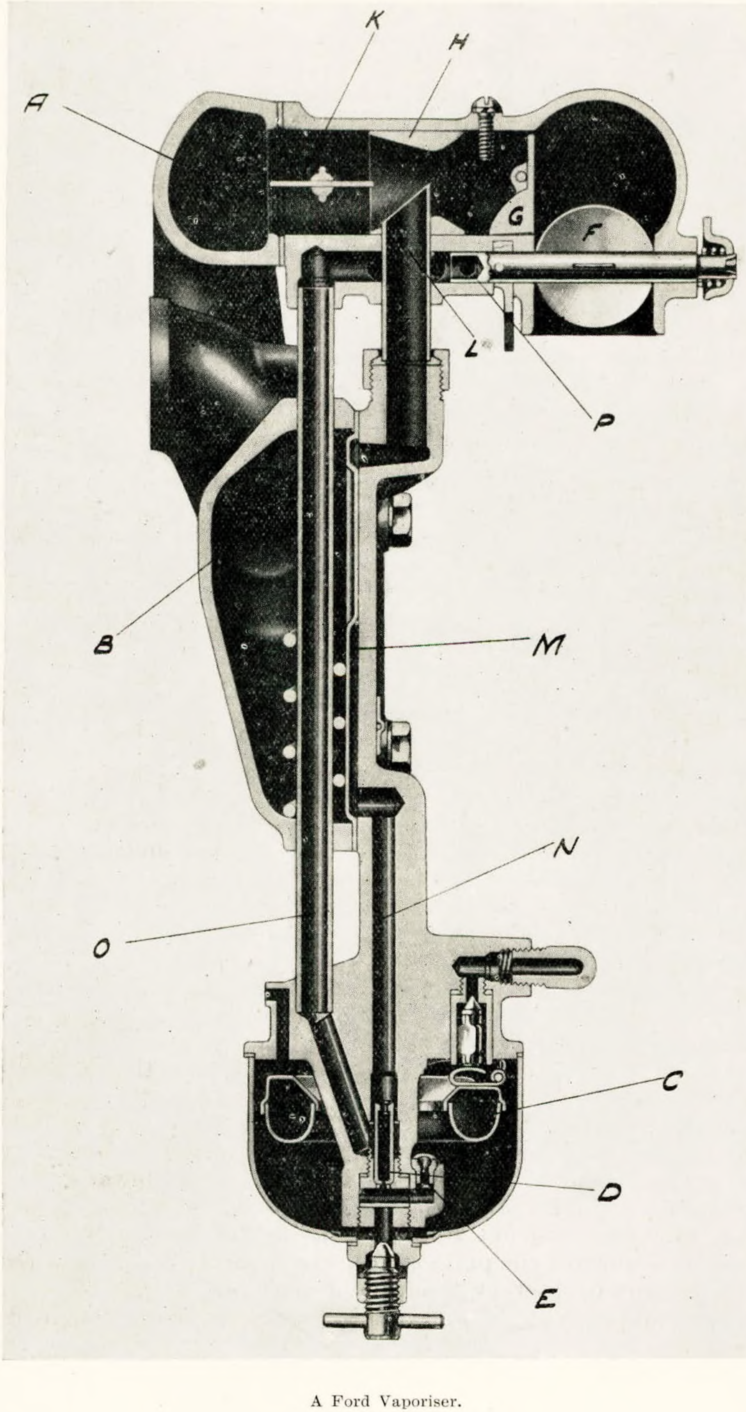
The double-acting four-stroke is an endeavour to cheapen the construction of an engine, in doing which it succeeds but at the cost of the introduction of mechanical details and combustion chamber shapes that are not altogether convenient or correct.

On the other hand the double-acting two-stroke has much to recommend it. It is so sound, both mechanically and economically, that it is bound to dominate construction practice as times goes on. Besides the advantage of increased output for a given swept volume we have the decelerating effect of compression at each half stroke, thereby allowing higher piston speeds, the only real defect being that the bottom combustion chamber cannot be altogether in accordance with requirements.

The rocking lever has, throughout the whole development of the internal combustion engine, proved very attractive to the designer. Unless this lever can be employed to reduce the total amount of mechanism, weight, or space occupied, and unless it can also be employed for some other important purpose it is not justified.

Within the last few years an engine was designed by P. A. Low which employs the rocking lever with every justification, the arrangement being briefly as follows:—

Two inverted single action two-stroke cylinders are placed athwart the crankshaft, the axis of one being approximately over the centre line of the shaft. Under the cylinders is arranged a rocking lever connected by rods to the pistons, but the length of the rocker between centres is greater than the pitch of the cylinders to such an amount that when at the end of the stroke the rocker centres are just beyond the axial plane of the cylinders. One end of the rocker is connected to a crank in the usual manner, thereby providing the elements of a double-acting engine, inasmuch as the action on the crank is in both directions, and the inertia forces of the rocker and pistons are in opposition to the force set up by compression. As the speed of revolution is increased a balance is approached, till at a speed somewhat above ordinary requirements an approximate balance is reached and the crankshaft is relieved of inertia stresses. This arrangement obviously has a considerable value from the balance point of view, and it also halves the number of cranks with very little increase in the height of the engine, another factor of importance. The offset of the arc of movement of the rocker allows the side thrust on the piston, which is very small, to be always in the same direction, towards the inlet ports, and this in turn allows full piston clearance to be arranged. Low did not stop here, as to the free end of the rocker he connected the plunger of a full capacity double-acting scavenge pump, thereby complying with an axiom set out earlier in this paper by providing cheap scavenging, ten per

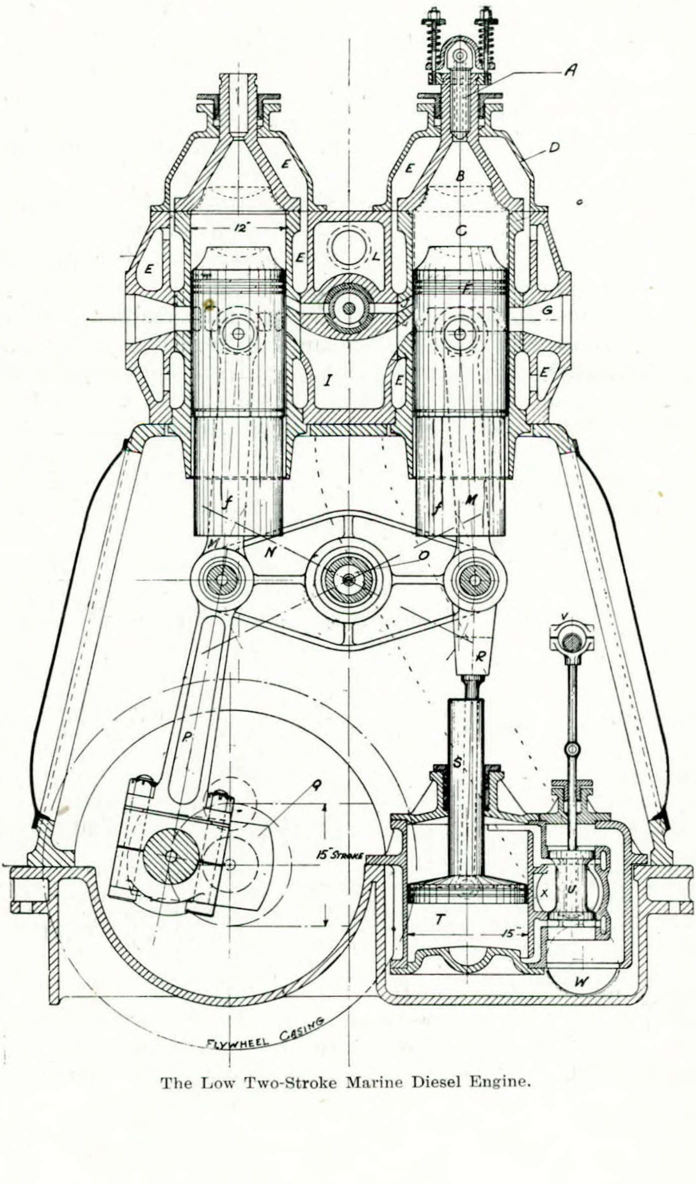


A Ford Vaporiser.

cent.or even less instead of fifty per cent. Having this positively driven scavenge pump, it was a simple matter to design the pumps to withstand fifty pounds air pressure, to arrange them with mechanical valves, and to use this scavenge pump as a manœuvring engine, using air at 40 or 50lb. and exhausting into the scavenge belt of the cylinders. Air at this pressure is sufficient for starting and manœuvring the engine under all circumstances, and although the author is interested in this design, he feels that this somewhat extended description is warranted as the employment of the rocking lever is something more than just an interesting alternative of no particular value.

Supercharging and scavenging are problems that are becoming very closely allied. We have mentioned the Büchi system, that is so well known. Here it is but one problem and not as with a supercharged petrol aviation engine, but the subject is so very technical that space does not allow the author to attempt to outline its development, but he will add that there can be no doubt that the engine of the future will embody supercharging to a very considerable extent.

The Vaporiser Engine.—To return to the treatment of the fuel in oil engines, a close observation of past records shows that there were two schools formed. One advocated the outside vaporiser and the other the internal form, the line of demarcation being formed by the position of the induction valve. The Priestman engine had an outside vaporiser, and so has the Kelvin. In the former great pains were taken to spray the fuel into the heating chamber. With the latter engine a jet spray is allowed to suffice. If we take the relative performances, after making due allowance for compression pressures, mechanism and piston speed, there is very little difference in the results. In the Kelvin the whole of the air passes into the vaporiser, thereby reducing the temperature of the retort and increasing that of the charge, both being detrimental factors that were soon recognised. In those engines that stood out owing to their performance, this crude arrangement had been modified by mixing cold atmospheric air with the vapour as close as possible to the engine, the Gardner and the Fordson being good examples. We lock in vain for the final, logical evolution of this system, but an arrangement was projected, made and tried by Constantinesco which is a very clear exposition of all that can be hoped for. In this scheme the inner annulus of a double jacketed silencer formed the vaporiser, and this was filled with rivets to provide an increase surface. Into this annular chamber was led a jet supplying the oil, and as a carrier a pipe, led from the exhaust, supplied a proportional amount of hot exhaust products which helped to carry the paraffin through the mass of rivets.

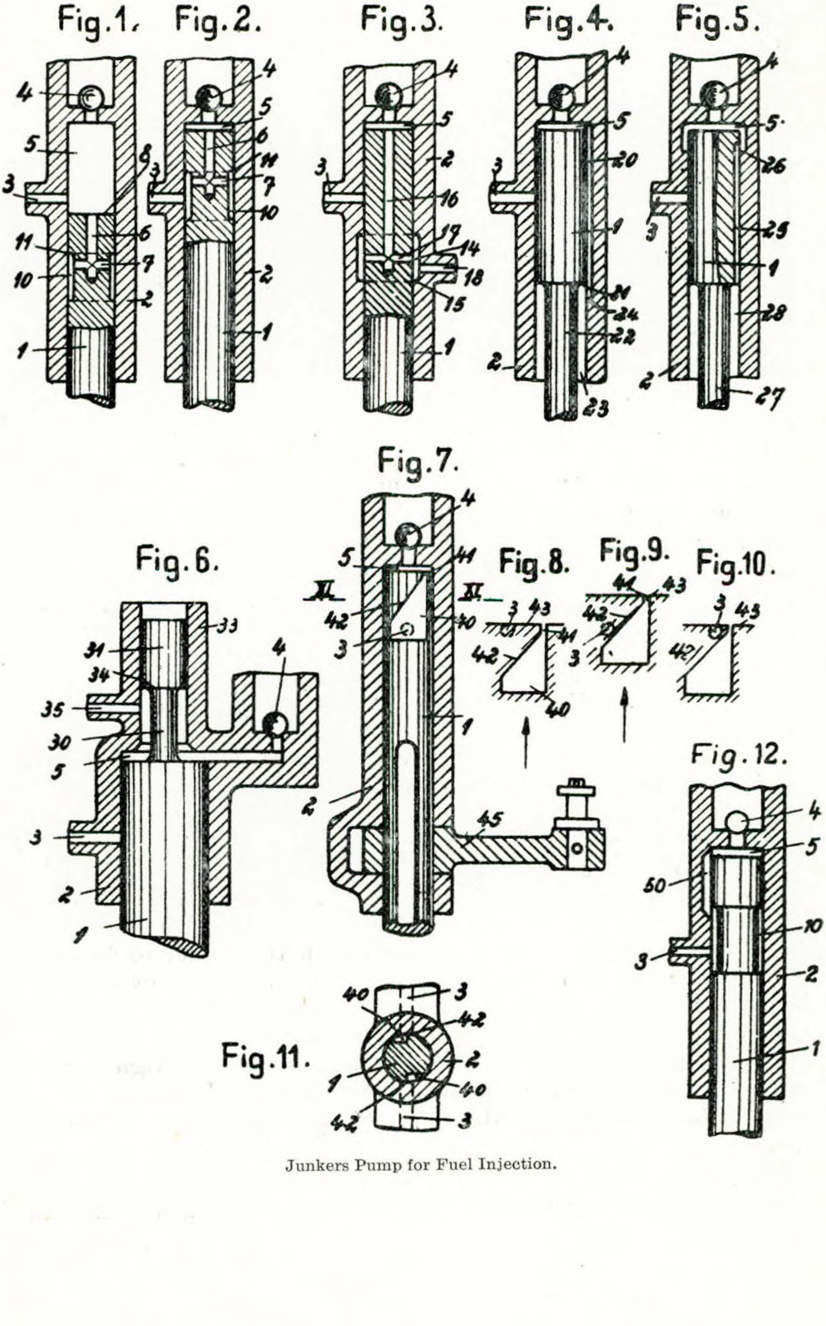


The Low Two-Stroke Marine Diesel Engine.

The employment of air for this purpose causes some obscure catalytic action which decomposes the oil and produces irregular action and tar deposits, therefore exhaust gas was employed. The result was a very rich vapour of a fairly stable nature, and this vapour was led to a carburettor proper which was, in effect, an injector, and as this injector was dealing with two gases, air and vapour, the proportioning remained the same under all conditions. The gas proportion was very small, and therefore the temperature of the charge was low, the net result of the arrangement being that it could be used on the motor vehicle engine of fifteen years ago without any alteration of the engine and with every success, the results being almost identical with those of petrol. Why this theory and practice were not accepted by builders of paraffin engines is hard to suggest, though it is harder to explain why the primitive arrangement is still adhered to.

The interior vaporiser had perhaps a more spectacular career. It was introduced by Capitaine and continued in many forms till at last, instead of drawing in the oil from the air valve seat, as is the case with the Campbell engine, the oil was delivered to this seat by means of a metering pump. The internal vaporiser was obviously heated by the combustion of the charge, and was at first a complex affair. Later on, instead of delivering the oil by the metering pump to the outside of the induction valve it was delivered inside the vaporiser. Then the vaporiser was simplified, and we arrived at an engine that was really a crude Hornsby-Akroyd. Stuart himself accidentally solved all these pre-ignition problems which other workers had encountered by fitting the bottle neck so as to insulate the inflammable vapour from the air charge. Stuart's invention was incidental. It was the outcome of his failure to produce the Diesel engine. He had advanced the period of injection in an endeavour to prevent "after burning" to such an extent that the pre-ignition made the engine impossible. He then reversed the order of things, delivered his oil early in the cycle, provided the bottle neck, and then displaced the air in the cylinder, through the neck, to the charge of oil vapour in the combustion chamber. This process occurred elsewhere, and we can distinctly trace the evolution of the modern horizontal high compression oil engine (which has at last evolved itself into a Diesel) from the inside vaporiser, through various stages, to the present practice.

The Carburettor for Petrol.—We must not attempt to deal with this through lack of space, but it is of interest to note that no



Junkers Pump for Fuel Injection.

real logical progress was made till Hinchley introduced the Venturi in 1901, thereby bringing this apparatus into line as a logical contrivance. It will be noted that after this the development was but a matter of detail, the climax being reached when the Venturi was surrounded by a row of holes leading to an annular chamber into which an emulsion of petrol was metered.

The Akroyd Stuart Type.—This engine has been mentioned previously, but the author will now endeavour to show how it came into being, its general effect, and the subsequent development of the modern engine from this source. It has been explained how Stuart's first conception was a Diesel, how the Diesel idea failed, and how he reverted to the internal vaporiser with automatic ignition. It was in 1890 that Stuart lodged his Specification No. 7146 in the names of Akroyd Stuart and Richard Binney in which occurs this very historic clause:—

"In order to prevent the pre-ignition of the explosive mixture, owing to the high heat of the vaporiser, we first compress the requisite supply of air for the charge and then inject the oil into this compressed charge by the use of a pump or the like, the injection of the oil being correctly timed to correspond with the position of the piston at the time the explosion is to take place."

If we turn to the claims of this Patent we find that No 1 refers to the vaporiser and to that alone. Claim No. 2 is for introducing combustible gas or vapour into this compressed air, and not oil as one would expect, the claim reading:—

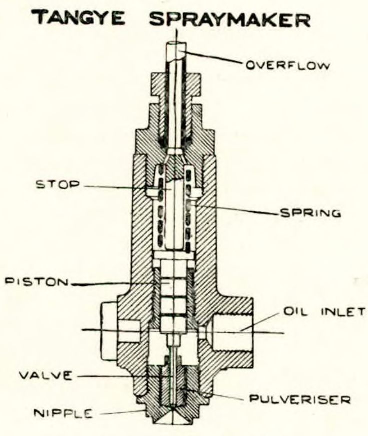
"Claim 2. In an engine operated by the explosion of a mixture of combustible gas or vapour and air, forming the said mixture by introducing the combustible gas or vapour into a charge of air under compression, substantially as described."

Where does the combustible vapour come from and how is it injected? may be asked as soon as this claim is carefully studied. And why is this the second claim?

Perhaps the answer is to be found in the fact that before the year was out the whole scheme was dropped, all prospect of just such another epoch as was produced by the acceptance of the Beau de Rochas cycle by Otto was thrown away, and just as the said Dr. Otto became the involuntary introducer of the merits of the four-stroke cycle, so Akroyd Stuart unconsciously invented that method of oil engine construction which was to prove superior from every practical point of view to any other system, including even the petrol engine, if we may for the moment substitute prophecy for history.

It has been pointed out previously that Priestman had already invented a cycle where the fuel was injected into the air charge at maximum compression, and this is set out in Patent No. 10,227 of 1885. As he used a form of blast air injection it is most strange that he did not make some progress.

We have not to search far for the reason for the abandonment of the early scheme. Stuart met with a difficulty, the same difficulty that remains with us to this day, the difficulty of pumping oil through a spray jet in the desired manner. Perhaps it was because Stuart was more interested in the exploitation of his vaporiser than anything else that he so soon abandoned his scheme, and by doing so placed on the market an engine that had a very low output, was very sensitive as to the fuel employed, and was far from flexible either as to speed or load. The fact remains that this engine built up a great industry. It was simple, and it was obvious, and he soon had very many imitators all over the world.



A Differential Fuel Valve.

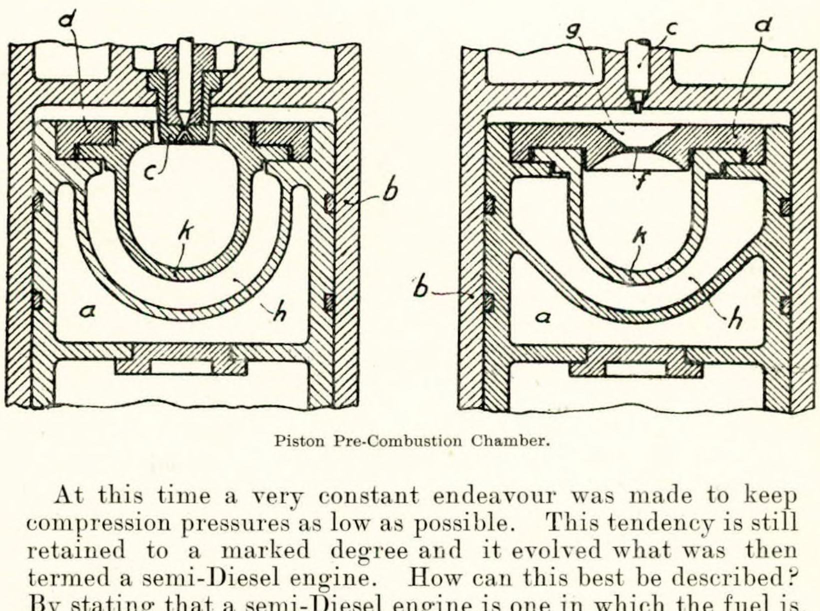
It is a curious fact that when the hot bulb, two-stroke, crank chamber scavenge engines were introduced many years later the evolution started again and followed exactly the same path, but we will return to 1897, when Mietz and Weiss brought out their first engine, which had practically no neck and was devoid of the lip that was so characteristic of their later engines.

There were many other workers in this direction but the name of E. A. Rundlof is historic, for in 1903 he invented the two-stroke crank-chamber scavenge hotbulb engine. He passed this invention on to the firm of Bolinders of Stockholm, and we had the beginnings of a vast series of engines, made and used all over the world, and all of them of a type that can be termed a "Two-stroke Hornsby Akroyd." It will be granted that this was far from being acknowledged by their vendors. They claimed them from the start as semi-Diesel, whatever that may mean, but in all but quite recent times injection of the fuel was arranged as early as could very well be, 120 degrees, or 90 degrees at the latest, and pre-ignition was guarded against, just as it was with the Akroyd, by injecting into a combustion-chamber having a narrow neck communicating with the cylinder. These two-stroke engines gave an incomparably better performance than the old Hornsby engine. The compression was higher and the pumping was more efficient, but the power factor was about the same per cycle, which obviously doubled their overall performance. They unfortunately reverted to water injection (claiming it as a virtue), but this was never done by the Grantham firm. (Stuart projected the use of water injection but nothing came of it.) In one design Stuart introduced stratification. This is very strange when it is considered that perhaps the greatest merit possessed by the old Akroyd Stuart engine was a product of turbulence in the vaporiser, and its fault, vide Clerk, was the absence of turbulence in the cylinder.

A very famous two-stroke Hornsby engine was, and is, the Avance, its merit being that the combustion chamber and the neck were designed on symmetrical lines and the jet was co-axial. Hornsby's flirted with the two-stroke in 1908, but they introduced an air valve in the jacketed part of the combustion chamber, and air valves in two-stroke engines have always been associated with failure.

Van Rennes made a very interesting modification. They separated the combustion chamber from the cylinder by a valve and then, at the top of the stroke, this valve was opened and the compressed air passed into the vapour in the combustion chamber and the mixture was ignited.

To turn to another subject, Brandis in 1911 introduced the snout on the end of the piston, arranged to enter a neck leading to the combustion chamber. This had been foreshadowed many years back, but in this case the objective of the snout was to increase the velocity of the air entering the combustion chamber and to ensure better pulverisation. Oil was injected into the path of this high velocity air. Crossleys and many other makers do the same thing, except that the oil is generally injected so as to meet the air stream. The device then is merely a turbulence arrangement.



Piston Pre-Combustion Chamber.

At this time a very constant endeavour was made to keep compression pressures as low as possible. This tendency is still retained to a marked degree and it evolved what was then termed a semi-Diesel engine. How can this best be described? By stating that a semi-Diesel engine is one in which the fuel is injected at or about the desired moment of combustion, and in which ignition is procured by some means other than the heat of compression? If so, it rules out, not only the hot bulb engine, but if carried to its logical conclusion, every so called full Diesel engine there is.

If, from this point, the position is reviewed, it will be seen that the sole reason that existed for the abandonment of the Diesel cycle by Stuart, the cause of practically all the trouble, and the various devices that were introduced, was the difficulty that had been experienced in pumping the fuel in a correct and efficient manner, and we shall see as we proceed that this fault or failure still dominates the situation.

Stuart immediately introduced a palliative, a chamber in which the fuel could be injected, where it would vaporise and then, when compression delivered some of the air, combustion would take place and the remainder of the fuel would be injected into the cylinder.

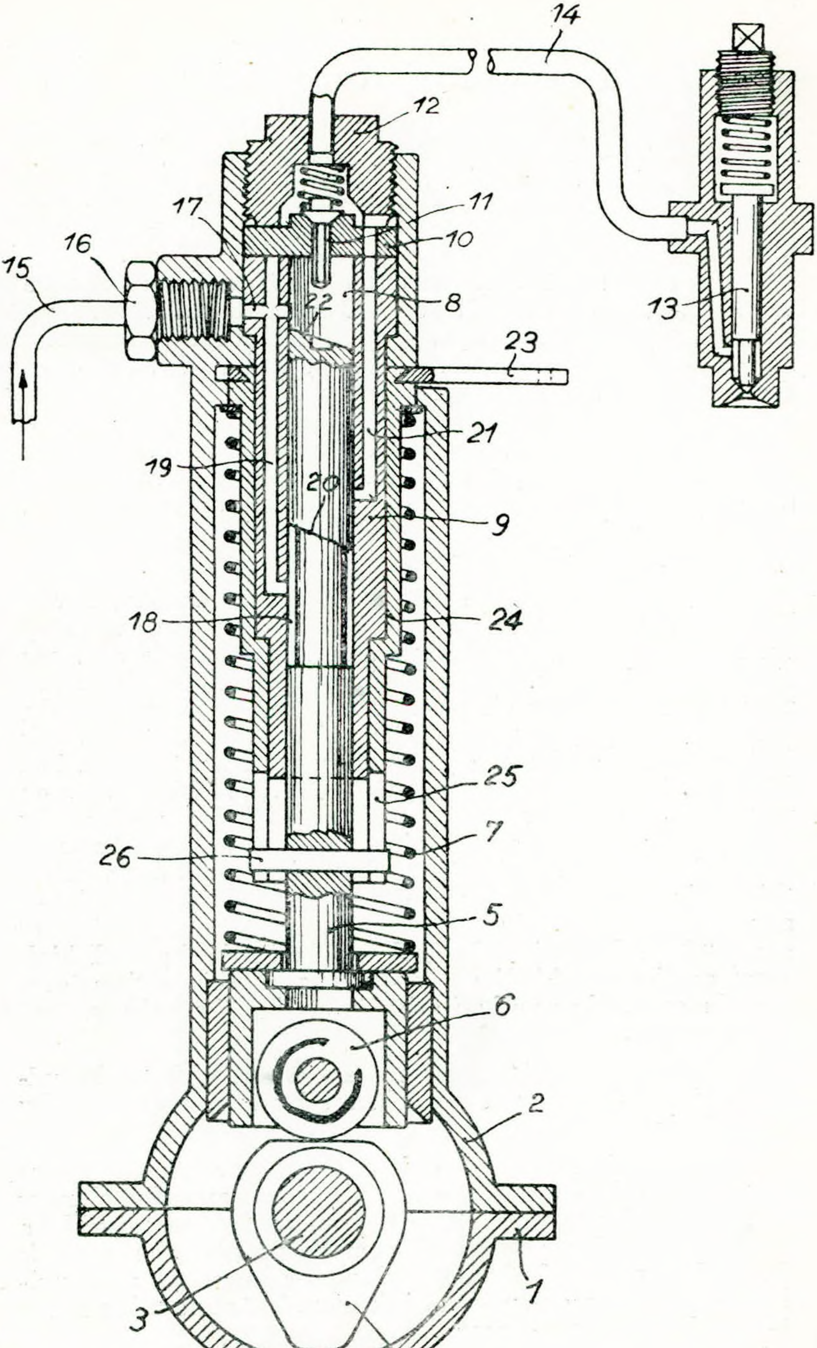
Fuel Injection.—This refers to the injection of fuel in Diesel and other injection engines, and it should be pointed out that the progress of the oil engine has been in exact phase with the progress that has been made with the injection of fuel. The blast injection system which Diesel introduced was but accidental. It has now served its day for the reason that the engine itself has progressed to such an extent that blast air injection has become obsolete, while airless injection has hardly arrived at that state in which it meets approbation for the higher forms of engines, engines, it must be remembered that would be entirely out of the question if associated with the blast injection system.

Akroyd Stuart's conception of a fuel pump and spray was a very simple affair. It was a small edition of the boiler feed pump seen on any portable or traction engine; it was opperated by a cam and lever, a drip tray was placed underneath and several feet of pipe led to the spray jet, a fairly large single jet that was insulated from the hot vaporiser by knife edge contacts. Incorporated with this jet was a spill valve that was opened by the governor and by-passed some of the fuel back to the tank.

The author has run an engine of this kind at its normal speed with the jet spraying into the atmosphere, and he found that the jet never ceased to flow. There was a sudden rise when the plunger descended and then a gradual tail off to a dribble, and before this ceased, another impulse.

This is the answer to the question, why did Stuart's Diesel fail? It explains the injection chamber that he fitted. it explains the modern pre-ignition chamber, and it brought into being the differential fuel valve and every other device that has been invented to improve fuel injection.

Dr. Diesel failed, but he had available the blast air apparatus that he had made for the injection of coal dust (of late years the coal dust engine has been revised). This apparatus served very well indeed to inject the oil, and therefore the initial development of the Diesel engine was carried out with blast air, at an extra cost of perhaps 30s. per h.p. and a mechanical loss of from 7 to 10%.



Bosch Pump.

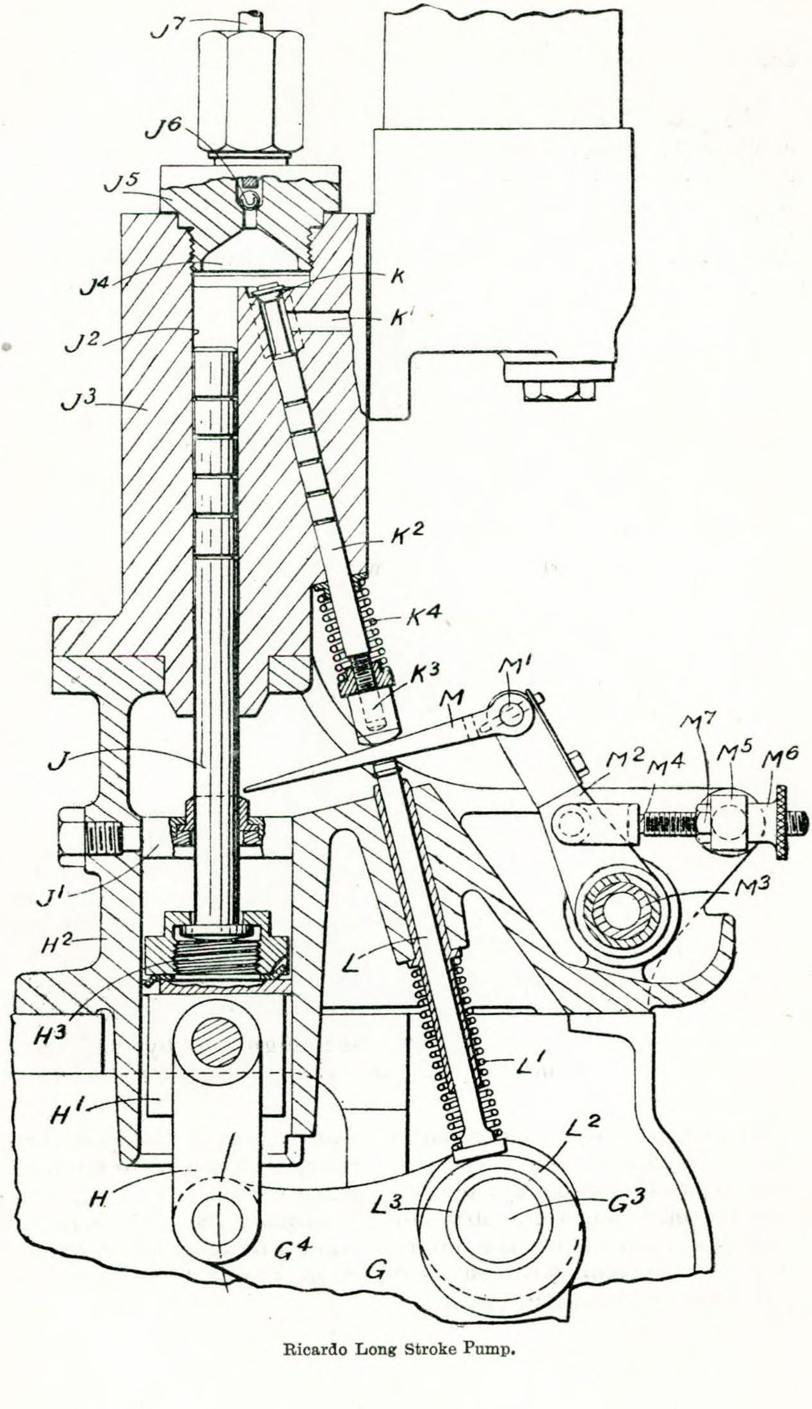
Fuel injection development was retarded by many factors. Some workers thought that it was advisable to allow a spray to impinge on a metal surface, a hot one for preference, while as late as 1921 Bolinders were using a whirling spray which is quite inadequate for the purpose.

Thornycroft endeavoured to evade the issue by providing a valve with a groove on the seat. The valve was loaded by steam pressure and the delivery of oil caused the valve to rise slightly off its seat; in consequence the steam passed through the opening so formed and pulverised the fuel. A further alternative that has many modifications was to pump some oil into a pocket in the combustion chamber, and then at the correct moment to displace this oil by an air blast supplied by a stroke by stroke pump, by trapped combustion products, etc., while all the time workers were endeavouring to arrange for solid injection by the pressure injection of fuel.

McKechnie is rightly credited with the establishment of airless injection for large engines, and his system was to pump the oil by a metering pump into a spring accumulator some time during the cycle. A mechanically operated fuel valve was then opened, and the oil passed from the accumulator to the spray jet, the pressure he selected being about 3,000 lb., this in itself being an important progressive step, as 500 lb. had been considered sufficient up till then. McKechnie soon modified his arrangement for multiple cylinder engines by simply delivering the oil to a pipe line that was carried around the engine, branches being led to the various fuel valves. Now this is the system that has given the best published results of any Diesel engine, 121 lb. b.m e.p. at a consumption of about ·39 lb., but it is to be doubted whether in the small high speed application this live line system will prove satisfactory, and the author has no hesitation in stating that the output figure given is very far below the possibilities.

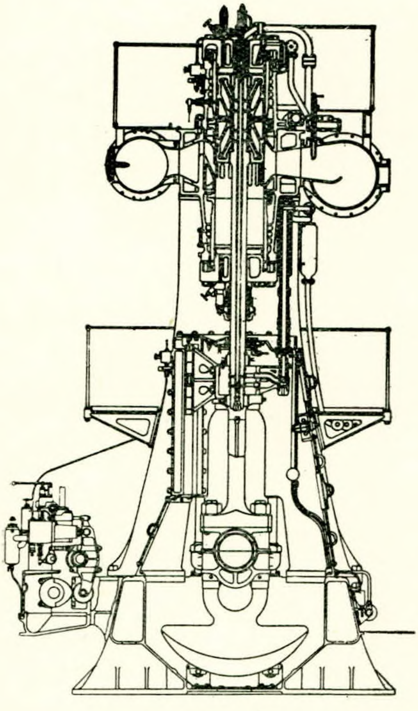
As a matter of fact the system was inaugurated by G. Brandstetter in 1905, some five years before it was re-introduced by McKechnie.

Hornsby's did try a scheme that gave them all the apparatus for the McKechnie arrangement. They had a metering plunger and above this was a dry plunger spring loaded and raised by a snail cam. When the dry plunger slipped off the cam it descended and struck the pump plunger a hammer blow, excellent for the commencement of injection, but of no value to the terminal or important part.



Ricardo Long Stroke Pump.

The present Blackstone system is perhaps the best example of metering pump and accumulator that we have, for here the oil is delivered to a chamber containing a free plunger which is forced outwards. A rocking lever then engages the plunger, which is in two halves and has an initial spring load, forces it in, compresses the spring, and then when the terminal move-

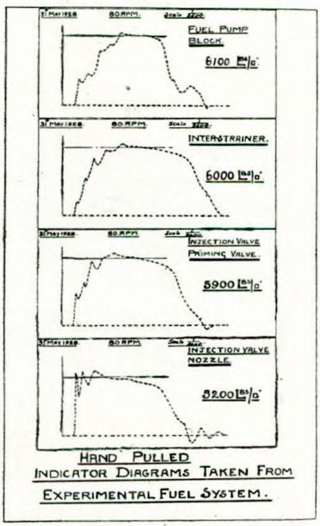


Burn D.A. Two-Stroke Engine.

ment of the lever opens the fuel valve the spring plunger expands to the stop and the oil is delivered in a reasonable manner for a medium output slow speed engine.

May we ask at this juncture why there should be such difficulty in pumping oil into a cylinder at a few thousand pounds pressure and at one, two or three hundred revolutions, and why Stuart and apparently everyone else failed? The dominant factor that explains this is the failure, one might almost say refusal, of designers to recognise that oil is compressible as it is to an amount equal to about one per cent. for every 3,000 lb. In one particular case of a standard oil engine investigated at Cambridge this resulted in one third of the displacement of the plunger at full load being absorbed in compressing the fluid.

Another factor, a resultant of the first, was the wave action in the fluid column, and the whole of the later development of airless injection has consisted, with a few exceptions, of the provision of palliatives for the results of these natural phenomena.



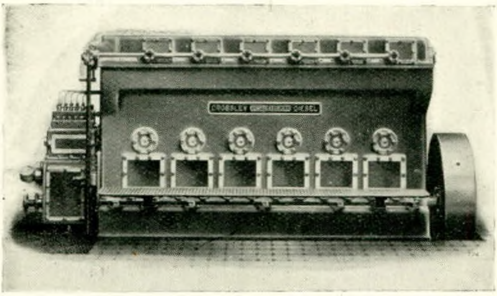
Fuel Injection Diagrams, Richardsons-Westgarth Engine.

The Differential Valve.—The most important of these is a valve that was devised by Thornycrofts in 1908, in the form in which it is now used. It was a spring loaded valve, that was carried on a plunger which was lifted against the spring by the oil pressure. This soon became the standard injection valve. It was next heard of from Rustons a year after, and in the following year Lamplough introduced a modification of some merit. He combined the pump with the valve and mounted the combined unit on the cylinder head, thereby eliminating the wave action in the supply pipe that has caused so much trouble.

The general faults of this valve and the effect of wave-making were investigated at Cambridge in 1926, and this research was embodied in a report published by this Institute in August, 1927.*

Crossley's came next, then Hall of the Bates Gas Engine Co., while in the same year Norman introduced the diaphragm packed plunger to eliminate the inevitable leak, these being just a selection of the many instances.

In 1921 Hesselman throws some light on the difficulties that were being experienced owing to the compression and expansion of the oil. He interjects a small cam operated plunger in the capacity in the hope that the withdrawal of this plunger will be effective, but it must be pointed out that no mechanically operated plunger can ever keep pace with the expansion of oil from a capacity.



Crossley Vertical Diesel Engine.

The Pre-ignition Chamber.—The author has pointed out that the Stuart vaporiser was but the precursor of the pre-ignition chamber, evolved for the same purpose and functioning in the same manner, and this device adds one more palliative to counteract ineffective pumping.

The pre-ignition chamber receives a roughly sprayed charge some time before combustion is required. This is vaporised, or partly vaporised, by the walls of the hot chamber, and on the instroke of the piston air is forced out of the cylinder, through the narrow orifice, into the chamber. At or about the dead centre the air that has been forced into the chamber forms a combustible mixture that is ignited, partly by compression,

* "Airless Injection and Combustion of Fuel in the High Compression Heavy Oil Engine," by D. H. Alexander, M.Sc., Transactions, Vol. XXXIX, p. 366.

and partly by the hot chamber walls. This ignition causes expansion and the contents of the chamber, vapour, products of combustion, and oil spray, are transferred through the orifice to the cylinder. This transfer tends to maintain equal pressure, and the higher the piston speed the greater the pressure difference and the higher the velocity of flow, the burning products ensuring the ignition of the remaining oil in the air available in the cylinder.

It is submitted that the above is a correct description of the functioning of the Hornsby vaporiser, and it is also suggested that it correctly defines the action of the modern pre-ignition chamber, the difference between the two being only a matter of degree, the ratio of the chamber and cylinder volumes increasing with the rise in compression pressures and the efficiency of injection.

This chamber takes many forms. In its most recognisable form it was introduced by Hirsch, as has been pointed out. Diesel suggested forming a chamber in the piston, but it hardly complied with the Acro arrangement, though the outstanding pioneer in this direction was J. Brons (Patent No. 14,165/1904) who invented a thimble-like capsule suspended in the combustion chamber. Oil was drawn into this capsule, which was provided with some small holes, and the air was then compressed through these holes and mixed with the vaporised oil in the capsule. At the top of the stroke the small air and vapour charge in the capsule fired, and the remainder of the fuel was injected into the compressed air charge, which being at 500lb. ignited in the usual manner. Why this device adhered to the required timing may very well be asked. the answer perhaps being that it is not fully established that it did. There were numerous other instances, Tartrais for instance, but the objective was the same and the means of attaining that objective differed so little that they need hardly be reviewed.

We have now reached the point where we can say that the airless injection engine is usually fed by a combined system of fuel pump, differential valve, and pre-ignition chamber, with the addition in the case of the Bosch apparatus of a withdrawal plunger that was introduced by Van Amstell about 1920.

An alternative method is the live line as has already been mentioned, while a very good modification of this is the Cummins system where each cylinder has a fairly easy working pump and a mechanically operated fuel valve. The first part of the stroke of the pump compresses the fuel in the supply pipe, then the valve is opened and before the end of the plunger stroke the valve is again closed, load variations being dealt with by curtailing the duration of lift of the valve and the stroke of the pump plunger.

There have been so many improvements in pump design and construction that we cannot hope to deal with them in this paper, but the author will take the somewhat unusual course of submitting his own views in this matter and suggesting that they more or less comply with the ideal characteristics.

The requirements of the ideal injection may be summarised by stating that:—

(*a.*) The mechanism should be balanced and free from mechanical shock, and should have no speed limits within reason.

(*b.*) The pressure of the fuel at the actual jet should rise from zero to a suitable working pressure in a fraction of a degree of crankshaft movement.

(*c.*) The designed fluid pressure of the fuel should be maintained over any desired angular period.

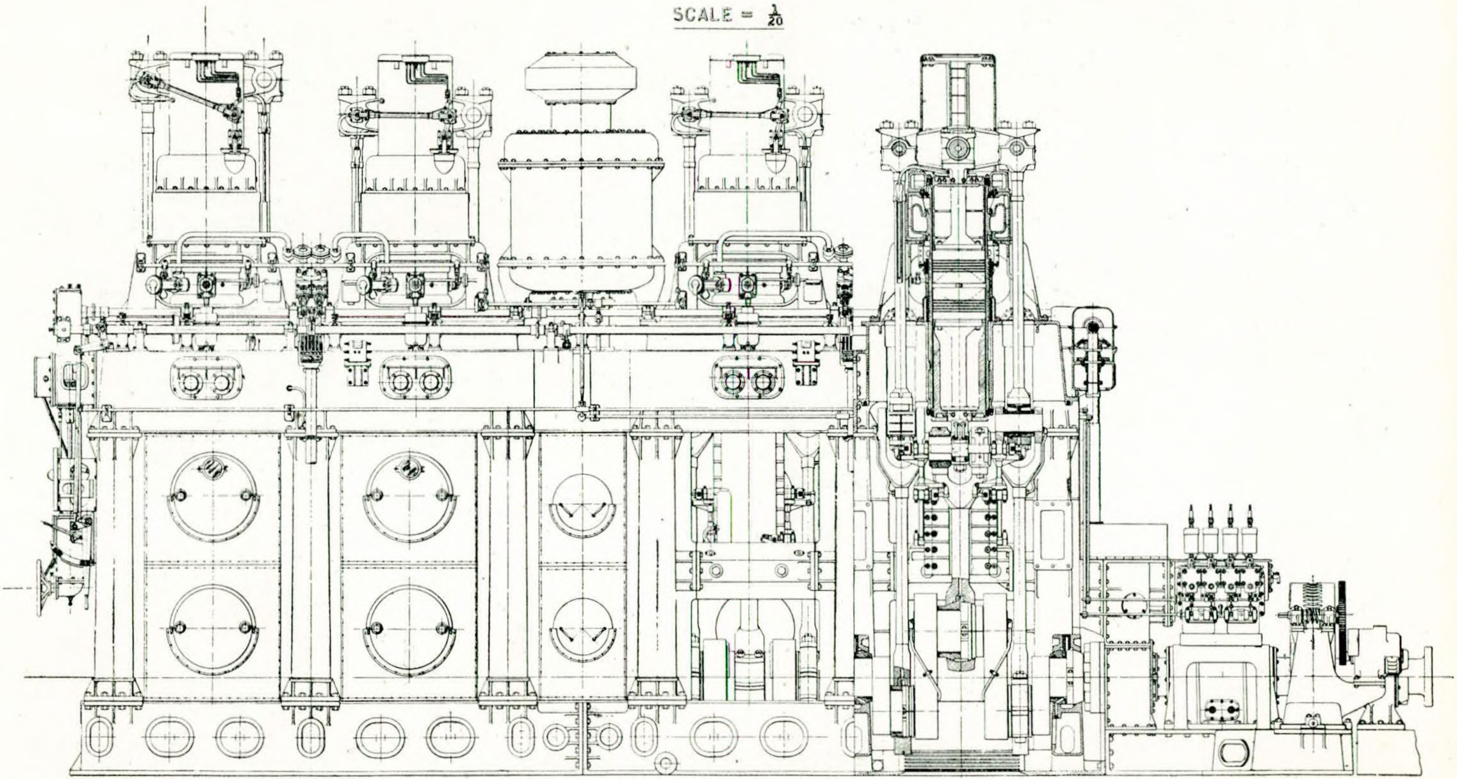
(*d.*) The fall of pressure to zero at the jet should also be accomplished in a fraction of a degree.

(*e.*) The timing of the commencement of injection should remain constant for all loads.

(*f.*) The pressure should remain constant for all loads.

(*g.*) The timing and regulation should be under easy and definite hand control.

The above conditions, it is submitted, are those the fulfilment of which has been the endeavour of all designers of fuel injection apparatus, and to this end the author, in 1913, brought out a fuel pump which he terms the "Harmonic Pump," as the reciprocation of the plunger is harmonic. This pump had a stroke of perhaps eight times the required delivery displacement, and it operated in opposite phase with a piston valve of the same stroke and diameter and was therefore in balance with it except for a small moment. The plunger and valve were submerged in an oil reservoir, and the pump functioned as follows: on the down stroke oil was drawn in to follow the plunger, and was discharged again on the upstroke until about half stroke, and therefore the maximum velocity, was reached. At this point the descending piston valve cut off the by-pass, and the oil was then delivered through a conventional delivery valve into the system. The regulation of the amount of oil delivered



Doxford Opposed Piston Engine.

was effected by providing the top edge of the piston valve with a helical surface, and therefore, as the valve was rotated, by means of a square shank, rotating neck ring, pinion and rack, and a ball coupling on the drive end of the valve rod, the by-pass port was opened earlier or later to suit the load. This harmonic motion was, after some years, adopted by several makers, Fielding, Beardmore, Ricardo, and others, and certainly their engines have made quite a reasonable showing, but the pump had a very grave defect that was entirely missed by the author at the time. The column of oil between the delivery valve and the jet was left under compression, and therefore had to expand and percolate through the jet, thus causing just that dribble that is so disastrous.

The author has projected certain arrangements that have for their objective the immediate release of pressure at the fuel jet, but as they are not yet established practice a description of same can have no place in an historical review, such as this.

The Diesel Engine.—This paper was written to lead up to the development of the heavy oil engine which has culminated in the Diesel engine. The paper which the author submitted to the Institute gave only a very bare outline of some of the salient examples of this evolution. This excerpt is less than one-sixth of the volume of the paper in question, and the allowance of space has already been over-stepped, therefore he will refrain from dealing with any description of types of Diesel engines, but he would like to be allowed to make one prophetic gesture and couple with this some advice. Let the designer for ever keep clearly before him the laws of Beau de Rochas, and visualise the future of the Diesel engine, whether for sea, land or air, as being concerned with substantial increases in speeds and pressures, and a very great decrease in weight per horse-power.

DISCUSSION.

Mr. W. A. TOOKEY (Visitor): It was quite a surprise to me to be called upon to propose the vote of thanks to Mr. Evans this evening. I do so with great pleasure and a full knowledge that you are willing to pass such a vote of thanks with hearty approbation.

As I understand it, Mr. Evans has really given three papers, the one which gained the award, another of which printed copies were distributed to us before this meeting, and the paper he has just delivered. I think we must therefore express to Mr. Evans our thanks for the way in which he has performed his titanic task.

As I have been connected with internal combustion engines for the past 38 years, the paper has been immensely interesting to me, and it brings back many memories. I had the privilege of meeting James Atkinson when he was with Crossleys, and an outstanding impression remains of one visit to Openshaw when he was trying out his 500 B.H.P. twin single-acting horizontal Tandem Gas Engine with the gigantic rope brake he used in testing it. It was before water dynamometers of the Heenan and Froude type were available. To keep that brake wheel cool Atkinson had a man standing by in sou'-westers throwing water on it at frequent intervals! A month or so ago I went to Gloucester to meet John Fielding (now over 80 years of age) to shake hands with him once more and talk over old times. You may guess how interesting that meeting was for me. I have also had the privilege of discussing gas engines with J. J. Griffin of Bath, who invented the six-stroke cycle engine and subsequently his vapourising engine, of which a slide has been shown this evening. I have not had an opportunity of talking with Robson, but have been closely acquainted with his son, who has been responsible during the past 40 years for the development of the Tangye gas and oil engines, some of which have been shown on the screen to-night. I need only refer also to Sir Dugald Clerk, who is still in the forefront in internal combustion engines and, as always, ready to discuss old and new developments. It may be interesting to know that J. Hamilton of the Premier Gas Engine Company at Sandiacre and the inventor of the supercharging differential piston engine tested in 1907 by the Research Committee of the Institution of Mechanical Engineers, and Hugh Campbell of Halifax, were draughtsmen under Sir Dugald Clerk at Stern's of Glasgow away back in their younger days. Both were painstaking pioneers of the earlier days and are still actively engaged in the industry.

I had the privilege of hearing the late Dr. Diesel discoursing on his engine in London in 1912. His paper at the Institution of Mechanical Engineers was read on a Friday evening and I left London on the following Sunday for Nuremburg to inspect some large gas engines of 2400 H.P. each which were going out to Japan. Whilst at the M.A.N. Works I was interested to hear that Diesel had not been so closely concerned with the successful developments of his engine as most text books and technical publications have led us to believe. Certainly he was the man who described the Diesel principle as we know it, but it is to the engineers of M.A.N. of Augsberg and Krupp of Essen that credit is due for the development of the engine through its earlier experimental stages.

These personal remarks may be concluded by saying that when the late Akroyd Stuart came over to this country on his last visit from Australia, he called at my office and we had a chat over his part in the development of the oil engine. I think he has done wisely in giving the sum of money for the Award on this subject, because we must never be allowed to forget Akroyd Stuart's really valuable contribution to the development of the internal combustion engine. He has done more than he knew he was doing at the time of his early experiments, and we must recognise that fact. I do not suppose we shall ever get his name coupled with the engine as Diesel has, but we must nevertheless give him due credit and the future bestowals of the Award of which Mr. Evans is the first recipient, will remind us of our debt to him.

I notice that the author has referred rather slightingly to the work of our early engineers in the internal combustion engine world, but he must realise that we can see to-day the work in its true perspective. Not only were those pioneers—some of whom I have mentioned dealing with a working fluid, of the physical characteristics of which they were not fully aware, but they were up against financial difficulties and manufacturing difficulties also, difficulties which we to-day can scarcely realise. They had to do every step of the whole thing themselves, they had no modern machine tools, no text books and no papers such as Mr. Evans' compendium, which is henceforth available to the young engineers of to-day.

This slight criticism, however, makes Mr. Evans' paper none the less interesting and none the less valuable, and I call upon you gentlemen to thank the author for the pains he has taken in its preparation.

Mr. NAPIER PRENTICE, Visitor (Past President, Diesel Engine Users' Association) : It gives me great pleasure to add a few remarks to those of my esteemed friend Mr. Tookey, who has so excellently dealt with the paper and the author's extraordinary—I was going to say ability—power of taking pains. He must have spent a lot of time in getting all this information, and he has presented it in a form by which we can read back into the past and see the development of a very interesting instrument of use. I have been associated with the development of the internal combustion engine for over 40 years, and I am interested to see how cycles of development occur. We see Hero's turbine of ancient history and now we have come back to the turbine. Dr. Diesel proposed to use coal dust in the engine cylinder, and we are told that a certain inventor had previously used an internal combustion turbine. He burned oil for the gas and expanded it against a Pelton wheel. Again we have the Humphrey pump with a water piston, and I wonder whether these things will be combined, as Diesel's trouble would be overcome if we burned coal dust with a water piston. Surely we might use the pumped water in a water turbine and get rid of a lot of trouble with the internal combustion engine. I hope some of the younger men will develop a combination of the Diesel powder engine, the Humphrey pump, and a water piston.

It is such men as Mr. Evans, who carefully put before us all the developments of the past years, who give us ideas for the future. I beg to second most heartily Mr. Tookey's vote of thanks to Mr. Evans for his most interesting paper.

Mr. E. G. WARNE: On rising in response to the Chairman's invitation I may say that had I known now that I was going to be called upon to pass any remarks I should have hesitated, because in view of the long experience of Mr. Evans and those who have already discussed the paper, I should have considered it hardly necessary to add any further remarks. My own experience of oil engines does not exceed 15 years, but modest as that experience is, I think I would like my remarks to take the form of a suggestion to others who may be bold enough to follow in Mr. Evans' footsteps in the competition, that they should deal in a rather different way with the development of the engine. I for one am not quite able to associate the development of the petrol engine and paraffin vaporiser with that of the heavy oil engine. The origin of the heavy oil engine was more in using a heavy oil than a light oil and vaporising it, and if we can get an account of the development of the engine down to a more concrete form it would be easier to comprehend than by going back through the whole development of all types of oil engine and covering practically the entire field. It leaves me a little bewildered, not having had sufficient time to go into all the details of the paper.

When the author remarked on the Bolnes engine as being an open engine and therefore appealing to marine superintendent engineers, he may have lost sight of the fact that the latest Bolnes engines are totally enclosed.

The author referred on one or two occasions to two-stroke engines as being double-acting engines, because they use the lower side of the piston as a scavenging pump, but it seems to me that that is scarcely the case. He went on to remark that the two-stroke double-acting engine will win through; none of us will disagree with that. One of the best known builders of the four-stroke engine has now decided to build two-stroke double-acting engines.

In connection with the engine motions no mention was made of the Benz. That is an interesting example. There is one unit in a ship of 3,250 tons gross in which two pistons are connected to each crank, i.e., a six-cylinder engine running on three cranks. I think Mr. Evans should have mentioned that example.

The paper leaves us in wonderment that the author has been able to go so fully into the development of internal combustion engines as a class, and I find myself fully in agreement with the author's final method of presentation of the paper, i.e., in a summary rather than reading through the paper as it stands. I am sure that we all owe Mr. Evans our very best thanks for the manner in which he has put these almost innumerable facts before us.

Mr. G. J. WELLS (Vice-President): Mr. Tookey asked us to bear gently when criticising our forefathers concerning the progress of the internal combustion engine. One of their difficulties was to obtain sufficiently accurate workmanship. With their steam-engine standards of accuracy it was very difficult for the workmen to realise the necessity for gas tightness. In the case of the steam engine, the conditions were—abundance of working fluid at low temperatures and pressures, so that leakage past valves and pistons was not a great matter comparatively, whereas in the gas engine, leakage was very serious, since a loss of fluid meant low compression pressures with consequent loss of efficiency. Indeed it has been said that if any fault appears the internal combustion stops, whereas in similar circumstances the steam engine will continue at work, such neglect only spelling a consequent increase in steam consumption, which, growing gradually, will probably escape detection. Even to-day it is not an unknown event for difficulty to be experienced in obtaining cylinders sufficiently accurately bored to hold compression pressures of 500 lb. per sq. in.

The causes that made the progress of the internal combustion engine apparently so slow were many—the steam engine prejudiced designers as regards form and character of the details; ignorance as regards the conditions that made for efficiency; and when an idea was grasped, practical considerations at the moment prevented any advance. Ignition troubles persisted for a long time, and held up improvements that were overdue. Patent law troubles were not unknown. How many of us have experienced the grip of the commercial interests in engineering progress! In the speaker's experience a case occurred, in which some steam engine cylinder covers of traditional design failed in a short time from commencing work. An experiment was made, the new covers stood up to their work, and then all worry ceased, no attempt being made to discover if the change made was the best possible or not. In short the usual attitude is, the engine sells with a good profit, it gives satisfaction, consequently the business manager urges (usually successfully) "Why scrap patterns, tools, drawings, etc., for another engine which may achieve an improved efficiency, but probably no more profit?"

Mr. Tookey mentioned Sir Dugald Clerk, who very kindly undertook to read the papers submitted, and to determine which paper deserved the Akroyd Stuart premium. Mr. Evans may therefore be congratulated, in that he will head the list of recipients for all time, and that he has the gratification of knowing that his position is the result of a critical examination of the essays submitted by the leading authority on internal combustion engine matters.

Mr. Evans in his paper mentions classification, but why worry about that matter? A Committee of experts met and discussed the subject of classification from all angles, but reported that they could not reach any satisfactory result. Why raise the subject again?

Mr. Warne's reference to fuels, in which he mentions the original idea of Dr. Diesel to use coal dust in his engine, leads one to restate the fuel problem and its varying aspects at different times. Coal and wood have each been used for almost every sort of prime mover. Oil has been employed in lieu of coal, but difficulties of combustion stood in the way, and for this reason carburettor designs have been produced by the hundred with only varying success, except for petrol, paraffins, and the lighter oils which are volatile at low temperatures. The residues remaining behind have led to engine stoppages sooner or later by reason of clogged jets and orifices. Now in this way it is easy to see why heavy oils have been tried and laid aside in favour of the lighter oils or gas, until the temptingly low cost of the heavy oils and residuals led to the evolution of the modern oil engine. An interesting example of this aspect of the cost question is the experience at the Stratford works of the Great Eastern Railway. When the late Mr. Holden was appointed as Locomotive Engineer, the passenger coaches were gas lighted and the residues were turned into the drains, until the local authorities objected. There was the problem of its disposal, and since there was no market for such matter, it had to be dumped somewhere. Mr. Holden, realising that it was rich in hydro-carbons, studied the matter of its use in lieu of coal and eventually devised a scheme for its use on his locomotives, as well as for certain heating operations in the works. But having achieved success, owing to the increased demands for fuels, the market price obtainable for the residues (previously wasted) made coal again the cheaper fuel, hence the oil-burners were removed and coal used. Finance was the reason for this return to coal from oil, and in a similar manner it is probably possible to show how internal combustion engines have fluctuated between the use of gas, lighter oils, and heavy oils.

*This Akroyd Stuart Award is well worth competing for, and as there may be some here who may be thinking of entering for it perhaps the following scheme or basis may be useful. With our present knowledge of the laws which govern the efficiency of internal combustion engines, together with the progress of workshop processes and the steadily increasing theoretical knowledge it should be possible to draw up a very useful review of the real progress of internal combustion engines. Such a review would probably leave out many engines except possibly to illustrate some phase of the ignorance then prevailing.

I will conclude by once more congratulating the author upon his effort, and the Institute as well, on the very successful first award of a premium which will doubtless become the most coveted award in the disposal of the Institute.

Mr. A. H. MATHER, Vice-President (Joint Convener, Awards Committee): In coming to this meeting to-night I had no thought of joining in the discussion, but I thought it might be desirable to put before the members an account of how the result of the competition, the first for the Akroyd-Stuart Award, was arrived at. The Institute was chosen by Mr. Akroyd-Stuart to administer a trust fund to provide an award for the best paper written on the development of the heavy oil engine, and as a result of the announcement of the first competition under the terms of the bequest a number of papers were

* Akroyd, Patent 15994. Oct, 8th, 1890.—J.A.

sent in. The adjudication of the relative merits of the several papers was a serious matter, and it was felt by the Awards Committee and the Council that it was desirable in the interests of the competitors and all concerned that it should have associated with it the name of someone accepted as an authority in the oil engine world. The choice fell upon Sir Dugald Clerk, who very kindly acceded to our request to judge the papers, and I think it will be agreed that we could not have had a more influential name to attach to the award. I see that Sir Dugald is mentioned in the paper as being one of the earliest pioneers of the internal combustion engine, and his name has been associated with it up to the present time. We are under a very great debt to him for helping us in a rather difficult situation.

I should like to congratulate Mr. Evans on being the first to obtain this award, and on giving us such an excellent address in addition to the paper in its printed form for publication in the Transactions.

The AUTHOR'S Reply: First I should like to say how greatly I appreciate the remarks which have been made by the Chairman and the various speakers. I assure you that this task has been a most pleasurable one. It made one look upon things in a somewhat different light and in cataloguing the important steps in the development of the oil engine I was soon made to realise that I could never hope to collect all the essential details necessary for the illustration of this development, that it was beyond my power to correctly compend these details and that the allowable length of the paper forbade anything more than a somewhat arbitrary selection of incidents.

Perhaps I have been instrumental in clearing the way for someone to follow and deal, as Mr. Warne suggests, with the heavy oil engine as it is, in a more practical and intimate manner.

As regards Mr. Tookey's remarks, he very rightly took me to task for criticising those old stalwarts of days gone by, but I was at a disadvantage in presenting the abridged paper before the members. I can give this excuse, and with your permission I will read two short paragraphs of my original paper which bear on this point:

"An analysis of this kind, to be of any value, should rely a great deal on criticism. Surely we may be allowed this freedom, we who are so long after the event, who are wise with the wisdom of others, and who have seen such things as those early workers never dreamed of. We can motor to an aerodrome, fly to a seaport, and embark on a liner, each of these forms of transport being propelled by a prime mover that is but a development of the oil engine, therefore we may fearlessly point to that which was wrong.

Of what value is a history of this kind, to the layman, student or expert? The oil engine is but yet waiting development, it is at that period of its history which may be termed the eve of its renaissance, and if there is nothing else that can be gleaned, there remains the lesson to the expert that history, in the form of precedent, does surely act as a drogue on development, though on the other hand the student will gain both ideas and warnings from its intimate study, for which this paper may act as an index."

Mr. Tookey mentioned Dr. Diesel. I had the pleasure of meeting Dr. Diesel on the occasion to which Mr. Tookey refers. I pushed through the crowd and finally buttonholed him and asked why he did not use solid injection for his engine. He said, "I tried to and could not. I found it such an easy matter to use the compressed air that I employed for coal dust that I gave up troubling about solid injection." I have never forgotten that. It was perfectly true and has remained true up to the present day.

I was shocked when I had finished my paper to-night to find that I had not mentioned Sir Dugald Clerk. It is like the case of a man looking for his spectacles when he has them on his forehead! Sir Dugald Clerk's work is so well known to myself that I entirely overlooked its inclusion.

Mr. Warne thinks that I am wrong in endeavouring to trace the development from the vaporiser engine to the injection engine. I do not think so, because if we refer to present developments there is the Hesselman engine which injects fuel, and very well indeed, during an earlier part of the cycle, and then that fuel is ignited by a spark, just as it was in Hoch's engine of 1798. The Hesselman engine vaporises the fuel inside the cylinder by injecting it as a spray, and it is only that timing which has altered it from the Diesel engine. We may similarly take the vaporiser and trace that through.

I am very glad to hear that the Bolnes people were wrong, and that the marine superintendents were right; I thought so myself. In my use of the term "double-acting" I made reference to the mechanical or constructional side, and not the cycle. An engine is built that is, constructionally, a double-acting engine, but in which only one side of the piston is employed for power purposes. Mr. Warne refers to the Benz engine, the whole wonder of the engine being that it worked at all, but it did. I went down and had a run on one of those boats. It was quite simple. You had two four-stroke pistons connected to one end of a very wide lever with the connecting rod between the two piston rod ends, the lever being pivoted at the other end. I saw the vessel after she had completed 110,000 miles of sea and the Chief assured me that there was no wear to record on the rocker pins. Mr. Warne also rather took me to task for belauding the one and only example that we have of the commercial high speed, high power, light Diesel engine. We know it goes round and we know it pushes and drives things! Whatever its technical faults may be, it does show some enterprise.

Mr. Wells says there is no value in classification. I agree; I say so in my original paper. It is interesting to try to classify internal combustion engines, and I suggest one classification, namely, those engines in which the fuel is injected and enters the cylinder before it is required to be burned, and those in which the fuel enters the cylinder at the moment when combustion is required. I would refer you to my paper for further details of this suggestion. Mr. Wells then refers to the low compression that we worked with in the old days. I may say that the probability, as far as one can judge by general developments, is that compression will go up much higher than we are thinking of at the present moment. I heard of a French engine a few days ago in which the compression is up to 12,000 lb. I think Mr. Tookey could enlighten us upon some experiments carried out by Atkinson at Messrs. Crossleys at a very high compression and speed. There are many engineers now who think that we shall, before long, get up to these figures. Perhaps when the next paper for this Award is written someone will be able to record them as historic facts.

I again thank you, Mr. Chairman and gentlemen, for the reception you have accorded my paper, and I assure you that I fully appreciate the very great honour you have conferred upon me.

Mr. W. HAMILTON MARTIN (by correspondence): We have all listened to an extraordinarily fascinating lecture to-night, and I for one, who have lived among the Dutch, was greatly interested to learn that the origin of the oil engine really lay with that great Dutch scientist, Huyghens, who lived in the seventeenth century. I feel sure the author will be only too glad to see that just appreciation is meted out where due.

It was mentioned in the paper that Dr. Diesel lost all interest after his engine was taken up by the M.A.N. Co., Mirrlees and others, and that this inventor accomplished little that was of interest or actual value up to the time of his sad death. It was also considered doubtful whether he was the real inventor.

My personal impressions of Dr. Rudolph Diesel certainly led me to believe otherwise. Mr. Tookey will forgive me, I am sure. I had the privilege and good fortune of meeting Dr. Diesel several times with my father during and after the time I was working at the M.A.N. Works and at the Flushing Dockyard, which held an early M.A.N. marine Diesel engine license in pre-war days. Dr. Diesel, after completing his first successful stationary engine, spent his life partly breaking down strong prejudices of manufacturers against its introduction, and later in materially assisting the several makers to perfect it for the world markets, and subsequently evolved from it a reliable type for marine service. Messrs. Krupp, M.A.N., Nobels in Russia, and others kept in continuous touch with him. Dr. Diesel chiefly studied the theoretical problems involved, heat stresses, thermal efficiency, etc., the practical problems being tested out in the works in close conjunction with the inventor, who directed, advised, and studied the results in his own laboratory with his staff at Munich.

Valve scavenging problems were exhaustively tried and led to port scavenging being ultimately preferred on two-cycle engines. Piston heads, cylinder covers, and liners, when designed in great numbers and tested in large size engines, gradually eliminated heat stress failures. Injection valves, fuel pumps, etc., were all laboriously designed and tested for him by the various firms, and Dr. Diesel in consequence spent his life and the greater part of the royalties amassed by him in bringing his engine to a reliable and highly efficient stage, with a judicious use of suitable materials to reduce weight and cost, so leading up to the marine Diesel engine as we know it to-day.

Just as his stationary engine patents were coming to an end, his marine type became a sound proposition, but it had, however, cost the inventor his health and a great part of his capital to bring this about. His untimely death prevented him reaping the just reward of his wonderful labours. Many outstanding men of his day, such as Dr. Rieppel, Ludwig Nobel, Dr. Lanster, Lippart, Schwarz, Pawlikowski, Feilner, Wolfensteffer, Meyer and others abroad gave of their best to assist in perfecting his engine for land, mercantile marine, naval and road traction purposes, as a result of which its adoption has been phenomenal.

In my contribution to the discussion on Baron Steinheil's paper on the Nobel Diesel engine which was read before this Institute (Printed in the January, 1923, Transactions), I gave further details of these activities. I am the proud possessor of an autographed copy of a book which indicates what the oil engine world owes to Dr. Diesel's untiring researches. Although the author may not have been quite aware of these facts I consider, nevertheless, that they are worth recording.

As the development of oil engines has been dealt with in this paper, it may not be out of place to mention here a likely future development closely allied with efficient combustion in such engines, which especially relates to a means which overcomes the fuel injection difficulties which Dr. Diesel had in his original engine as patented. It is known that the pulverisation of coal, being a preliminary to colloidising, is becoming less costly every year, methods being worked out for colloidising on a large scale with very inexpensive ingredients from the coal itself, so that it is reasonable to anticipate in the near future a colloidal fuel produced from the raw coal and a suitable oil at a total grinding and colloidising cost of less than 10 shillings a ton on the solid material, or about six shillings on the mixture of 60% coal, 40% oil basis. Such fuels, so far prepared, which may be strictly called colloidal, have remained perfectly homogeneous over long periods, which is of interest from the bunkering and storage point of view. The liability to explosion is reduced to a minimum as its flash point is that of the oil used. Its calorific value is over 16,000 B.T.U. Volume for volume it is 10% more efficient than the actual fuel oil used in its composition, which is a remarkable and most important fact. It can be handled by pumping and fired by atomisation, and stored for long periods without deterioration or risk of fire.

Labour costs are enormously reduced; specific gravity being round 1·1, it can be covered with water without the latter mixing or emulsifying with it, thus reducing the fire hazard and simplifying water ballast questions in double bottoms, deep tanks, etc.

It should be understood that the colloidal fuel is not a simple mixture of coal and oil, but a preparation made from coal and oil based on processes involving a strict application of mechano-physico-chemical laws.

My reason for bringing this forward is that it would seem likely that before long the above fuel will not only take a prominent place in boiler firing, but it may supersede injection of fuel or pulverised coal in internal combustion engine cylinders. It would allow of the original coal injection system of Dr. Diesel which has since been further improved by his old assistant, Pawlikowski, to be perfected and simplified. We are bound to see very great changes in the methods of preparing and introducing fuels in power production plant within the next few years.

I would add my thanks to the author for his so profusely illustrated and interesting paper.

Mr. B. JACKSON (by correspondence) : The paper read before the Institute by Mr. Evans on the 26th November is indeed formidable in its scope. It seems to me that it would be more correctly entitled "The History of Internal Combustion Engine Development," dealing as it does with every type of internal combustion engine—gas, petrol, light oil and heavy oil. The title implies that the modern heavy oil engine is the natural progression of the development of these various types, whereas there is no strict sequence of development of one type from an earlier one, although it is most interesting and instructive to compare engines and to observe points of similarity.

The heavy oil engine really came into being with the advent of the Diesel engine, which marked a very considerable advance on anything which had been accomplished previously. The author does not appear to have sufficiently stressed this point.

It is true that Dr. Diesel's original conceptions did not materialise, but then he was aiming to evolve an engine which was to be thermo-dynamically very near perfection.

He had come to the conclusion after many years of experiment with heat engines that little improvement could be effected unless the principles of working were considerably modified. He, therefore, proposed to construct an engine which would operate as nearly as possible on the principle of Carnot's cycle, i.e.,

1. During the first portion of the compression stroke the volume of air in the cylinder is compressed isothermally, i.e., without rise of temperature.

2. During the second portion of the compression stroke the air is compressed adiabatically, i.e., without transfer of heat to or from the surrounding walls.

3. During the first portion of the expansion stroke the air expands isothermally (heat being supplied to keep the temperature constant).

4. During the second portion of the expansion stroke the air expands adiabatically, the temperature and pressure at the end of the expansion being the same as at the commencement of the cycle.

The first engine built to demonstrate Dr. Diesel's theories was constructed without a water jacket so as to allow approximately the adiabatic portions of compression and expansion. The isothermal compression was obtained by means of a suitably timed spray of water injected into the cylinder, and the isothermal expansion was obtained by controlling the fuel admission so as to keep the temperature constant. Coal dust was used as fuel and the high temperature resulting from the compression of the air in the cylinder was sufficient to cause combustion of the fuel. Considerable difficulties were encountered both mechanically and with the type of fuel and the engine was not successful. Experiments were continued during the next few years, using oil as fuel, and eventually successful results were obtained.

The modifications involved included the cooling of the cylinder by water which was circulated round it, which affected the adiabatic portions of the cycle; isothermal compression was abandoned by the elimination of the water spray and isothermal expansion was substituted by combustion at a constant pressure.

Although the original objective was not attained, the resulting high achievement must be acknowledged.

It is a matter of satisfaction to know that a British firm were sufficiently far sighted to recognise the value of the invention and took an active part in the initial development of a successful engine. This firm, The Mirrlees Watson Co. of Glasgow, built their first Diesel engine in 1897 (this was the first to be built in Great Britain and the third in the World), and an illustration of this engine is given in the paper. It is interesting to note that it is still working perfectly.

With the Diesel engine three salient features were introduced, which were previously unattainable:—

1. Heavy and non-volatile oils hitherto of no use for oil engines could be used. Furthermore, oils of widely varying characteristics could be used.

2. The oil was delivered and burnt directly in the cylinder and as the heat of compression was sufficient to ignite the fuel so delivered, the engine was independent of any external agency for ignition. The engine could be started up immediately from cold, and full load could be applied within a minute or so from starting.

3. A very high thermal efficiency was attained.

The author's remark that the use of air for the injection of fuel into the cylinder is obsolete is sweeping and incorrect, for the air injection engine is still acknowledged to hold a premier position both as regards reliability and economy.

Although Dr. Diesel may have used air in the first place as an expedient because compressed air happened to be readily available, it was without doubt, one of those strokes of good fortune which occasionally brighten the path of the inventor, and it is quite probable that if the early experimenters had been faced with the many difficulties which have had to be overcome with regard to the solid injection, they would have abandoned their work and the oil engine as we know it to-day would not have been in existence. As it was, the success which was obtained by using air injection established the engine and attention was later turned to mechanical injection, which is what one would naturally expect.

Air injection has inherent features which are of very material benefit:—

1. It thoroughly mixes with the fuel on its way through the atomiser and ensures that the combustible charge enters the cylinder in perfect condition for ignition. The oil is broken up into very fine particles which are initially surrounded by oxygen, this being necessary for good combustion.

2. The comparatively large volume of the combustible charge forced into the cylinder produces considerable turbulence and thus the best possible conditions for combustion are obtained. Perfect combustion at all loads is a marked feature of the Diesel engine.

3. It permits a very definite control of combustion which is spread over approximately 10% of the stroke and thus the maximum pressure in the cylinder varies only slightly from the pressure of compression.

4. The orifice of the fuel valve is large and thereby immune from choking troubles due to particles of foreign matter being present in the fuel.

The fuel consumptions per B.H.P. of engines using air injection are equal to the very best that can be obtained with mechanical injection, and consistent results are more certain.

The engines which are commercially known as semi-Diesel and cold-starting engines are developments since the advent of the Diesel engine and as previously mentioned, might not have been in existence to-day if the Diesel engine had not proved successful.

The semi-Diesel engine was the first of this type to be developed and commercial influences were responsible for this development, for there was a very large field for engines of small powers where initial cost was of prime importance. They cannot compare with the Diesel engine either in economy or performance.

The cold-starting engine is a later development and was initially intended to meet a market which required a more economical engine than the semi-Diesel engine but which at the same time could be purchased more cheaply than the Diesel engine. Both these types employ mechanical injection which is still in progress of development, the ideal aimed at being to obtain the same perfection of combustion as is obtained with air injection. The difficulties encountered are:—

1. The oil has to be very carefully treated to ensure that it is free from small particles of solid matter otherwise the nozzles would choke.

2. The oil is dependent on, and is very sensitive to, the correct pressure and size of orifice in order to produce a sufficiently fine spray to both penetrate into the air in the combustion space and give sufficiently good atomisation to attain good combustion.

3. With this method of fuel injection the oil enters the cylinders almost instantaneously, it ignites immediately and combustion is more of the nature of an explosion. This causes a very sudden rise in pressure in the cylinders and thus gives a maximum pressure very considerably in excess of the compression pressure.

Engineer Lieut.-Commander A. J. ELDERTON, R.N., S.R. (by correspondence): It is a very happy circumstance that the first paper which obtained the Akroyd Stuart Award should be a history of the development of the heavy oil engine. No two people interpret history in the same way, so perhaps I might be pardoned for making a few remarks with reference to the paper.

Neglecting the gas engine, the oil engine generally seems to have had three principal phases which are mainly connected with the method of obtaining ignition of the working charge, viz., the low compression phase where petrol was used as a fuel and ignition obtained by means of an electric spark, the medium compression or semi-Diesel phase where heavy oils are used as fuels and ignition is obtained partly by the heat of compression and partly by external aid, such as a blow lamp or the like, and the third phase, accredited to Diesel, where ignition of the fuel is brought about by the heat obtained from compressing the working charge. It is not singular that ambiguity should arise as to the real inventor of the Diesel engine; the same kind of controversy is connected with the steam engine and the name of James Watt, and with most other inventions; invention after all is usually a matter of evolution. The generally accepted definition of a Diesel engine is ' an internal combustion engine where ignition is effected by the heat obtained from compression of the fuel or working charge.' Such being the case I think Rudolph Diesel must be credited with the invention of the Diesel engine.

The remark by the author that the crosshead scavenge engine, where the lower half of the cylinder is employed for scavenging, is illogical and uneconomical might be accepted if the ultimate type of design is to be the double-acting engine. While this type may be the best mechanically it does not follow that it will be the best economically, considered from a cost, maintenance and fuel consumption point of view. It is interesting to note that the motor tanker *Megara*, engined by Werkspoor, was recently put into service wherein the lower half of the cylinder was used for supercharging.

The author's remark that air valves in two-stroke engines have always been associated with failure must not be construed that they will always be so in the future; if the two-stroke engine is to be supercharged to the same extent as the four-stroke it would appear that they will be a necessity. Brons, of Holland, and Burmeister and Wain have recently marketed two-stroke engines in which air valves are used. While Hirsch may have been the first to design and commercially operate the pre-ignition chamber in an engine, ignition of the fuel was obtained with the aid of external heating, and it is to Brons that the credit of the first cold-starting pre-ignition chamber oil engine is due, where ignition was obtained solely by the heat of compression.

It was my privilege to be connected for three or four years with the Brons Company over which J. Brons still presides, and I can assure the author that, contrary to his doubts, this system of ignition does adhere to the required timing. As an item of interest, about two years ago a towing launch propelled by a Brons engine was placed into service on the River Thames which had the distinction of being the first high-compression cold-starting oil engine to be used on the river.

The remarks of the author on ideal injection and fuel pumps are very interesting. It may be that mechanical penetration has nearly reached its practical limit; before much increase in cylinder diameter could be made, some other system would have to be called into use. A patent was recently granted for a system where two pre-ignition chambers were fitted into a cylinder head, thereby assisting each other to obtain turbulence, etc. Perhaps along similar lines there is a field for future development.

I wish to thank and congratulate the author for his masterly paper.

The AUTHOR's supplementary reply to written communications: With regard to Mr. Hamilton Martin's remarks, there is nothing more distasteful to the author than to have to detract from the work or reputation of any inventor, but the evidence is so clear, unless the legal factor of estoppel is applied, that Diesel did not contribute much more than the full establishment of his cycle. On the mathematical side he certainly did a great deal of work, but mathematics has not helped us to produce a fuel pump because neither Diesel nor we ourselves have fully grasped the physics of the problem, and heat stresses, heat flow and heat losses still bulk big as factors in the problem. Again, the evidence is very clear that Capataine did actually produce a working Diesel cycle engine before Diesel himself, and according to very excellent authority this engine exists in Germany and can be seen.

On the question of Dr. Diesel's patents, I do not find anything that applies to the modern development of this engine or which shows that he went any further than the original conception, though this may have been a fault of drafting in the specification itself.

The author's personal conception of the position is that Diesel, in common with Priestman and Akroyd Stuart, failed to carry out that which they had devised, while on the other hand Capataine succeeded and Diesel then took up Capataine's work from that stage. I certainly am not in such a favourable position to form an opinion on these matters as is Mr. Hamilton Martin, but on the facts that I had available I feel that my opinion was a correct one.

The particulars given relative to the use of powdered fuel are interesting, but has Pawlikowski really succeeded?

Regarding Mr. B. Jackson's remarks at the time that Akroyd Stuart conceived the idea of a Diesel engine, and for many years after, fuel oil was not a marketed commodity and so when Griffin made a heavy oil engine the fuel he used was turpentine residue and such like.

The author remembers with considerable pride that his enthusiasm was immediately aroused on first hearing of the wonderful engine that had been produced in Germany by a Dr. Diesel; this enthusiasm, and appreciation of its value, has never abated. He espoused the cause of the Diesel ship, for years he has advocated the Diesel road vehicle and the locomotive, and he is just as enthusiastic as ever in the matter of the Diesel aeroplane.

He will re-iterate that air for injection purposes is technically obsolete and is rapidly being eliminated, and he will say that as soon as the available means of injecting fuel without air are generally employed there will remain few, if any, advantages to the credit of blast air. In the matter of flexibility there will be none, even if they exist at the moment. On the other hand he fully agrees that it was a stroke of good fortune that brought compressed air to the aid of oil injection, though its success has engendered such complacency that the more reasonable airless injection has been neglected.

As things are at present the results in consumption per B.H.P. in certain solid injection engines so closely approximate those of the best air injection practice that we can turn to the saving of perhaps 30/- per h.p. for the compressing plant. When we come to output, surely the record of 121 lb. per b.m.e.p. held by an airless injection engine is the highest we have.

The semi-Diesel and the cold-starting engines were surely nothing more than products of our inherent conservatism; we were simply afraid to reach the higher pressures, before ignition, though we did not mind at all providing the charge had fired.

It is put forward by Mr. Jackson as a defect that the oil, with airless injection, enters the cylinder almost instantaneously and the ignition is more of an explosion. The author wishes this were more near the truth, for the one great problem that we have facing us is the factors of lag in injection and lag in inflammation of the charge. The whole of the troubles, faults and failures in connection with the injection of fuel without air are directly due to the erroneous view, so generally held, that oil is incompressible; once eliminate that fallacy and the way is perfectly clear, providing you have a full conception of the meaning of time in a high-speed Diesel engine.

Commander Elderton brings forward a subject for controversy that the author has endeavoured to avoid. He puts forward the definition that a Diesel is an internal combustion engine where ignition is effected by the heat obtained from compression. Is this really the case? First of all it is not the heat of the charge that causes ignition, it is the temperature. The heat was there, the heat contained in the iron, in the air itself. Then as the air is compressed the temperature increases till the temperature of inflammation of the particular fuel is reached, a high figure in the case of alcohol or petrol and a comparatively low one in the case of gas oil. Hall superheated his air charge for the initial ignition by wiredrawing the said charge, Doxfords use steam in the jacket, Werkspoor use exhaust products in the lower end, Stuart employed a blow lamp, but a Hornsby Akroyd engine would start in winter on the shores of the Athabaska, while Hall's engine would entirely fail, as would the conventional Diesel.

So far, the use of scavenge or other valves, as opposed to ports, in two-stroke engines has been associated with failure; this is all to the good as the great merit of the two-stroke engine is the absence of valves. It may be that all this will be altered, but for the purpose of supercharge surely a valve in the cylinder head is quite redundant.

In regard to the Brons engine the author was perhaps drawing upon his memory of the same about twenty years ago. Certainly the impression of makers who investigated this principle was that the ignition was somewhat erratic; logically it should be, but the author's personal experience with the engine is not large, though he was on board a Dutch vessel in the Thames some nineteen years back that was fitted with one of these engines.

AUTHOR'S REPLY TO DISCUSSION

ON

PAPER ENTITLED "ELECTRIC PROPULSION AS APPLIED TO PASSENGER LINERS," BY ESKIL BERG, READ OCTOBER 8, 1929.

(See page 720, November issue.)

The very kind remarks of Mr. Fielden are certainly deeply appreciated by me as his work and vast experience in connection with the construction and planning of the vessels were always available, and we all feel that the great success of the three ships is in a great measure due to his untiring efforts and the good advice that he gave us. When the question of propulsion machinery for the new ships first came up, Mr. Fielden came over especially, at the request of the Panama-Pacific Line, to give his recommendations and opinion as to the best type of drive to adopt. Only after a long and intense study did he give full approval to electric propulsion, and I venture to say that, had he after this study given a negative report, there is no question in my mind but that single reduction gears would have been installed, and the application of electric drive would have been retarded still longer.

Mr. Fielden is right that the words " more detailed " would have been better than " accurate." The second trip was also chosen because during this trip the ship was, so to speak, " tuned down." During the first trip all motors and machinery were run off and on at full power so as to test them—even though they were not actually needed.

In regard to condenser tube leakage—electric drive of course does not help erosion troubles, except for the fact that smaller condensers may be used on electric ships due to increased economy. The author had in mind leakage due to rapid change of temperature of the condenser tubes as when reversing with separate turbine. Under this condition, during the act of stopping the propeller, the inertia of the turbine gears, propeller shaft, etc., creates work done on the steam, which means superheating the steam. In other words the temperature of the condenser may be—say 90 degrees—when going forward, and this temperature may go up to double or much more while stopping the propeller—then, after the propeller is reversed, the temperature will go down as then and not before work is taken out of the steam and not added to it.

In regard to Claim No. 10, Mr. Fielden's point is a very good one and has been fully borne out in the Panama-Pacific liners.

The suggestion of Mr. Fielden to substitute B.t.u. instead of shaft horsepower in the Admiralty coefficient is a most advisable one and, if done, would show up electric drive for high powered liners in its true light, and would indeed represent the cost to the owner and also give a figure easily understood by him. This suggestion of Mr. Fielden is most valuable to your Institute and should certainly be followed up.

Regarding Mr. A. C. Hardy's remarks, the author is not entirely familiar with the very latest developments of Diesel engines and thus his opinion cannot have much value. With his limited knowledge, however, he feels that either direct-connected Diesel or Diesel-electric drive for high powered liners is out of place if for no other reason than comfort to the passengers. The travelling public in the future will demand smoothness and vibrationless ships and they are very little interested in cost, weight and fuel consumption.

While the fuel consumption of the *Virginia* at full power is ·715, designs have been made for large liners using high steam pressure, 500 lb.—725 deg. temperature steam, steam extraction for feed water heating with boilers using economizers as well as air preheaters, in which the fuel consumption figures out at ·55 lb. and ·6 can be guaranteed with safety. This figure of ·6 lb. includes everything, and the ship's horsepower will be correctly read by calibrated electrical instruments.

Referring to Mr. P. Jackson's remarks, Diesel-electric drive certainly has its proper place in certain types of vessels and no general rule can be made for them any more than turbo-electric. It is, however, the author's firm opinion that turbo-electric drive for very large, high-speed liners can be made to-day with no uncertainty as to success, reliability, economy, and absolute comfort to all the passengers.

In reply to Mr. E. G. Warne, the fuel capacity is 5,436 tons and the total fuel used on the round trip, including all the port usages, is 3,599 tons. As she fuels in San Pedro for the round trip there are some 2,000 tons over in her bunkers if she should fuel to her full capacity. As a matter of interest the *Virginia* has unloaded 2,000 tons in New York on one of her trips.

In regard to the run from San Diego to San Pedro, if Mr. Warne had ever been there, he would not venture to attach much accuracy to the ·843 per S.H.P. The ship stops in this port about 12 hours and the distance is only 83 knots, requiring

5 hours and 21 minutes. The channel out of San Diego and into San Pedro is very shallow and many miles long, requiring very slow speed, the taking off and on of pilot and warming up of boilers, making this run of no practical value from an engineering point of view.

Thousands of turbo-generators and synchronous motors operating on land have efficiencies as given—some even better (if larger) and some slightly lower (if smaller). There is absolutely no doubt as to the figures given in the paper as they are test results. 13% loss for direct current transmission is indeed good—and few can reach it.

Referring to Mr. D. Gemmell's remarks in regard to the refrigerating plant—the 100,000 cubic feet space is used for carrying fruit. At Panama Canal some 10,000 stems of bananas are put aboard and these must be chilled quickly by blowing cold air, etc. As the fruit becomes cold the power is reduced and eventually only one of the CO_2 machines operates.

I fully agree with Mr. G. R. Hutchinson that any electrical diagram looks complicated to anyone not familiar with such a thing, but I can equally well state that the wiring diagram of the auxiliary switchboard used on any passenger liner is many times as complicated, and they are in daily use and no complaint has been given as to their operation. As a matter of fact the control board is only one-fifth as long as that for the ship's lighting and auxiliaries.

In regard to the Duchess class of ships, if they require the power stated to obtain ·63 lb., they must have a very poor model, which I doubt, and I for one feel that the power readings must be wrong in about the ratio of the Admiralty coefficient—293 to 350—or 20%, so that the figure of ·63 should be multiplied by 1·2, making ·758—which is not so good considering the steam pressure and superheat used. The figures of the *Bremen* were given me by Dr. Ing. Emil Sorensen. If 130,000 S.H.P. is correct, it will make the *Virginia's* performance still better.

Mr. Belsey's remark is exactly in line with my own. Every type of propulsion has its place and no general rule can be laid down. A complete study must be given to each particular requirement.

The remarks made by Mr. W. E. Farenden have been answered in the discussion of the previous speaker.

The author certainly appreciates Mr. S. A. Smith's remarks as they check so closely with statements made in the paper. The *Virginia* has only two stage feed water heating.

In regard to the refrigerating plant, it is probably larger than it should be, but the 10,000 bunches of bananas seem to be to blame, and I know very little about that particular branch of marine engineering.

In regard to the advantages in No. 1 claim—I do not agree with Mr. Smith, as for instance in the *Virginia* I can build a turbine far superior in economy for electric drive. Here the steam travels through the turbine in one casing. If gears were used the turbine, on account of the length of pinion, must be split into two and more likely three casings. The steam would, therefore, have to start and change its direction two or three times before it reaches the condenser. Actual experience has shown that when steam is stopped and made to change its direction through properly designed pipes and led into another turbine the loss is very great indeed.

In regard to Claim 5—the author had in mind the temperature strains only due to reversal when superheated steam enters the condensers.

Claim 9—the figures as to make-up water were given me by engineers of the International Mercantile Marine and were a direct comparison with their geared turbine ships. I simply had to take their words, but the experience of our navy on their electric ships also shows a great big saving.

In conclusion I would like to take this opportunity to thank the Institute of Marine Engineers for the very kind attitude it has taken toward my paper. As I could not be present I thought a paper giving real facts as to the performance of the *Virginia* was in order and then there could be no doubt as to the claims made for her. Such complete and accurate performance data has, to my knowledge, never before been published and I am glad the Institute of Marine Engineers appreciated my efforts.

I have just returned from the maiden trip of the S.S. *Pennsylvania* from New York to San Francisco and return. The performance of the *Pennsylvania* on her whole trip was 100% and the economy checked on the 3rd decimal with that obtained by the *Virginia*.

Thomas Newcomen: Father of the Steam Engine.

By Windsor Martin (Associate Member).

In the September issue of the Institute Transactions, there appeared an article on Newcomen which was written by Mr. H. W. Dickinson, and a further article appeared in the November Transactions which was written by Mr. W. T. Tucker. Both these articles are of a very interesting nature, inasmuch as they take us back to the infancy of the steam engine. I visited the premises of the Birchgrove Colliery Co., Llansamlet, Swansea, one day last week, and by kind permission of the management was allowed to see two old Cornish engines at work. I thought it may interest you to learn of these engines as, possibly, they may be the only two such relics which are still at work in this country.

One of these engines is used as a winding engine at the Colliery, while the other is used for pumping at the Sister's Pit, about a mile away from the Colliery. The winding engine was built by Stubs and Coussens in the year 1847, and I understand that it was installed at the Colliery about that time. I noticed that the cylinder bears the name of a local foundry, the Clydach Foundry, and the date 1853, from which I presume that a new cylinder was fitted during that year. I was unable to obtain the actual sizes of the cylinders, but I should judge them to be approximately 36 ins. diameter by 5 ft. stroke. The steam pressure is 50 lbs. per sq. in.

I was in conversation with the driver of this old engine and was told that she is capable of lifting from 300 tons to 350 tons in a shift of eight hours, that is one minute per draw from a depth of 92 yards. The piston rod packing, which I understand is of the metallic type, has not been renewed for 15 years, while the piston rings have not been out for five years. This engine works regularly day after day, and I should imagine it to be a wonderful performance for so old an engine.

The pumping engine at the Sister's Pit was built by Harvey and Co. of Hayle, Cornwall, in the year 1859. The steam pressure for this engine is also 50 lbs. per sq. in. This engine works constantly, day and night, and it is of great interest to watch its operation and to see the massive beams rise and fall. I should say that the sizes of this engine are approximately 72 ins. diameter by 7 ft. 6 in. stroke.

The drivers of these engines, who have graduated from stokers, consider it a great honour to hold such positions, and I should imagine it to be so on such interesting old engines.

ABSTRACTS.

THE FUTURE OF MARINE ENGINEERING. "The Engineer," 13th December, 1929.

At the close of his presidential address to the Institute of Marine Engineers, Engineer-Vice-Admiral Sir Robert Dixon put forward a strong personal plea for a further advance in marine engineering practice as it exists to-day in the ships of the British mercantile marine. He suggested that shipowners, marine superintendent engineers and operating engineers alike should not entrench themselves behind the hitherto conservative slogan of "Safety First," but by taking a lead from the power station engineer, should press forward with more courageous schemes for economical ship propulsion. The very wide experience of the Institute's new president in modern naval engineering practice has, for many years past, kept him in the closest touch with the various directions in which progress has been made, and his opinion is to be carefully weighed. Sir Robert's address, which we reprint in an abridged form elsewhere in the present issue, covers the wide field of oil engine, steam engine, steam turbine and boiler practice, not excluding the newer developments of electric propulsion. As Sir Robert points out, marine practice must of necessity lag somewhat behind that of land power stations, but the margin need not be a wide one. Already, the best results of boiler practice, turbine design and condensing plant practice, the closed feed system and inter-stage feed heating, have been applied to our modern liners, and in the newer ships excellent results are being obtained. It seems possible that, with steam pressure of 650 lb. per square inch and temperatures up to 750 deg. Fah., and the employment of feed-heating and a regenerative cycle, fuel consumptions of 0·5 lb. of oil per shaft horse-power-hour and 0·73 lb. of coal per shaft horse-power-hour, are to be attained. Those figures will yield results very close to those which are now being obtained with marine oil engines of the latest designs.

In reviewing the progress made within the last ten years in the development of the marine oil engine, Sir Robert finds some satisfaction in the fact that British builders are now becoming alive to the advantages of independent development and are moving forward with designs of their own. There is, however, still room for further British progress in the direction of using exhaust gas turbine-driven blowers for pressure charging. In the field of marine turbine practice there is no doubt that the pioneer work which was done by Sir Charles Parsons is giving ever increasing results, so that British builders and designers occupy the leading position in marine turbine practice. Some ground is being gained in the recovery of the trade won by continental designers in the combination on one shaft of a steam reciprocating engine and an exhaust steam turbine, but British efforts have recently been concentrated principally upon the electrical solution of the problem, by the utilisation of alternating or continuous current generators and motors. In view of the increasing use of electrically driven auxiliary machinery for engine-room, deck and navigational machinery, such a development is of undoubted importance. With regard to advance in the design of the high-pressure reciprocating steam engine, such as incorporating new valve gears or the use of the uniflow system, but little has yet been done by engine builders on the Clyde and Tyne, although research and development work is proceeding rapidly in Germany, Holland and Sweden. This is a field in which British designers were at one time preeminent, and it is to be regretted that our shipowners and shipbuilders are not making more progress in this direction. The position with regard to the marine steam boiler is more encouraging, and it is satisfactory to record that British designed high-pressure boilers are not only giving excellent results in actual service, but are to be fitted into new liners for owners abroad. We may refer, perhaps, to the high efficiency of 85 per cent. obtained in service with the Yarrow 375 lb. pressure boilers on the P. and O. liner the *Viceroy of India*, and to the good results achieved with large 400 lb. pressure water-tube boilers of the Babcock and Wilcox type on the Holland-America liner *Statendam*, with which boiler operating efficiencies of over 87 per cent. are being obtained. There seems to be little doubt that these successes will lead, in turn, to the adoption of still higher steam pressures and temperatures in marine installations. In concluding his address, Sir Robert Dixon referred to high-speed rotary steam and possibly rotary oil-driven machinery, combined with improved hydraulic means for transforming the mechanical energy thus generated into propulsive thrust. That there is need for a further investigation into the characteristics of high-speed propellers for large passenger vessels is revealed by the recent examination of the propellers of the North German-Lloyd liner *Bremen*, which indicated signs of erosion. It has also been recently suggested that further advances in the economical propulsion of ships would be expedited if fuller details of the tank tests and experimental trials of ships were to be made available with a view to co-ordinating the technical work which has been carried out in the leading maritime countries.

Advances which in the future may possibly be made along the lines we have above referred to will certainly bring with them an increased need for highly trained operating engineers. In his presidential address to the Institute of Marine Engineers two years ago, Engineer-Captain Wm. Onyon stated that there was then no dearth in the supply of marine engineers, and that it was then possible to select the best men. The position in this respect seems to have altered, if we are to believe the recent report which has been prepared by the Society of Consulting Marine Engineers and Ship Surveyors. That body, which has recently submitted a report to the Board of Trade and the Chamber of Shipping, finds that there is a real shortage of qualified men to take charge of the more complicated main propelling and auxiliary machinery which is now being installed in merchant ships. Some suggestions are made as to the qualifying time for certificates, the value of experience gained in deep sea and coastal steamers, while the question of a lower grade of examination for a proposed third-class certificate is discussed. It is stated that the shortage of engineers is more marked in cargo steamers than in liners, but it must not be overlooked that the newer forms of propelling machinery are now finding increasing use in fast cargo ships. In these circumstances, any tendency to lower the standard of efficiency is to be strongly deprecated. Both in operation and design we require the brightest intelligence and the most daring brains, and we express the hope that British shipowners, shipbuilders, and particularly the members of the Institute of Marine Engineers, will take to heart the words of their President, and, like the modern power station engineer, while taking commendable safety precautions, will proceed apace with more economical and advanced machinery designs, accepting gladly the increased responsibilities which the supervision and operation of such machinery must inevitably entail.

MARINE ENGINEERING. "Engineering," 20th December, 1929.

In his presidential address to the Institute of Marine Engineers on December 10th, Vice-Admiral Sir Robert Dixon discussed recent developments in marine engineering, the most notable of which has been the extraordinary growth in the tonnage of Diesel-engined ships, which has risen during the past ten years from 700,000 to over 6,000,000. Moreover, whilst even now 85 per cent. of the total number of engines are rated at less than 4,000 brake horse-power, some 28 per cent. of the new vessels have engines of over 10,000 brake horse-power, and in some of those actually in service the figure has risen to 20,000 or 25,000 brake horse-power. It is a highly regrettable fact that British engineers have played but a minor part in this development. Although British firms have constructed about three-fourths of the Diesel engines now in use on land or sea, they have for the most part been content to purchase (not, unfortunately, always intelligently) ideas from abroad. There are on the other hand some honourable exceptions, and British engineers may fairly claim the credit not merely for the introduction of airless injection, but also for the best system which has yet been devised for effecting this. Nevertheless, most of the success achieved in adapting the Diesel engine to sea service must be attributed to the enterprising foreigner. In his address, Sir Robert suggested that the war was responsible for this highly unsatisfactory state of affairs, but the cause, we fear, lies much deeper since the same sorry story was repeatedly spelled through in pre-war years.

Switzerland, though devoid of coal and iron, competes with marked success in the heavy engineering trades. The visitor to the leading Swiss establishments is immediately struck by the magnitude of the experimental work ever in progress. How many British firms of marine engine builders, it may be asked, showed, during the pioneering days, any interest whatever in the possibilities of the marine Diesel engine? How many of them, indeed, had a staff sufficiently well equipped technically to tackle the new problems involved? In actual fact, most of them seemed content to be manufacturers rather than engineers. In manufacture, experience forms an all-sufficient guide, but higher qualifications are essential for successful pioneering. The persistent refusal to leave the easy highway of manufacture for the adventurous but ultimately profitable path of intelligent experiment has had very deplorable results. Certain firms of marine engine builders, some even of world-wide reputation, have found it necessary to go into liquidation whilst others, shrinking from the idea of having to think instead of merely to copy, have acquired licences from the foreign originators to make devices which, with a more competent staff, they could very well have developed for themselves. Fortunately, we have had some brilliant exceptions to what has long been too general a rule. Were it otherwise, we should gradually have sunk in engineering matters to the level of mere hewers of wood and drawers of water, organisers, traders and mechanics, rather than creative thinkers. It is thus satisfactory to note Sir Robert Dixon's assurance that more and more British shipbuilders are now coming forward with Diesel engines of their own design.

In the recent development of the marine Diesel engine, nothing has been more remarkable than the increased output per cylinder. Admiral Dixon states that engines developing 1,500 h.p. per cylinder are now at sea, and we may note that some years since, Messrs. Sulzer succeeded in getting 2,000 h.p. from an experimental single cylinder engine having a bore of 920 mm. It may be noted, however, that with internal-combustion engines generally, an increase of size is not, as is usually the case with steam prime movers, accompanied by any increase in thermal efficiency.

The increase of output per cylinder has been accompanied by a corresponding reduction in engine weights. The earlier Diesel engines, Sir Robert noted, weighed about 450 lb. per brake horse-power, whilst to-day this figure has, he stated, been reduced to about 50 lb. per brake horse-power in the case of large single-acting submarine engines. This figure refers, however, to the engines only, and the total weight of the machinery needed for propulsion on the surface is stated to be 124 lb. per shaft horse-power. As a comparative figure, Sir Robert gave the corresponding weight of the turbine-engined K submarines as only 44 lb. per shaft horse-power.

Conditions in the Navy differ very materially from those ruling in the Merchant Marine, where there may be long spells of continuous running at full power, and as a consequence engine weights are higher than in the Navy. Sir Robert gave 155 lb. per brake horse-power as the engine weight of the main engines of one of the largest Diesel-engined liners now in service, but the Diesel engines used for driving auxiliaries may, he said, weigh as little as 40 lb. per brake horse-power. With high-speed engines this figure can, of course, be materially diminished. The laws of similarity indicate that in corresponding conditions the engine weight per horse-power should be directly proportional to the cylinder diameter and at a meeting of the Institution of Mechanical Engineers, held in 1914, Sir Dugald Clerk exhibited a diagram in which the engine weights of internal-combustion engines plotted against cylinder diameter showed a really remarkable agreement with this theoretical deduction.

Small cylinders, however, imply high speeds of revolution if the theoretical saving in weight is to be realised. Motor cycle engines have, in fact, been run at 5,000 r.p.m. and more, a feat which 30 years ago would have been thought mechanically impossible and even to-day is sufficiently remarkable. Diesel engine makers are now attempting to follow this lead, and some firms have already built engines developing 200 h.p. at 2,000 r.p.m., and experimentally much higher speeds have been reached.

Such speeds are, however, ill-adapted for marine purposes, and the saving in weight secured by them is partly offset by the weight of the reduction gearing then needed between the engine and the propeller shafting. Sir Robert, in concluding his address, looked forward to the time when the screw propeller will be replaced by some equally effective device capable of working at high speeds; but hydrodynamic theory seems to afford little hope of the realisation of this attractive dream; and other methods of reducing Diesel engine weights seem to afford a greater prospect of success.

Amongst these, supercharging occupies a leading position. Dr. Büchi claims that by supercharging to a gauge pressure of 6 lb. per square inch, the output per cylinder may be raised by 50 per cent. The gain is in part indirect, since in the normal Diesel cycle about 8 per cent. of the burnt gases are trapped in the clearance space, so that the temperature at the end of the admission stroke is correspondingly raised and the intake of air diminished. With supercharging, the temperature at the end of the compression stroke is lower, and may, it is claimed, be as little as 1,320 deg. F. absolute.

In spite of the present popularity of the Diesel engine, Sir Robert evidently inclines to the view that the future lies with the turbine rather than with any type of reciprocating engines. As matters stand, the internal-combustion engine has the higher thermal efficiency, but there seems little prospect of any material improvement in the best figures hitherto attained. The smaller class of marine Diesel engine is credited with an oil consumption (engines only) of 0·36 lb. per brake horse-power hour; whilst Sir Robert gives 0·4 to 0·44 lb. per brake horse-power hour as the full rate for the larger engines.

There is some prospect of rivalling the latter figures with the steam turbine. Indeed, Admiral Dixon claims that should it prove possible to use, at sea, steam at a pressure of 1,200 lb. per square inch and at a total temperature of 900 deg. C., a fuel rate of 0·37 lb. of oil per shaft horse-power should be attainable. The steam conditions premised must, however, for the present, be deemed as somewhat beyond the range of possibility, but with a pressure of 650 lb. per square inch and an initial temperature of 750 deg. F., a fuel rate of 0·5 lb. of oil, or 0·73 lb. of coal, should, it is claimed, be realised.

So far as the turbine is concerned there seems to be no limit to the initial pressure, although it may be necessary to reheat the steam before it enters the low-pressure turbine in order to avoid excessive blade erosion. Some authorities hold that, to this end, the wetness of steam at final exhaust must not exceed 12 per cent. With super-pressures, however, the wetness may, in the absence of reheating, exceed 17 per cent. It may be noted in this connection that certain firms are now experimenting with stage-by-stage drainage of the low-pressure turbine, and it may prove possible in this way to dry the steam nearly as effectually as by re-heating it. The plan, though by no means new, is still, however, on its trial, and is, moreover, hardly applicable to all types of turbine.

The turbine is, of course, a much simpler piece of mechanism than a Diesel engine, but the accessories essential to the attainment of high thermal efficiencies are becoming daily more elaborate. Super-pressures, if adopted at sea, will necessitate the abandonment of the well-tried Scotch boiler, which, even when constructed of high tensile steel, is ill-adapted for pressures beyond 350 lb. per square inch.

The water-tube boiler has, ton for ton, a much higher evaporative capacity, but its small water content involves the introduction of special devices to prevent accidental over-heating of the tubes. In a power station plant now in course of erection, the total water content of the boiler corresponds to as little as four minutes' supply of steam, a condition which has necessitated the duplication of feed pipes, and a variety of automatic and interlocking safeguards. At sea, reliability is all important, so that extremely high pressures and temperatures are little likely to be attempted there, until the pioneering troubles have been surmounted elsewhere.

Whilst the gap between the fuel rates of reciprocating engines and turbines is steadily diminishing, the latter still holds a marked advantage in the matter of machinery weights. Thus the geared turbine machinery fitted in the *Duchess of Bedford* weighed (inclusive of boilers) 282 lb. per shaft horsepower, whilst the corresponding figure for Diesel machinery would, it is stated by Mr. J. Johnson, have been 410 lb. per shaft horse-power. The complete propelling machinery of the

Hood weighed 81 lb. per shaft horse-power, whilst a figure of 33 lb. per shaft horse-power has, Sir Robert says, been reached in the case of destroyers. These figures are interesting, but it must be borne in mind that, as already noted, naval vessels have not to run at something approaching full power day in and day out.

Sir Charles Parsons was the first to suggest that the efficiency of existing marine engines might be very substantially bettered by the addition of an exhaust steam turbine driving the propeller shaft through gearing. Credit is due to German enterprise that this plan has been adopted in a number of old ships, but it also appears, from the address under discussion, that machinery of this type is now being introduced on a number of entirely new ships. The fuel saving, as compared with the simple steam reciprocating marine engine, is estimated at 20 per cent.

Automatic stokers are growing in favour, and Admiral Dixon looks forward to the day when hand-firing will be obsolete at sea. The experience gained with the experimental pulverised-fuel plants has, it is stated, been such as to induce those responsible to proceed further. An advantage of this system of firing is that practically any grade of coal can be successfully used, and the ash problem is probably much less important at sea than elsewhere.

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BOILER EXPLOSION REPORT.

REPORT NO. 2976. *Train Ferry No. 2.*

O.N. 145207.

Report No. 2976 deals with the explosion from a main stop valve chest on Train Ferry No. 2. The investigation was conducted by Mr. W. Lewis Jones, B.o.T. Surveyor, London.

The chest was made of cast iron and the valve, seat and spindle of brass. The valve, which was $4\frac{1}{2}$ inches in diameter, was attached to the spindle by means of the usual horse-shoe fitting. The spindle was $1\frac{3}{8}$ inches in diameter, screwed six threads per inch Whitworth thread, passing through a bridge secured to the cover by two pillars. The chest was secured to the boiler by means of a flange with eight $\frac{7}{8}$ inch diameter studs on a $9\frac{1}{4}$ inches pitch circle. The centre line of the outlet branch was at an angle of about 120 degrees to this flange in the vertical plane and secured to a Y piece on the pipe line by a flange with ten $\frac{3}{4}$ inch bolts on an $8\frac{3}{4}$ inches pitch circle. The metal of the casting was of a uniform thickness of $\frac{7}{8}$ inch, designed for a working pressure of 180 pounds per square inch.

The valve chest was made by The Wallsend Slipway and Engineering Company, Limited, in 1917, and was, therefore, 11 years old.

No repairs had been made.

A fine hair line crack developed at the root of the flange on the outlet branch from the stop valve chest. A slight intermittent escape of steam was observed through this crack when the vessel was working in a seaway. When the vessel reached smooth waters there was no leakage to indicate the position of the fracture and steam remained on the line for over one and a half days after the crack was first noticed.

The fracture was due to stresses imposed upon the metal of the chest at the root of the flange owing to the flange on the stop valve outlet branch not being parallel with the flange on the Y piece at the time the joint was made.

The train ferry was built and engined under Lloyd's survey by The Wallsend Slipway and Engineering Company, Limited, for the Government, in 1917, and was originally run from Richborough during the War. It was purchased by the present owners in the autumn of 1923, and has since been run under the supervision of the superintendents for the London and North Eastern Railway at Harwich. When the vessel was new it was designed to burn oil fuel. It was converted to coal burning in May, 1925, and to make room for the coal bunkers the run of the steam pipe lines had to be altered. This work was carried out by The Antwerp Engineering Company at Hoboken. As many as possible of the original fittings, including the Y piece, to which the stop valve of the port after boiler was connected, were utilised, and new pipes supplied as necessary. The arrangement of the main steam pipes and the design of the valve chest are shown on Plates I and II respectively. The pipes were all tested in the shop to 360 pounds per square inch, i.e., twice the working pressure, but the valve chest does not appear to have been tested at that time. In re-erecting the steam pipe line the original Y piece, which was made of cast iron, was broken. This was probably due to the set of the pipes not being quite right and the flanges, therefore, not parallel. A new Y piece was made of cast brass with very heavy flanges $1\frac{1}{2}$ inches thick. In making the joint it would appear that the flange of the Y piece was not parallel with the flange on the branch from the stop valve chest. It is assumed, although there was no evidence to this effect, that this was the cause of the original Y piece breaking. The flanges of the new Y piece, as previously stated, were very heavy. The flange on the branch from the stop valve chest was well supported by a heavy gusset on the side nearest the chest. In making the joint it would appear that the flanges came together on the outside of the branch while remaining open on the side of the gusset and that in pulling up the joint a heavy stress was imposed on the flange, eventually developing a fracture at the part unsupported by the gusset.

An inspection of the chest after removal from the boiler showed that the flaw extended around nearly half the circumference of the branch, as shown on Plate II. This flaw was quite distinct on the internal circumference of the branch in a line with the root of the radius to the flange and was open about $\frac{5}{1000}$ inch, whereas it appeared only as a hair line and was hardly visible to the naked eye on the outer side. This would appear to bear out the contention that the flanges came together as previously stated. The flaw, as shown on Plate II, was only around the body of the branch and did not extend into the flange. After examination the flange was broken off with a flogging hammer, and there was nothing to indicate that the defect was an original one. The casting through the flange was sound and of good quality cast iron and the grain was identical with that of the fracture, excepting for the discolouration. There was heavy corrosion on the outside of the branch in the vicinity of the flaw. This indicates that although no escape of steam had been noticed, the flaw had been in existence for a considerable period.

A new valve chest of cast steel has now been fitted. All the steam pipe range has been tested in place to twice the working pressure. It has also been decided to fit a bracket on the boiler to take the back of the flange on the stop valve branch and relieve it of any thrust due to the expansion of the steam pipe.

Observations of Mr. A. E. Laslett, Engineer Surveyor-in-Chief.

For the avoidance of undue stresses in steam pipe fittings it is, of course, important that care should be exercised, during erection, to ensure that the flanges are in proper alignment. If, as is probable, the breaking of the original junction piece to which the stop valve chest was attached, when the steam pipes were re-fitted after alteration, was due to non-alignment of the flanges, it should have indicated to those in charge that the replacement of the broken fitting was not all that was necessary. Apparently there was a slight escape of steam from the crack only when the vessel was labouring in a seaway, but the heavy corrosion of the metal at the position of the crack afforded definite evidence of a defect the further development of which might have had very serious results.

BOARD OF TRADE EXAMINATIONS.

List of Candidates who are reported as having passed examination for certificates of competency as Sea-going Engineers under the provisions of the Merchant Shipping Acts.

For week ended 7th December, 1929:—

NAME.	GRADE.	PORT OF EXAMINATION.
Ferguson, James	1.C.	Glasgow
Milne, James S.	1.C.	,,
Peddie, William G.	1.C.	,,
Watson, Joseph	1.C.	,,
Cameron, John	2.C.	,,
Kennedy, Donald A.	1.C.M.E.	,,
Procter, George H.	1.C.M.E	,,
Dingle, Norman L.	1.C.	Liverpool
Entwistle, Frank	1.C.	,,
Mould, Richard A.	2.C.	,,
Ryan, John H.	2.C.	,,
McNeish, James M.	2.C.M.	,,
Walker, Frank B.	1.C.M.E.	,,
Greenaway, Thomas P.	1.C.M.E.	Hull
Jarman, Edward	1.C.M.E.	,,
Langdale, Philip L.	1.C.	,,
Lovell, George	2.C.	,,
Smith, Albert M.	2.C.	,,
Fife, Thomas	1.C.	North Shields
Lee, Arthur J.	1.C.	,,
Swan, John S.	1.C.	,,
Wiseman, William	2.C.	,,
Ashcroft, Henry	1.C.M.E.	,,
Murdoch, James	1 C.M.E.	,,
Jenkins, William	1.C.M.E	London
Rashleigh, William J.	1.C.M.E.	,,
Brooks, Edward H.	1.C.	,,
Levack, Oswald A.	1.C.	,,
Joslyn, Valentine	2.C.	,,
Ward, Frederick J.	2.C.	,,
Adie, Harry F.	1.C.	Sunderland
Baker, Thomas R.	1.C.	,,
Harland, Joseph E.	1.C.	,,
Snowdon, Frank M. H.	1.C.	,,

For week ended 7th December—*continued.*

NAME.	GRADE.	PORT OF EXAMINATION
Acheson, James	2.C.	Sunderland
Boxall, Edmund S.	2.C.	,,
Elder, Frederick K.	2.C.	,,
Marshall, Thomas H.	2.C.	,,
Cummins, Kenneth M.	2.C.M.	,,
Walker, Herbert C.	2.C.M.	,,

For week ended 14th December, 1929:—

Spence, Sidney S.	1.C.M.E.	Leith
Dobbie, James E.	1.C.	,,
Galbraith, Philip	2.C.	,,
MacAlpine, Kenneth D. ...	2.C.	,,
Reid, William	2.C.	,,
Spence, James S.	2.C.	,,
Shirra, James W. M.	2.C.M.	,,
Liddell, Hugh	1.C.M.E.	Glasgow
Beatson, David S.	1.C.	,,
Crossley, Robert J. W.	1.C.	,,
MacKirdy, John W.	1.C.	,,
Robertson, Alfred W. J. ...	2.C.	,,
Stewart, Alexander B.	2.C.	,,
Torrance, James T.	2.C.	,,
Auld, Robert L.	2.C.M.	,,
MacPhee, James E.	2.C.M.	,,
Griffiths, Griffith W.	1.C.	Liverpool
Johnston, John A.	1.C.	,,
Rawlinson, Thomas W.	1.C.	,,
Jackson, Matthew W.	2.C.	,,
McBride, Francis D.	2.C.	,,
Cook, George H.	1.C.M.E.	,,
Oliver, John T.	1.C.M.E.	London
Inward, Alfred J.	1.C.	,,
Stevenson, James	1.C.	,,
Walker, Eric J.	1.C.	,,
Darroch, Reginald R.	2.C.	,,
Filshie, Gilbert	2.C.	,,
Grant, Francis S.	2.C.	,,
Middleton, Donald W.	2.C	,,
Warner, Arthur C. S.	2.C.	,,
Howell, Thomas H.	1.C.	North Shields
Hughes, James	1.C.	,,
Hall, George W.	2.C.	,,
Morgan, Trevor W.	2.C.M.	,,
Crampton, Arthur E.	1.C.	Southampton
Miller, Frederick L. C. ...	1.C.	,,
Evans, John H.	2.C.	,,
White, Oliver	2.C.	,,
Robbie, Alexander C.	1.C.M.E.	,,
Evans, Cyril L.	1.C.	Cardiff
Hodges, Arthur H.	1.C.	,,
McPherson, Reginald J. S. ...	1.C.	,,
Barker, Hector E. F.	2.C.	,,
Coslett, Leonard J.	2.C.	,,
Dunstone, Leslie A.	2.C.	,,
Findley, Francis A.	2.C.	,,
Morris, Trevor O.	2.C.	,,
Phillips, Anthony	2.C.	,,
Sweett, Thomas J.	2.C.	,,

For week ended 21st December, 1929:—

NAM .	GRADE.	PORT OF EXAMINATION.
Paterson, Walter	1.C.E.	Glasgow
Paton, Robert C.	2.C.E.	,,
Lee, Frederick	1.C.M.E.	,,
Robertson, William J.	1.C.	,,
Allison, James W.	2.C.	,,
Clark, Joseph McC.	2.C.	,,
Mackenzie, James	2.C.	,,
MacPhie, Charles	2.C.	,,
Phillips, David G. R.	2.C.	,,
Robson, Kenneth	2.C.	,,
Taylor, John McF.	2.C.	,,
Walker, James	2.C.	,,
Milne, Hugh	1.C.M.	,,
Morton, James R.	1.C.M.	,,
Bowler, Charles J. B.	1.C.	London
Hoes, William E.	1.C.	,,
Jones, Cyril W.	1.C.	,,
Williams, George H.	1.C.	,,
Cullum, Stanley J.	2.C.	,,
Dickens, Charles W.	2.C.	,,
Hulkes, Ernest H.	2.C.	,,
Lake, Harold V.	2.C.	,,
Waplington, John F.	2.C.	,,
Smith, Deans C.	1.C.M.E.	,,
Entwistle, Harry	1.C.M.E.	Liverpool
Walley, John	1.C.M.E.	,,
Scales, John S.	1.C.	,,
Gething, Walter N.	2.C.	,,
Hunter, Robert	2.C.	,,
Kerr, John	2.C.	,,
Palin, Frederick G.	2.C.	,,
Petterson, Philip J.	2.C.	,,
Dobson, William G.	2.C.M.	,,
Procter, Rowland H.	1.C.	North Shields
Turnbull, Robert G.	1.C.	,,
Turner, Robert B.	1.C.	,,
Wilson, Charles E. C.	1.C.	,,
Fearon, Gordon	2.C.M.	,,
Willis, John T.	2.C.M.	,,
Gordon, Frank	1.C.M.E.	,,
Lacey, Henry B.	1.C M E	,,
Adie, Harry F.	1.C.M.E.	Sunderland
Kennedy, Thomas W.	1.C.M.E.	,,
Chandler, Ernest	1.C.	,,
Marsh, Cyril	1.C.	,,
Souter, George W.	1.C.	,,
Spink, George T.	1.C.	,,
West, Wellard P.	1.C.	,,
Brodie, Edward N.	2.C.	,,
Ellerington, Andrew L.	2.C.	,,
Lee, Arthur W.	2.C.	,,
Forster, Harold	1.C.M	,,
Ward, William B.	2.C.M.	,,