The INSTITUTE of MARINE ENGINEERS

Founded 1889 Incorporated by Royal Charter, 1933

SESSION 1948 *Transactions* Vol. LX No. 1

Patron: HIS MAJESTY THE KING President: SIR AMOS L. AYRE, K.B.E., D.Sc.

The Burning of Boiler Fuels in Marine Diesel Engines

By JOHN LAMB, O.B.E. (Member)

Read on Tuesday, December 9th, 1947, at 5.30 p.m. at 85, Minories, E.C.3

Chairman: W. SAMPSON (Chairman of Council)

About fifty years ago it became apparent that if the Diesel engine was to become a commercial success a specific grade of petroleum, which ultimately became known as Diesel fuel, would have to be employed. Because of this the prospects of this type of engine for the propulsion of ships were not particularly bright until the oil companies provided a very widely distributed supply of this high grade fuel at prices which enabled a motor ship to show a lower fuel bill than a corresponding steamship.

During the period that the Diesel engine has been used for ship propulsion much has been done to ensure greater reliability in service and lower maintenance charges, whilst much thought and effort have been spent in endeavouring to increase the fuel flexibility of such engines. Diesel engines, however, still require high grade Diesel fuel if the maintenance charges are not to off-set the advantage gained by the lower fuel consumption per unit of power developed when compared with the steam engine.

Roughly speaking the fuel consumption of an efficient steamship is twice that of an efficient motorship of corresponding size and speed, and this would be the ratio of the fuel bills if the two installations operated on the same grade of fuel. The grade of fuel required for each class of ship, however, varies greatly, not only in composition but in price, so that the fuel bill of the motorship is much more than half that of the steamship. In composition and physical properties the fuel required by motorships varies only slightly, but in fuels commonly used in steamships these factors vary more widely, as will be seen from the following typical specifications:—

TABLE 1.

	Diesel Fuel	Boiler Fuels 1	2	3	4
Specific Gravity @ 60°F.	0·896	0·94	0·960	0·980	0·99
Viscosity Red. I @ 100°F. Secs. ...	43″	430″	1480″	3400″	6400″
Flash Point P.M. Closed	186°F.	200°F.	207°F.	200°F.	196°F.
Pour Point *below* ...	20°F.	20°F.	20°F.	20°F.	20°F.
Ash Content ...	0·02%	0·05%	0·05%	0·07%	0·06%
Sulphur Content ...	1·1%	1·9%	2·3%	2·7%	2·8%
Water Content ...	0·03%	0·05%	0·05%	0·05%	0·05%
Carbon Residue Conradson ...	1·25%	8%	10%	14%	14%
Sediment by Extraction	0·05%	0·03%	0·03%	0·04%	0·06%
Calorific Value B.T.U.'s lb. ...	18,950	18,750	18,600	18,400	18,300
Price per Ton...	83/-	65/8	61/-	57/9	56/11

From the differences in costs per ton it will be seen that if a motorship could be made to operate on any of the boiler fuels listed above, which are available on most routes followed by steamships, the saving in the fuel bill would be substantial. Actually the annual saving in the case of a 4,000 i.h.p. installation having a fuel consumption of 0·3lb. per i.h.p./hr. operating for 300 days yearly and

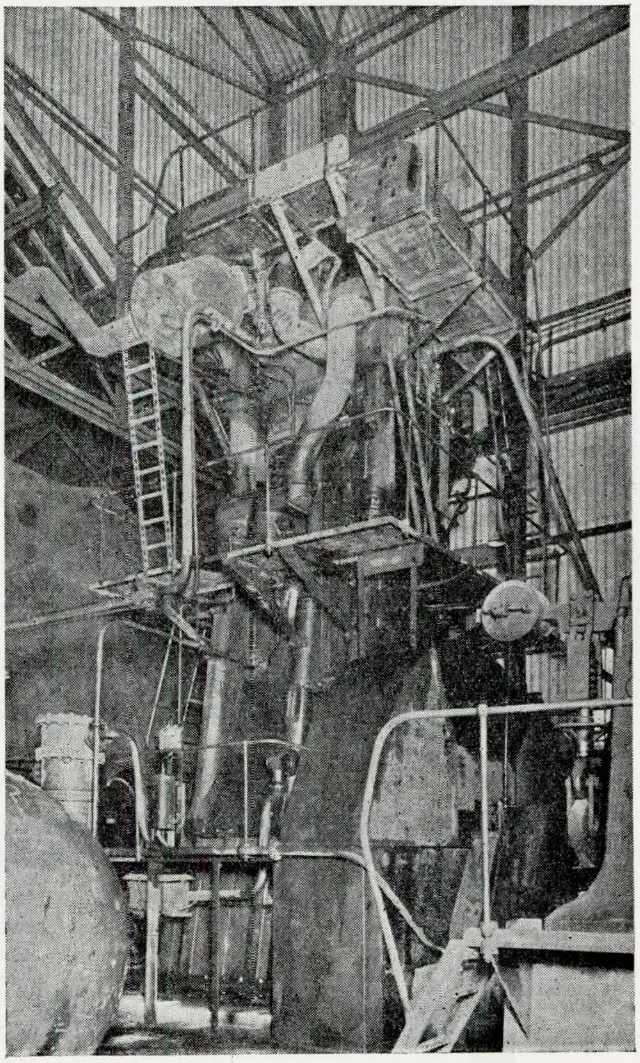


FIG. 1.—*View of the 500-i.h.p. experimental engine.*

lifting bunkers at Dutch West Indian ports would be:—

No. 1 Boiler Fuel ...	... £3,340
No. 2 „ „ ...	... £4,240
No. 3 „ „ ...	... £4,870
No. 4 „ „ ...	... £5,030

With higher powers the saving would be proportionately increased, and that for an 8,000 i.h.p. installation employing even No. 3 boiler fuel would be particularly attractive. In calculating the above savings no allowance has been made for the slightly lower calorific value of the boiler fuels as compared with Diesel fuel.

Prior to the investigation now about to be described, the position regarding the burning of heavy boiler fuels in marine Diesel engines in service was that whilst such engines would start and work up to full rated power on any liquid fuel which could be satisfactorily handled by the fuel injection pumps, prolonged operation such as is required for ship propulsion was impossible. The reason was that after a comparatively short time in operation, carbon would form on the fuel valve nozzles and eventually interfere with the proper spraying of the fuel, thereby reducing the power output and causing the parts surrounding the burning fuel to become overheated. The state of incomplete combustion resulting would cause solid matter to accumulate in the cylinders, the piston rings to jam and blow and the exhaust valves, if the engine was of the four-cycle type, to require very frequent attention. In the case of two-cycle type engines the sulphurous gases blowing past the stuck piston rings would soon cause very serious mechanical trouble in the crankcase. Even if the grade of boiler fuel used was sufficiently high to enable the ship to trade without serious mechanical trouble, the wear rate of cylinder liners and piston rings would be much too great to justify continuing to use such fuel.

Reviewing the results obtained by previous investigators the author formed the opinion that failure to achieve the desired results was due to the burning of heavy fuels in Diesel engines being considered as one problem instead of two distinct problems. In other words, all previous attempts provided merely for the removal of water and grit from the fuel by centrifuging or other means, and adjusting or altering those parts of the engine directly concerned with injection and combustion to burn what remained. The author's approach was, first of all to remove from boiler fuel the objectionable matter not found in Diesel fuel, and secondly, to adjust the engine to burn fuel which differed from Diesel fuel only in respect of viscosity. His interest in this problem became greater when seven years ago he was made responsible for the technical operation of a very large fleet of tankers, the majority of which were propelled by Werkspoor type four-stroke engines of 4,000 i.h.p. These ships, like all other motorships, were using Diesel fuel, and the opportunity to put the author's theories to the test came three years ago when the Directors of the Royal Dutch Shell Group gave their consent and their money to a full-scale attempt to solve this age-old problem.

Instead of constructing a miniature of the type of engine in which the author was chiefly interested and carrying out the experiments on shore, or attempting to experiment with a ship at sea, both of which methods had obvious disadvantages, an exact duplicate of one unit was constructed and installed at the St. Peter's Works of Messrs. R. & W. Hawthorn, Leslie & Co., Ltd., who provided at their own cost a building to house the engine, and whose keen co-operation and helpfulness are here acknowledged. Particulars of this experimental engine, illustrated in Fig. 1, are as follows:—

Number of cylinders	1
Diameter of cylinders	650 m/m.
Stroke of piston	1,400 m/m.
R.p.m.	120
I.h.p.	500
B.h.p.	390
Mechanical efficiency	78 per cent.
Supercharge air pressure...	5·5lb./sq. in.

Sectional views of the cylinder head and fuel injection valve of the experimental engine are shown in Figs. 2, 3 and 4, which parts, like the remainder of the engine, conform to Werkspoor's standard practice.

In addition to the engine of standard design and material, special parts such as a chrome-hardened cylinder liner, piston rings of different composition and hardness, fuel valve nozzles of varying design, exhaust and air inlet valves of varying design and material, etc., were made, but the aim was to use such special parts only in the event of it being found impossible to obtain the desired results with the standard parts. A new design of cylinder head providing for the admission of fuel at more than one point was also prepared, as well as an arrangement for creating turbulence, and consequently better mixing of the air and fuel during the burning period, but as will be shown later, it was found possible to burn satisfactorily fuel of 1,500 seconds viscosity without making any major alterations to the engine. Arrangements were also made to permit the cylinders of other makes of engines to be fitted at a later date. This paper, however, deals only with the Werkspoor engine.

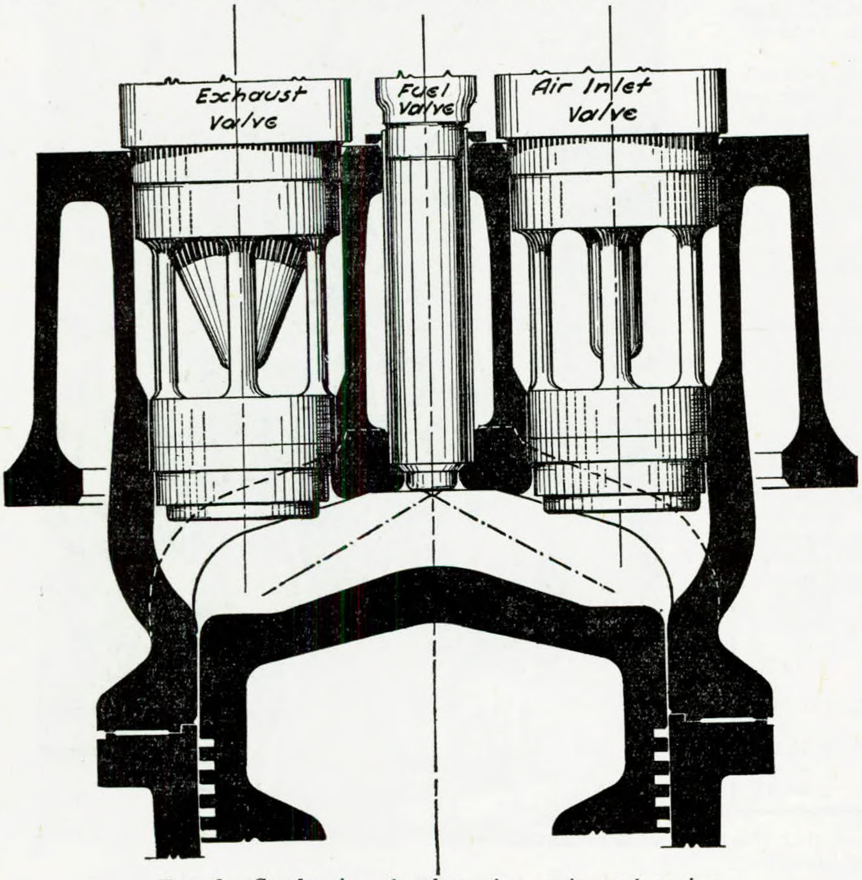


FIG. 2.—*Combustion chamber of experimental engine.*

As regards the first and most important problem, namely the extraction of objectionable matter from the fuel, it was felt that the desired results were more likely to be obtained by centrifuging than by any other method, most of which were in any case ruled out because of their limited capacity for a size which could be conveniently accommodated in the average motorship engine room. It was realised, however, that whilst centrifugal separators are most effective in separating water and the finest earthy matter from liquid fuel, the purifying process, if it was to be a success, would have to remove all trace of extractable ash and a proportion of the slow burning constituents.

When ready, the experimental engine was started up, and the first few days were devoted to carrying out the adjustments necessary to ensure the engine operating at maximum efficiency. These were of the usual routine character and need no further mention. The tuning-up operation completed, the engine was again started, and after being worked up to full rated power, was allowed to operate continuously for 168 hours (7 days) on Diesel fuel, in order to "run in" the engine and to obtain the data necessary for purposes of comparison when higher viscosity fuels were brought into use. During the first 162 hours of this test the engine was left to the attendants, who were instructed to keep the power output and the various temperatures and pressures reasonably constant, but as the end of this test approached, everything necessary was done to ensure the engine operating at the highest possible efficiency.

During the last 6 hours of this test the Diesel fuel used was run through a centrifugal separator of

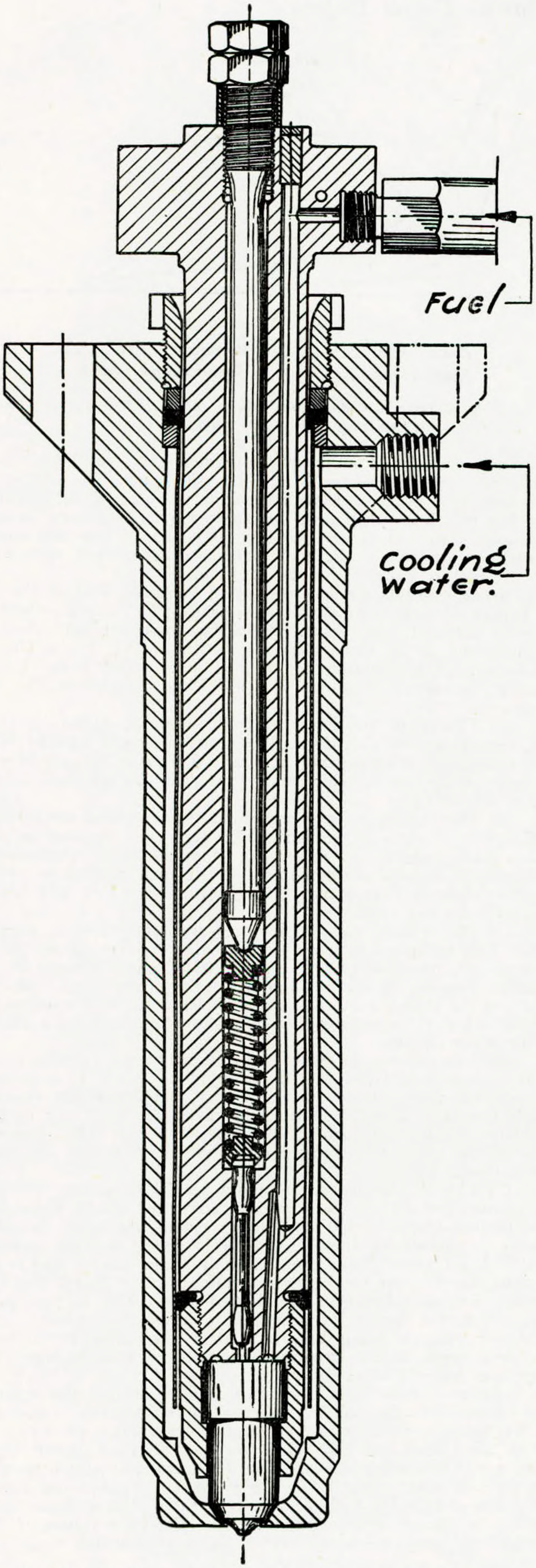


FIG. 3.—*Fuel injection valve of standard Werkspoor design.*

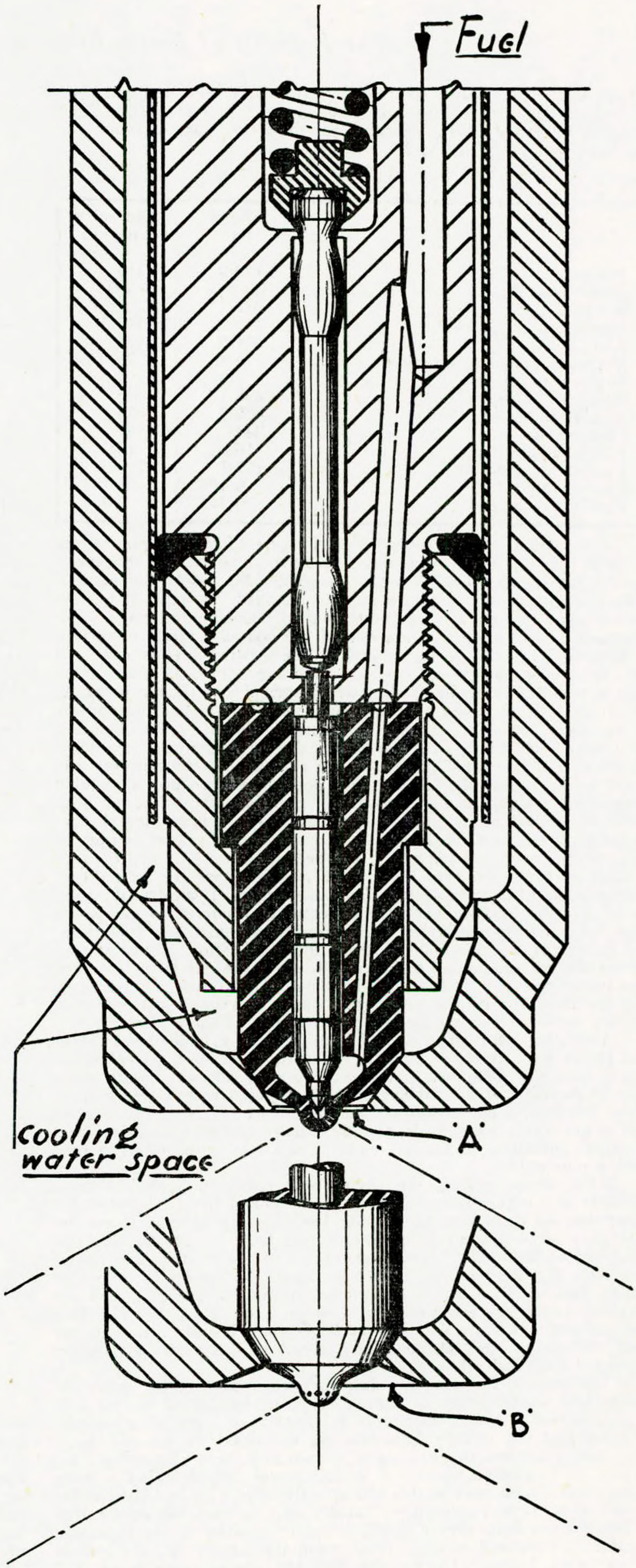


FIG. 4.—*Lower end of fuel injection valve.*

a type and in a manner no different from that used and practised in present-day motorships. Readings were taken at regular and frequent intervals and the averages for the 6 hours are shown in the left-hand column of Table 2.

TABLE 2.

	Diesel Fuel	Admiralty Fuel Oil
R.p.m.	119·2	119
Brake load, lb.	1,300	1,300
B.h.p.	387·7	387
M.i.p.	119·9	116·5
I.h.p.	511·8	497
Mechanical efficiency, per cent. ...	75·85	78
Superch. lb./sq. in.	4·4	4·5
Comp. P. lb./sq. in.	438·1	445
Max. P. lb./sq. in.	668·7	644
Exhaust °C.	344	351
Fuel lever position	16½	16½
Fuel, lb. used per hr.	177·7	190·8
Fuel, lb./b.h.p./hr.	0·458	0·494
Fuel, lb./i.h.p./hr.	0·347	0·384

The normal cylinder compression pressure of Werkspoor engines is 500lb. per sq. inch. The mean pressure recorded in the experimental engine was 438·1lb. which is some 62lb. below the normal. This low compression pressure was not intended, but after giving the matter some thought it was decided not to decrease the compression clearance at this stage because one of the common faults in service is low compression pressure, and if the desired results could be obtained under such conditions so much the better, as even better results would certainly be obtained with a normal compression pressure.

It will be observed that the fuel consumption per unit power is unusually high for a properly adjusted Diesel engine operating on Diesel fuel. This may have been due to inaccurate measuring of the fuel supply tank in spite of the care taken. As this test was carried out in wartime it was not possible to procure a suitable weighing machine, and the measuring had to be done by the not very accurate method of dipping and correcting for temperature change. Because of this, and the fact that the experimental engine comprised one cylinder only, and required a flywheel weighing 40 tons to ensure reliable starting and even turning, it was felt that the actual fuel consumption when operating on any one grade of fuel would have to be left in abeyance until the opportunity occurred to carry out tests on a multiple cylinder engine operating under sea conditions. As this most reliable indication of the combustion efficiency was denied the author, he had to be guided to a large extent in this test, and in the tests which followed, by the colour of the exhaust gases and the condition of the combustion space as regards accumulation of deposit, as well as the general performance of the engine.

After this 168 hours run on Diesel fuel, the cylinder head valves and piston were removed, and the walls surrounding the combustion space carefully examined. As was expected, all parts were quite free of deposit and the rubbing surfaces covered with a thin film of clean lubricating oil. Accurate measurements of the cylinder liner and piston rings were made and the earthy matter generally found in small quantities in the air, exhaust and fuel passages of a new engine removed.

After re-assembling, the engine was ready to begin the tests on fuels of a higher viscosity than that of Diesel fuel. The arrangement decided upon was to increase the viscosity in easy stages by mixing a large proportion of Diesel fuel with the heavy fuel, and gradually reducing the Diesel fuel content of the mixture and noting and recording the slightest change in engine performance. The first boiler fuel to be used is known as Admiralty fuel oil, and its physical properties are shown in Column 1 of Table 1. The first run was on a mixture comprising 90 per cent. Diesel oil and 10 per cent. Admiralty fuel oil, and the last run in this series was solely on Admiralty fuel oil.

The reason for running the engine on the highest grade of boiler fuel at this stage of the experiments, instead of on the fuel it was hoped it would ultimately be possible to burn satisfactorily, was to find out exactly how the engine would be affected by a moderate reduction in combustion efficiency after a reasonably long period of continuous operation at full power output. Had a more inferior fuel been used at this juncture the effects of bad combustion would have been produced so rapidly and to such an extent that it would have been very difficult, if not impossible, to say if certain conditions produced resulted from unsuitable engine adjustments or from other causes. During this test the engine operated on full

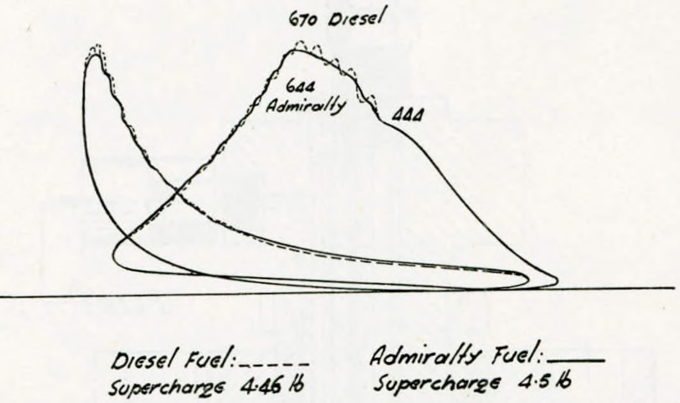


FIG. 5.—*Typical indicator diagrams taken when operating on Diesel fuel and Admiralty fuel oil.*

load for a period of 132 hours, 60 hours on mixtures of Diesel fuel and Admiralty fuel oil and finally 72 hours continuously on Admiralty fuel oil only. On every occasion the engine was started and allowed to run for one hour on Diesel fuel before changing over to the more viscous fuel. Moreover, the last hour of each run was made on Diesel fuel to ensure the fuel system being charged with this high grade fuel in readiness for the next run.

The average results obtained when using Admiralty fuel oil (No. 1, Table 1) on a 72 hour continuous test are shown in Table 2 alongside the results obtained when using Diesel fuel, and typical indicator diagrams taken during these tests are shown in Fig. 5, the Diesel fuel diagram being superimposed to facilitate comparison. Upon comparing the results obtained the following differences will be observed:—

(1) The m.i.p. was lower by 3·4lb. when on Admiralty fuel oil, indicating that with the more viscous fuel (430" against 97") the combustion efficiency was reduced. This is confirmed by the exhaust temperature, which was 7 deg. C. higher than when using Diesel fuel.

(2) The i.h.p. was lower by 14·8, but the improved mechanical efficiency (78 per cent. against 75·85 per cent.) resulted in the b.h.p. being practically unaltered. This improved mechanical efficiency is mainly attributed to the frictional resistances being further reduced during the period of running which took place between the two tests.

(3) The cylinder compression pressure is increased by almost 7lb. This difference is mainly due to the slightly higher supercharge air pressure (4·5lb. against 4·4lb.), and perhaps in a smaller measure to the bedding in of the piston rings. Moreover, as the engine comprised one cylinder only, the compression pressure had to be measured from a power diagram and a slight error is not unlikely.

(4) The greatest difference is in the maximum cylinder pressure, which fell from 668·7lb. to 644·0lb. Such a difference clearly indicates that the more viscous fuel burns less rapidly after ignition. This is confirmed by the lower m.i.p. and higher exhaust temperature, which also indicates that after-burning was taking place to a much greater extent than was the case with Diesel fuel.

(5) The higher fuel consumption per b.h.p., namely 0·494lb. as against 0·454lb. of Diesel fuel, is accounted for by the lower combustion efficiency and, to a lesser extent, the lower calorific value of Admiralty fuel oil, which is 18,750 B.T.Us. against 18,950 B.T.Us. for Diesel fuel. The difference can be said to be mainly due to some of the constituents absent in Diesel fuel not being completely burnt in the allotted time. This in turn may be due to the degree of atomization being less, although the injection pressure would be greater than when using Diesel fuel. At this stage of the experiments means to measure the fuel injection pressure were not available.

A feature of these tests worthy of mention is that the volume of fuel injected into the cylinder, indicated by the position of the fuel lever, was the same in each case although the weights were different.

Both the Diesel fuel and Admiralty fuel oil used during these tests were run through a standard type De Laval centrifugal separator at the full rated capacity of the machine. Neither the Diesel fuel nor the Admiralty fuel oil was pre-heated during these tests, but owing to change in climatic conditions the temperature of the two grades did vary, the temperatures and corresponding viscosities being:—

Fuel	Air Temperature	Fuel Temperature	Viscosity Red. I
Diesel fuel	56 deg. F.	70 deg. F.	138 secs.
Admiralty fuel oil ...	66 deg. F.	80 deg. F.	900 secs.

Outwardly there was no noticeable difference in the running of the engine when carrying the full brake load, except that the colour of the exhaust gases was slightly darker when running on Admiralty fuel oil. The figures given in Table 2, however, show clearly that the use of such fuel would not be an economic proposition unless the combustion efficiency could be increased and the consumption per unit power developed consequently brought nearer to that of Diesel fuel.

After this test all parts of the engine likely to be affected by burning this grade of boiler fuel were examined and their condition was found to be as follows:—

Cylinder Head. The underside was covered with a film of soft deposit of no measurable thickness, but on which distinct markings could be made with the finger tips.

Piston. Upper surface of crown similar to underside of cylinder head. Between the upper outward edge and the top piston ring groove was a black, sticky substance disposed as shown in Fig. 6, and of the thickness indicated. All piston rings were moveable but not free, whilst the oil scraper ring was stuck for one-third of its circumference. The annular space between the piston rings contained small quantities of a substance not unlike a mixture of oil and varnish.

Fuel Injection Valve. Internal parts in clean condition and all spray holes in nozzle clear, but a hard black substance had formed around the nozzle tip in the manner shown in Fig. 7.

Exhaust Valve and Passages. Apart from being covered with a thin film of soot all parts were in good order.

When considering the condition of the parts in respect of deposit it must be remembered that the final run was on Diesel fuel which, as will be shown later, has the effect of removing some of the deposit produced by burning heavy fuel, and altering the character of that remaining.

The observations made whilst operating and the condition of the parts when opened up after running on this high grade boiler fuel clearly indicated the lines which subsequent tests must follow, and what must be achieved if the problem in hand was to be solved. Two of the interesting points revealed by this test are illustrated in Figs. 6 and 7, which give the amount and location of the deposit found on the side of the piston and the fuel valve end. In each case it will be observed that the location of the deposit suggests a tendency to build-up in the direction of the exhaust valve.

Taking the piston (Fig. 6) first, the author thinks it can be assumed that any solid matter found adhering to the side above the top piston ring groove had been scraped off the cylinder liner by the upward movement of the piston. If this is so a probable explanation of the greater accumulation on the exhaust valve side of the piston is that during the later part of the exhaust stroke and the early part of the air inlet stroke, when both exhaust and air inlet valves were partly open, the ingoing air swept directly across the cylinder, driving before, or carrying with it particles of partially burnt fuel "floating" in the cylinder, the particles sticking to the oily surface of the cylinder liner until scraped off by the piston during the remainder of the exhaust stroke. In the Werkspoor engine the air inlet valve opens 53 deg. b.t.c. and the exhaust valve closes 36 deg. a.t.c., giving 89 deg. overlap. When the air inlet valve begins to open the piston is, therefore, about one-fifth from the end of its stroke.

Accumulation of solid matter on the end of the fuel valve is generally attributed to (1) the fuel valve leaking; (2) the fuel burning too close to the nozzle, causing it to become overheated, or (3) the fuel not being atomized to a sufficiently high degree. In this case the fuel valve was perfectly fluid-tight, although the possibility of the needle valve not re-seating with the usual smartness owing to the fuel used being more viscous than Diesel fuel must be considered. As regards cause (2), it is most unlikely that this viscous fuel would burn so close to the nozzle as to cause it to overheat, and if the accumulation of the deposit had been due to cause (3), i.e. under-atomization, it would occur during the fuel injection period and be of uniform thickness all round the nozzle, instead of at one side only.

The conclusion reached in this case was, therefore, that the deposit was due to the needle valve not re-seating smartly and consequently not giving a clean cut-off. After the valve closed the fuel left on the nozzle may have been little more than a dampness, but it would appear that its thickness was such that it remained during the working and exhaust strokes and until the air inlet valve opened, whereupon the supercharge air sweeping across the cylinder in the direction of the exhaust valve blew the film of oil from the nozzle on to the end of the fuel valve housing, where it was reduced in thickness and spread over a greater area, in which condition it was more easily carbonized. During subsequent tests with much more viscous fuels, deposit was found on several occasions in exactly the same position relative to the cylinder head valves.

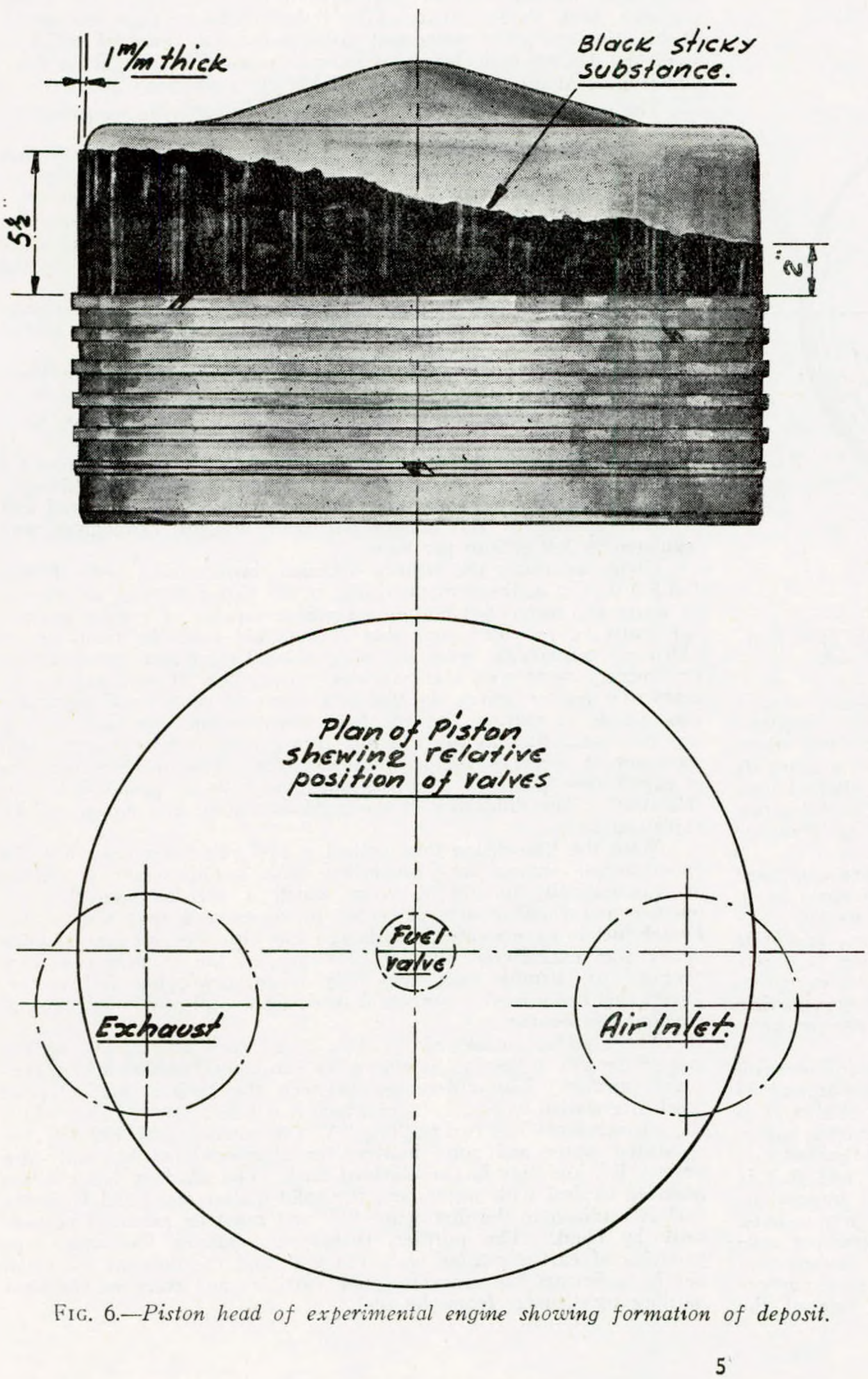


Fig. 6.—*Piston head of experimental engine showing formation of deposit.*

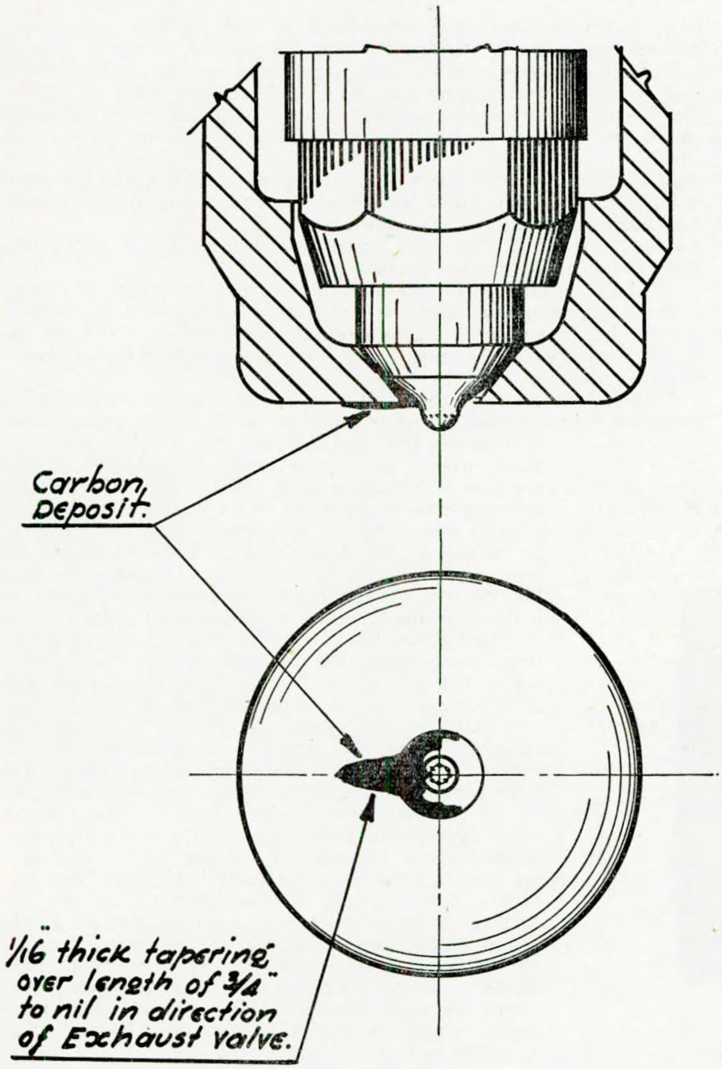


FIG. 7.—*Location of deposit on fuel injection valve nozzle of experimental engine after running on Admiralty fuel oil.*

Boiler fuels differ from Diesel fuel mainly in colour, specific gravity, viscosity and carbon residue value, which is to be expected because Diesel fuel is a distillate and is free from anything which will not evaporate at a temperature of about 700 deg. F. Consequently no difficulty is experienced in burning completely in the allotted time every particle of this grade of fuel in the cylinders of Diesel engines, wherein the temperature, once ignition has taken place, is in the region of 3,000 deg. F.

Most boiler fuels are blended, that is to say they are composed of a mixture of residual oil and distilled oil, the proportions being determined by specification requirements in respect of gravity, viscosity, pour point, Conradson value, sulphur content, etc., and it is in the residual portion of the mixture that matter which is objectionable in Diesel engine fuel is to be found. With the exception of water, earthy matter and inorganic ash, however, every particle of residual oil is burnable and convertible to gas at temperatures well below 3,000 deg. F.

The removal of water and earthy matter is a simple matter with present day equipment, so that the only objectionable constituent of boiler fuels for Diesel engine use in the ash content. Whilst it is stated that all other constituents of residual fuel are burnable within the temperature prevailing in Diesel engine cylinders, it is realised that the time taken for this process is an important factor, and that if every particle, with the exception of the ash which is impervious to heat, is to be completely burnt in the allotted time, provision must be made to increase the burning rate of the slowest burning constituents. Assuming that oil particles burn from the surface and that the combustion is complete only when the core of each particle is reached, the rate of burning is determined by the size of the particle. If, therefore, the particles are composed of slow burning materials, the rate of burning can be increased by reducing the size of the particles, or, in other words, atomizing the fuel to a higher degree. It is appreciated that comparatively light weight particles injected into Diesel engine cylinders produce difficulties in other directions, but as such difficulties were not encountered during these experiments further reference will not be made.

The only really objectionable constituent in boiler fuels when used for Diesel engines is, therefore, ash, which is composed of silica, iron oxide, vanadium oxide and other abrasive matter, and if this ash could be extracted from the fuel before it is injected into the engine cylinders there is every reason to hope that distilled fuels would no longer be necessary for Diesel engines.

Whilst the experimental engine was under construction and the foregoing tests were being carried out, a start was made to see what could be done towards extracting the ash from various grades of boiler fuel sent to the works of Messrs. Alfa-Laval & Co., Ltd., who placed their laboratory and their wide knowledge of centrifuging at the author's disposal. A series of tests were carried out, and whilst these were not conclusive owing to the particular size of centrifugal machines which were proved to be necessary not being available, they showed that whilst these machines were extremely effective in separating water and suspended matter, even of colloidal form, the desired high degree of extraction could not be obtained by centrifuging at usual temperatures and in the customary manner.

The main points brought out during these fuel purifying experiments were that:—

(1) to obtain the greatest extraction of ash the fuel must be heated to the highest practicable temperature before treatment and maintained at that temperature during treatment.

(2) the fuel should not be kept at this high temperature longer than necessary as it had the effect of driving off some of the lighter constituents and unduly raising the viscosity of the treated fuel.

(3) if the temperatures were too high certain asphaltic constituents in the fuel capable of being burnt satisfactorily, tended to separate.

(4) the larger the diameter of the centrifugal separator bowl the greater was the amount of ash extracted from the fuel, the amount extracted being proportional to the length of time the fuel remained in the bowl.

In regard to point No. 4, this condition was met by employing standard De Laval centrifugal separators and reducing the throughput to half their rated capacity. The machines finally employed had a rated capacity of 700 gallons per hour but the throughput was regulated to 350 gallons per hour.

Upon reviewing the results obtained during these tests it was decided that in addition to purifying in the ordinary way, to remove all water and suspended matter a machine capable of greater extraction must be provided, and that this should take the form of an additional centrifugal separator with a bowl of special construction. Preliminary tests with this machine proved that it was capable of extracting matter which the ordinary form of centrifugal separator was unable to extract, but the bowl construction was such that it was necessary first to run the fuel through an ordinary centrifugal separator at a certain temperature and rate. The ordinary machine is called the "purifier", and the machine with a special bowl the "clarifier". The difference in the construction of the bowls will be explained later.

With the knowledge thus gained a fuel purifying plant for the experimental engine was proceeded with. This plant is shown diagrammatically in Fig. 8, from which it will be seen that the purifier and clarifier are connected in series and that a tank for Diesel fuel is incorporated. Although the ultimate aim was to burn heavy fuel exclusively, the initial stages of the experiments were confined to burning such fuel only when developing full power, Diesel fuel being used to start and work up to full power and normal running temperatures.

The clarifier developed by Alfa-Laval for the removal of the last of the ash in the fuel is outwardly similar to the standard centrifugal purifier. The differences between the purifier and clarifier bowls are shown in Fig. 9, from which it will be observed that whilst the purifier bowl has two outlets, "A" for purified fuel and "B" for separated water and solid matter, the clarifier bowl has only one outlet "E", and this is for clarified fuel. The clarifier bowl is not intended to deal with water, and the solid matter separated from the fuel is retained in the dirt space "F" and must be removed periodically by hand. The purifier, therefore, removes the water and particles of earthy matter from the fuel, and the duty of the clarifier is to extract the extremely fine particles and some of the slow burning constituents from the fuel.

All the discs "PC5" in the purifier bowl are provided with holes near the periphery and separation takes place at these holes. The water and solid matter are thrown outward into the dirt space "C", and the fuel travels upwards as indicated by the arrow heads. In the bottom disc of the clarifier bowl the holes are omitted so that those provided in all other discs are screened and the fuel to be treated must flow to the outer edge of the discs before it can travel upwards and inwards. The fuel is thus carried a greater distance from the centre of the bowl and a proportionately higher degree of centrifugal force is applied. As the clarifier is not required to separate water from the fuel the upper end of the bowl is somewhat different from the corresponding end of the purifier bowl. A water seal is necessary in the purifier but not in the clarifier.

Before beginning the purifying process the temperature of the fuel is raised to 180 deg. F., which has the effect of reducing the viscosity of 1,500 secs. Red. I at 100 deg. F. fuel to 155 secs. As already mentioned, the initial temperature is important as too low a temperature makes separation of water and fine earthy matter more difficult, whilst if too high, the very slow-burning asphaltic contents of the fuel which should be extracted become so fluid that they would pass through the machines with the fuel supplied to the engine. To obtain the highest degree of purification the fuel should, therefore, be maintained at 180 deg. F. from leaving the storage tank until it reaches the tank from which it flows to the engine. A matter of 10 deg. F. higher or lower will not have a serious adverse effect, but such a range should be considered the permissible limit.

All fuel used during these tests was of Venezuelan origin and it might well be that with fuels from other sources the purifying temperature could be raised beyond the figure mentioned with beneficial effect, although it is unlikely that a temperature exceeding 200 deg. F. for any 1,500 secs. viscosity fuel would be necessary. On the other hand, the desired results may be obtained with temperatures below 180 deg. F. Without having had actual experience of purifying fuels from other sources by the process here described the author suggests that the desired results would be obtained with temperatures between 150 deg. F. and 200 deg. F.

When centrifugal separators are used on board ship to extract water and earthy matter from Diesel fuel the practice is to judge the effectiveness of the machines, or the proportion of impurities in any particular fuel, by the quantity of matter collected in the dirt space of the bowl for a given quantity of fuel treated. In the case of boiler fuels something more than water and earthy matter must be extracted if such fuels are to be used successfully in Diesel engines. With the purifying plant here described this is achieved provided the fuel is treated at the correct temperature. The temperature for fuels of Venezuelan origin has been given and it is suggested that the correct purifying temperature for a fuel from any particular source can be found by beginning at 150 deg. F. and after running a given quantity of fuel through the system, ascertaining the weight of solid matter collected by the purifier and clarifier bowls. Then raise the purifying temperature to 165 deg. F. and run through the system a similar quantity of fuel. If upon opening up the clarifier bowl it is found that a greater weight of solid matter is present than on the previous test it suggests that 165 deg. F. is more correct than 150 deg. F., but a further test at 180 deg. F. should be carried out. If, on the other hand, the weight of matter collected is no greater there is nothing to be gained by raising the purifying temperature above 150 deg. F. Should the weight of matter found be less than when purifying at 150 deg. F. it indicates that some of the waxy contents are passing through at the higher temperature, and if such matter has not had an adverse effect on the engine it should not be extracted.

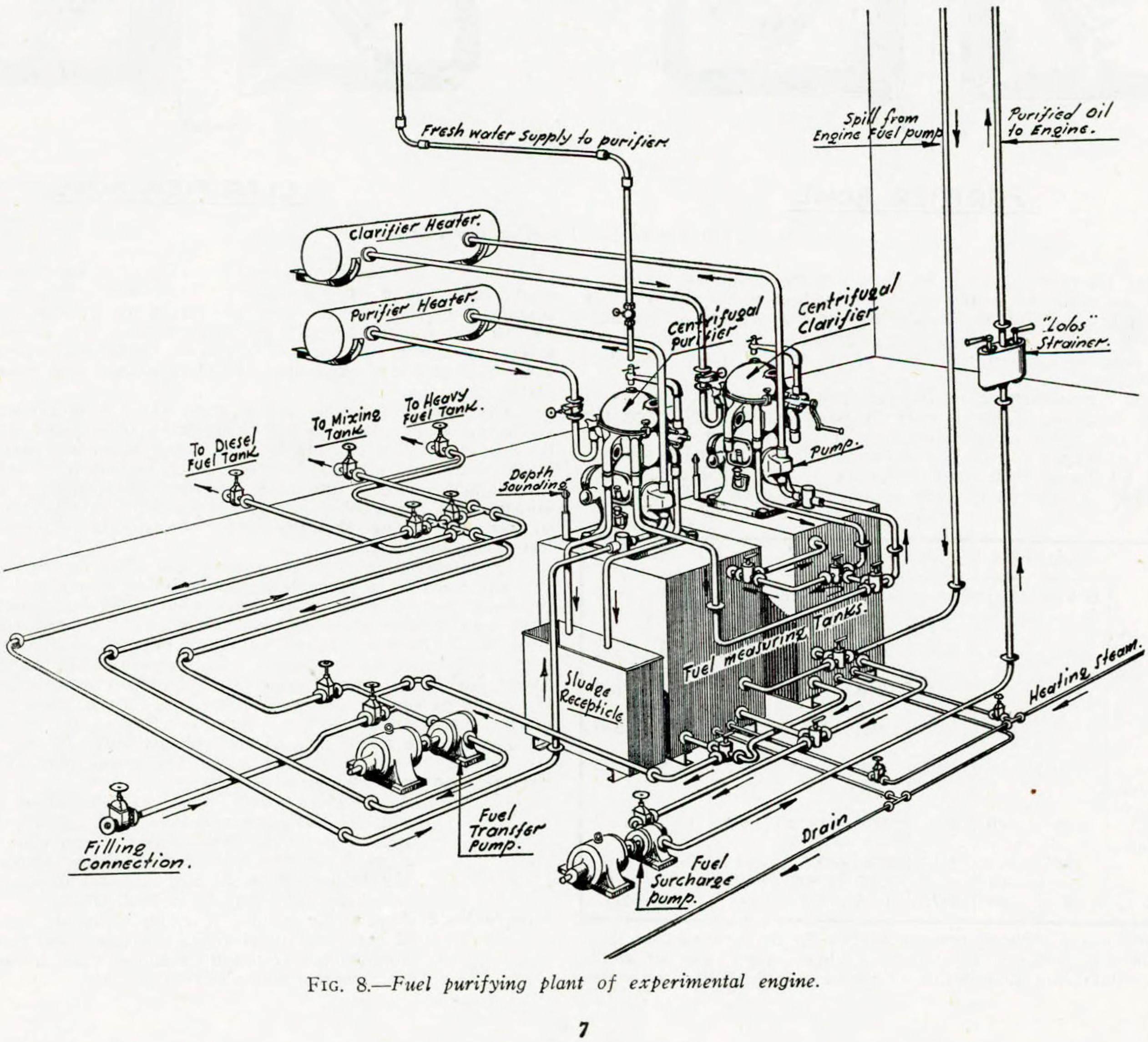


FIG. 8.—*Fuel purifying plant of experimental engine.*

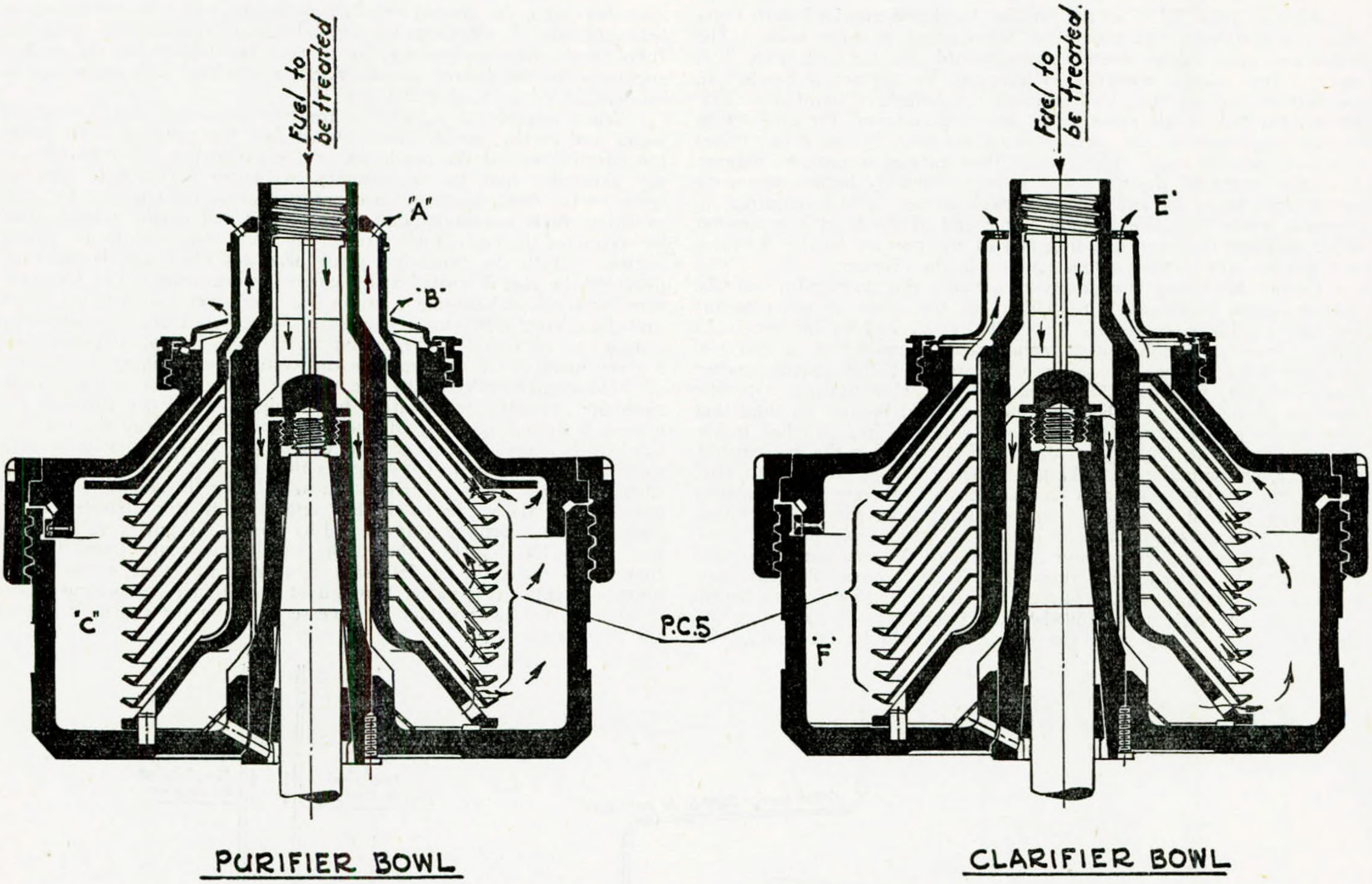


FIG. 9.—*Bowls for de Laval purifier and clarifier.*

During the experiments at St. Peter's the necessary guidance was given by analysing the matter extracted by the purifier and clarifier and carefully observing the results of varying degrees of purification on the engine. Countless tests of this nature were carried out but the data here given will be confined to the initial and final results obtained.

At the commencement of the purifying experiments samples of the fuels listed in Table 1 were analysed as received from the suppliers and again after being treated in the then best known manner, i.e. heating to 100 deg. F. and passing the fuel through a standard De Laval centrifugal separator at the rated capacity of the machine. The result of such treatment is shown in Table 3.

TABLE 3.

	Diesel Fuel		No. 1		No. 2		No. 3	
	Before	After	Before	After	Before	After	Before	After
Sp. Gravity @ 60°F....	·891	·892	·934	·933	·985	·987	·990	·992
Flash Point °F. ...	178	—	200	215	170	170	166	182
Vis. Red. I @ 100°F.	42	42	410	468	1447	1630	2344	2580
Pour Point °F. ...	−30	—	+25	+30	−5	−5	+5	+5
% Carb. Res. (Conradson) ...	·35	·40	7·7	7·8	14·2	14·5	14·2	14·7
Asphaltenes % ...	·15	·11	5·1	5·4	9·6	9·4	9·5	9·6
Ash % ...	·01	·01	·09	·06	·07	·09	·09	·09
Sulphur %	·8	·85	1·75	1·75	2·7	—	2·8	2·7

Apart from a general increase in viscosity the treatment of these fuels had not produced any effect. Where water was originally present in significant quantity, its amount was reduced to a minimum, but the treatment had no appreciable effect upon the carbon residue, asphaltenes, ash or sulphur content. The increase in viscosity after treatment maybe due to some of the more volatile constituents passing off when the temperature of the samples was raised preparatory to treatment. The deposit left in the centrifugal separator bowl after each run was exceedingly small in amount and mainly of an earthy character.

The conclusion to be drawn from these tests is that heating and centrifuging alone do not make heavy fuels more suitable for burning in Diesel engines if the removal of water and earthy matter is not taken into account. Actually such treatment makes the fuel less suitable since it increases the viscosity a not inconsiderable amount, and presumably reduces its calorific value, since the rise in viscosity indicates that the lighter constituents evaporate and are lost during the process.

It was apparent from these tests that after such treatment the fuel still contained a great deal of undesirable matter, and for future reference and in order to ascertain what effect such matter would have upon certain parts of the engine a 72 hour test was run on Fuel No. 2 (1,480 secs.) injected at 150 deg. F., no alteration whatever being made to the engine which was tuned-up to operate on Diesel fuel. After this engine test the deposit was scraped off (1) the inside of the exhaust valve housing; (2) the lower end of the exhaust valve spindle and the upper surface of the exhaust valve lid, and (3) the mitre face of the exhaust valve lid and seat, and the appearance of the deposit under low-power magnification and the break-down results were as follows:—

Sample No. 1. Appearance mainly of a light coloured crystalline material but containing also dark brown, black and metallic particles. Ash content 30 per cent., of which about 5 per cent. consisted of water soluble material. Metals present in the ash included iron, sodium and vanadium and about 3 per cent. silica.

Sample No. 2. Appearance similar to Sample No. 1. Ash content 62 per cent. of which 73 per cent. was water soluble compounds. Iron and vanadium were present and the silica content was about 10 per cent.

TABLE 4.

LOG OF 7-DAY TRIAL ON 1,300 SEC. RED. I AT 100° F. FUEL.

	No. of hours	Fuel notch	R.p.m.	B.h.p.	Supch. lb./sq.in.	M.i.p.	Mech. effy. %	I.h.p.	Compn lb./sq.in.	Max. press. lb./sq.in.	Exht. °C.	Fuel injectn.	Fuel temp.	Fuel specific gravity	Fuel ins./hr.	Fuel consumption lb./hr.	Fuel consumption lb./b.h.p./hr.	Fuel consumption lb./i.h.p./hr.
5.9.46 11 a.m. to 11 p.m.	12	18·8	120·3	391	5½	122·82	73·8	528·9	492	702	352	10,823	151	·9266	5·1389	189·68	·486	·359
6.9.46 11 p.m. to 11 a.m.	12	18·75	122	396	5½	122·37	74·2	534·4	497	696	350	9,854	150	·9270	4·9444	182·60	·468	·348
11 a.m. to 11 p.m.	12	18·38	120	390	5½	123·85	73·3	531·9	492	702	345	9,942	153	·9259	5·0695	187·01	·480	·352
7.9.46 11 p.m. to 11 a.m.	12	18·25	120	390	5½	122·37	74·2	525·6	495	702	345	10,083	157	·9243	5·0660	186·53	·478	·355
11 a.m. to 11 p.m.	12	18	122	396	5½	125·0	72·6	545·9	497	689	345	10,025	152	·9262	5·2604	194·11	·498	·362
8.9.46 11 p.m. to 11 a.m.	12	18	121	393	5½	123·25	73·6	533·8	500	702	343	10,000	154	·9255	4·9688	183·20	·470	·346
11 a.m. to 11 p.m.	12	18	119	386	5½	121·5	74·8	517·5	500	702	345	10,000	152	·9262	5·0104	184·88	·474	·355
9.9.46 11 p.m. to 1 p.m.	14	18	120	390	5½	122·40	74·2	525·6	500	702	340	10,000	150	·9270	4·9792	183·88	·471	·349
5 p.m. to 1 a.m.	8	19·12	120	390	5½	124·12	73·2	533·1	500	710	345	10,000	157	·9243	5·3281	188·68	·484	·354
10.9.46 1 a.m. to 9 a.m.	8	19	120	390	5½	123·25	73·7	529·4	500	709	345	10,000	153	·9258	5·3750	190·78	·489	·360
10 a.m. to 1 a.m.	15	18·67	120	390	5½	122·37	74·2	525·6	503	702	345	10,000	151	·9266	5·1387	188·20	·483	·358
11.9.46 1 a.m. to 1 p.m.	12	18·25	119·5	388	5½	123·25	73·7	527·1	501	700	349	10,020	152	·9262	5·1525	188·30	·483	·356
1 p.m. to 1 a.m.	12	18·25	120·75	392	5½	122·4	73·9	532·9	502	700	346	10,000	150	·9270	5·0967	188·22	·483	·357
12.9.46 1 a.m. to 1 p.m.	12	19·25	118·5	385	5½	125·87	72·1	533·9	504	696	348	9,750	150	·9270	5·5278	189·47	·486	·350

Brake load constant at 1,300lb.
Readings taken every hour.
Results given are average over No. of hours in left hand column.

Fuel temp. taken at inlet to main engine fuel pump.
Specific gravity corrected for inlet temperature.
Fuel ins. hour—depth in tank area × 1104·5 sq.in.
Fuel consumption corrected for leakage at pump.

Sample No. 3. In appearance similar to Samples Nos. 1 and 2 but with considerable dark brown material present. The ash content was 80 per cent., of which 55 per cent. was in water soluble compounds. Iron and vanadium were present in comparatively large quantities, the silica content being only 1 per cent.

After the deposit had been removed from the ground mitre faces of the cast iron exhaust valve lid and seat, it was found that pitting had begun, from the extent of which the conclusion reached was that the valve faces would not have remained gas-tight for a further three days under such operating conditions. Carbonaceous matter was also beginning to accumulate on the fuel valve spray nozzle and would soon have interfered with the fuel sprays.

The amount and location of deposit on the sides of the piston after this test were similar to those shown in Fig. 6, and as a microscopic examination revealed the deposit to be composed of black, soft, dry flakes with irregular black hard particles and a few small globules of liquid, it was decided to carry the examination further to ascertain whether it originated from fuel or lubricating oil, as the appearance suggested that the bulk of the deposit came from lubricating oil. The analysis revealed that the deposit comprised by weight 72 per cent. carbonaceous material, 17 per cent. oil, 5 per cent. water and 6 per cent. inorganic matter, while a breakdown of the last named proved that the bulk of the deposit came from the fuel, as a comparatively large amount of vanadium, a common constituent of fuel ash, was present.

The high proportion of carbonaceous matter indicated that better atomization and/or penetration of the fuel was necessary if the desired combustion efficiency was to be attained, and that the inorganic matter content of the fuel would require to be substantially reduced if undue wear of piston rings and cylinder liners and frequent changing of exhaust valves was to be avoided.

After the trial and examination just described, numerous alterations were made to the purifying plant and engine fuel system as dictated by the effects produced, some of which were retained and will be referred to when the tests carried out at sea are dealt with.

An examination of the material collected in the purifier and clarifier bowls during the final run in this series produced the following information regarding its composition:—

MATERIAL	FROM PURIFIER	FROM CLARIFIER
Water	35·0 per cent.	47·8 per cent.
Carbonaceous matter	16·16 ,, ,,	15·47 ,, ,,
Ash	48·84 ,, ,,	36·73 ,, ,,

The ash constituent of the two samples was analysed and its composition found to be:—

MATERIAL	FROM PURIFIER	FROM CLARIFIER
Silica	50·65 per cent.	19·83 per cent.
Barium Oxide ...	1.33 ,, ,,	—
Lead Oxide	1·80 ,, ,,	0·52 ,, ,,
Copper Oxide ...	0·14 ,, ,,	0·09 ,, ,,
Iron Oxide	18·84 ,, ,,	10·15 ,, ,,
Aluminium Oxide ...	14·38 ,, ,,	7·84 ,, ,,
Titanium Oxide ...	0·42 ,, ,,	0·42 ,, ,,
Vanadium Oxide ...	—	0·06 ,, ,,
Calcium Oxide ...	1·69 ,, ,,	1·28 ,, ,,
Magnesium Oxide ...	0·13 ,, ,,	0·73 ,, ,,
Sodium Oxide ...	7·20 ,, ,,	0·90 ,, ,,
Sulphur (as SO_3) ...	3·13 ,, ,,	9·57 ,, ,,
Phosphorus (as P_2O_5)	0·27 ,, ,,	0·28 ,, ,,
Sodium Chloride ...	—	41·86 ,, ,,
Undetermined ...	0·02 ,, ,,	6·47 ,, ,,
	100·00 ,, ,,	100·00 ,, ,,

The appearance of the material taken from the purifier bowl was that of a coarse carbonaceous sludge containing a considerable quantity of free water, while that from the clarifier was a black, viscous, fine carbonaceous material. The carbonaceous material extracted was probably burnable, but attempts to separate it from the ash during the purifying process were unsuccessful. It did, of course, represent a heat loss, but the amount was exceedingly small when converted into cash and compared with the saving accruing from the use of heavy fuels.

The fuel used in this particular test was of Venezuelan origin and its composition was practically the same as Boiler Fuel No. 2 in Table 1, excepting that its viscosity was 1,225 secs. Redwood I at 100 deg. F. The amount of material extracted per ton of fuel treated was, from purifier 19oz., and from clarifier 6½oz.

During the early part of these tests innumerable samples of fuel before and after treatment were submitted for analysis, and although the amount of matter extracted increased as the tests progressed, the reports upon the fuel samples before and after treatment showed no appreciable change and the author had to be guided solely by the amount of matter collected in the purifier and clarifier bowls, and particularly the ash portion of it.

When asked for an explanation the analyst stated that although there appeared to be little difference in the character of the fuels before and after treatment as shown by the tests, it should be borne in mind that the amount of impurities removed, although not inconsiderable in terms of pounds per ton of fuel treated, might not affect the result of such examinations as these to any great extent, especially when their inherent experimental error was realised. This will be readily understood when it is remembered that only 25½oz. of material was extracted from a ton of fuel and that one gallon, which would be a fairly large sample to analyse, would contain a mere 0·102oz., less than half of which would be ash.

Having carefully observed the effect of using a fuel of a higher viscosity than Diesel fuel without making any alteration to the engine or specially treating the fuel before injection into the cylinder, the next series of tests began with a mixture comprising 90 per cent. Diesel fuel and 10 per cent. No. 2 boiler fuel (Table 1), having a viscosity of 1,300 secs., and ended by using No. 2 boiler fuel only.

As in previous tests, the engine was started and allowed to become thoroughly warm on Diesel fuel before being run on the more viscous fuels. Also, during the last half hour of each run Diesel fuel was used. All heavy fuel used was treated in a manner which had been found to give the best results by analysis, i.e. the greatest extraction of the ash content.

The results obtained during these tests encouraged the hope that the final run on straight 1,300 secs. fuel would be accomplished satisfactorily without making any major alterations to the engine, and it was decided to run the engine on specially treated fuel for seven days continuously. The engine was accordingly stripped and all parts surrounding the cylinder combustion space thoroughly cleaned, cylinder head valves ground-in and cylinder liner and piston rings gauged. The only alteration made to the engine was to decrease the compression clearance volume in order to raise the compression pressure to the normal figure of 500lb./sq. in.

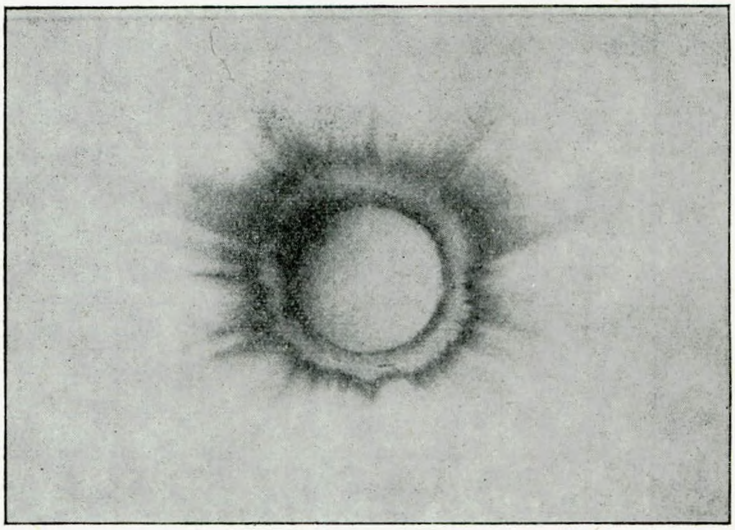
A copy of the log sheet for this seven day test is given in Table 4.

Readings were taken every hour, the results given being the average over the number of hours shown in the first column, while the averages for the whole period were as follows:—

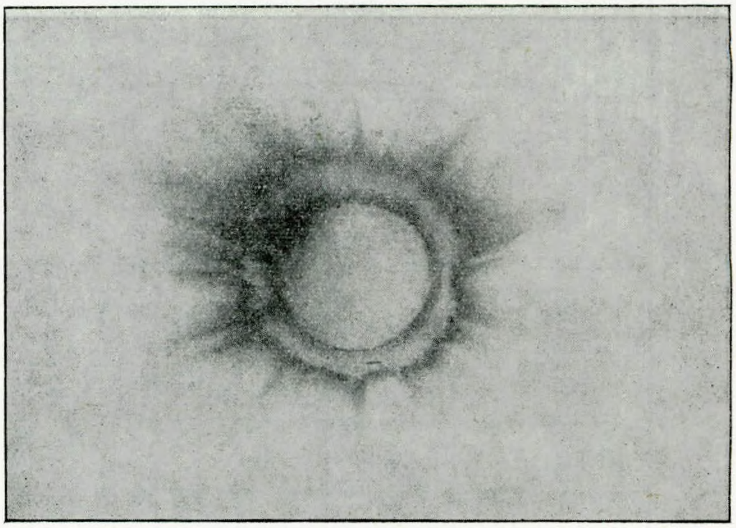
R.p.m.	120·2
Brake load	1,300lb.
B.h.p.	390
Supercharge air pressure	5½lb.
Mean indicated pressure	123·2lb.
I.h.p.	530·4
Mechanical efficiency	73·7 per cent.
Compression pressure	498lb.
Maximum cylinder pressure	701lb.
Exhaust temperature	346 deg. C.
Fuel injection pressure	10,060lb.
Fuel temperature at injection	150 deg. F.
Fuel consumed per hour	187·5lb.
Fuel consumed per b.h.p./hour	·481lb.
Fuel consumed per i.h.p./hour	·354lb.

Excepting for two stops of short duration on the fourth and fifth days to correct slight mechanical faults, the engine operated throughout this test with unfailing regularity, and so far as external observations could disclose the engine might have been operating on Diesel fuel. This applied to the colour of the exhaust gases also. As is well known, the colour of the exhaust gases is a good and ready indication of what is going on inside the cylinder, but as the appearance is affected by the state of the atmosphere at the time the observation is made, and as a Smokemeter could not be procured, the condition of the exhaust gases during this and subsequent tests was registered—crudely perhaps—by holding specially treated paper over an opening located in such a position that the exhaust gases would impinge upon the paper immediately they left the cylinder. The value of this substitute for a Smokemeter may be judged by the two exposures shown in Fig. 10, one representing an exposure of five minutes and the other of ten minutes when the engine was operating on Diesel fuel. In Fig. 11 two further smoke cards are shown, one taken when the engine was operating at full power on Diesel fuel, and the other under similar conditions when operating on 1,225 secs. boiler fuel, the exposure time in each case being the same. As will be observed, there is practically no difference in the degree of discolouration, which suggests that the combustion efficiency on heavy oil was equal to that when burning the lighter Diesel fuel.

The means provided to ensure that the smoke cards would be as truly representative as possible of the condition of the exhaust gases



Exposure: 10 min.



Exposure: 5 min.

11.30 a.m.
Afer ½-hr. in D.O.

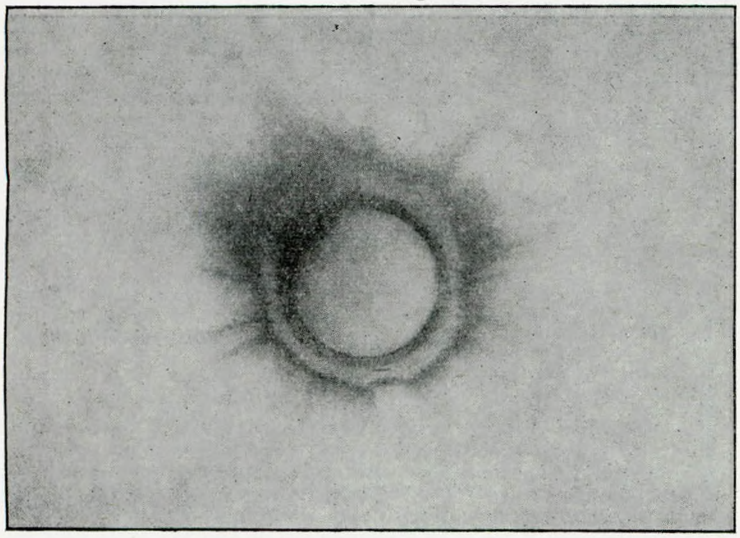
Exh. temp. ...	*350° C.*	*R.p.m.*	*120*
Fuel temp. ...	*90° F.*	*P.c. oil outlet* ...	*113° F.*
J.c.w. outlet ...	*119° F.*	*Inlet air temp....*	*119° F.*

Supercharge: 5½lb.

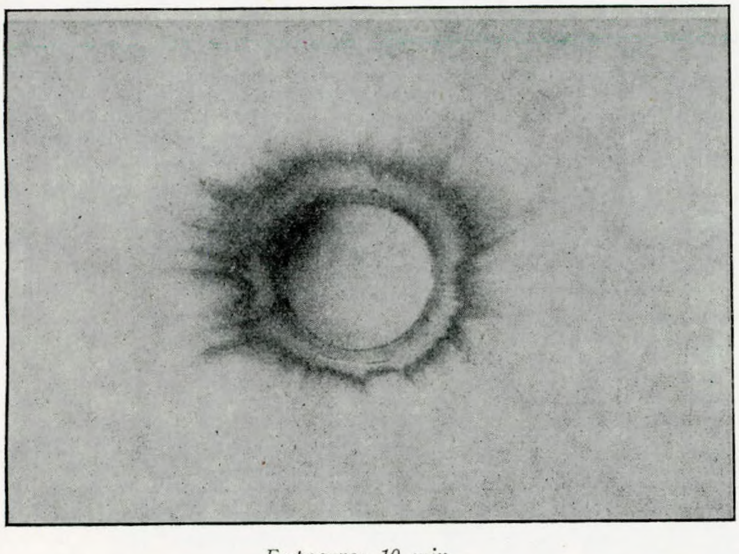
FIG. 10.—*Smoke cards showing effect of longer exposure when engine operating on Diesel fuel.*

is shown in Fig. 12. In designing this equipment the necessity for ensuring that all exposed papers were held against the opening with uniform pressure, and of a pressure that would allow a proportion of the gas to flow into the atmosphere, was duly considered, as was the necessity to ensure that the gases impinging on the paper were a portion of those released each time the exhaust valve opened. This was provided for by fitting an internal pipe, the lower end of which was shaped as shown in the illustration.

As already mentioned, this last test was run with a cylinder compression pressure of about 500lb./sq. in., and as all previous tests carried out on Diesel fuel were with a compression pressure of about 450lb./sq. in., the piston clearance was increased in order that a test at the lower compression pressure could be made on heavy fuel, and the results obtained compared with the results obtained when the engine operated under exactly similar conditions on Diesel fuel.



Exposure: 10 min.
2.2.46. *11.30 a.m.* *Diesel.*
Exh. temp. ... *350° C.* *R.p.m.* *120*
Fuel temp. ... *90° F.* *P.c. oil outlet* ... *113° F.*
J.c.w. outlet ... *119° F.* *Inlet air temp....* *119° F.*
Supercharge: 5½lb.



Exposure: 10 min.
8.45 a.m. *Boiler.*
Exh. temp. ... *358° C.* *R.p.m.* *120*
Fuel temp. ... *150° F.* *P.c. oil temp.* ... *112° F.*
J.c.w. outlet ... *117° F.* *Inlet air temp....* *117° F.*
Supercharge: 5½lb.

FIG. 11.—*Smoke cards showing discolouring matter in exhaust gases when operating on: (A) Diesel fuel, and (B) treated 1,225 sec.: fuel.*

The averages of these results are shown in Table 5.

TABLE 5.

	Diesel Fuel	Heavy Fuel
R.p.m.	119·2	119·7
Brake load, lb.	1,300	1,300
B.h.p.	387·7	388·7
M.i.p.	119·9	121·3
I.h.p.	511·8	520·6
Mechanical efficiency %	75·8	74·8
Supercharge air pressure lb./sq.in. ...	4·4	4·8
Cylinder compression pressure lb./sq.in.	438·1	450
Cylinder maximum pressure lb./sq.in....	668·7	654
Exhaust temperature °C.	344·4	354
Fuel consumption lb./b.h.p./hr. ...	0·458	0·509
Fuel consumption lb./i.h.p./hr.... ...	0·347	0·380

A typical indicator diagram taken during this test on heavy fuel is shown in Fig. 13, and in order that a direct comparison can be made a typical indicator diagram taken when operating under exactly similar conditions but on Diesel fuel is superimposed. As will be seen, there is no difference between the two diagrams if allowance is made for the usual slight errors in taking and measuring diagrams. When combining these diagrams the originals were enlarged to twice full size by photography, to ensure errors being reduced to a minimum. Of the many indicator diagrams taken during this test two selected at random, together with two typical diagrams taken when on Diesel fuel, are shown in Fig. 14. A noteworthy feature of these indicator diagrams is that when on Diesel fuel the line representing the fuel injection period was jerky, whereas the corresponding line of the heavy fuel diagrams was wavy, suggesting that with heavy fuel the ignition and subsequent pressure rise were less violent than with Diesel fuel. This was noticeable in the running of the engine, the "Diesel knock" being less pronounced when on heavy fuel.

Apart from the rather high fuel consumption, the only abnormal feature of these recent tests was the very high fuel injection pressure. The injection pressure of this particular type of engine when operating on Diesel fuel is about 6,000lb./sq. in., and although the fuel pump operating gear of the experimental engine showed no sign of weakness when injection pressures of 12,000lb./sq. in. were recorded with more viscous fuel, it was decided to try to reduce this pressure substantially without any loss in combustion efficiency. In the case of engines yet to be constructed there would be no difficulty in providing for such high injection pressures, as pressures of 10,000lb./sq. in. are not unknown, but as the main purpose of these experiments was to enable well over 100 existing motorships to operate on the cheaper fuel, there were serious objections to carrying out major and costly alterations to the fuel injection pump and operating gear, or to any other costly part.

Various fuel valve nozzles having a different number and size of spray holes were tried out with varying amounts of needle lift, as well as shapes of needle valve seat. After much patient experimenting it was found that the best results were obtained with a nozzle having eight 0·850 mm. diameter holes and a needle valve lift of 1·5 mm. Under these conditions and with the fuel strainer located at the point where the fuel entered the fuel valve body removed, the fuel injection pressure was reducd to about 7,000lb./sq. in. Removal of the strainer, the provision of which became standard practice when the airless system of fuel injection was introduced some years ago, caused about 1,000lb./sq. in. in drop in the injection pressure, and as such devices are unnecessary with specially treated fuel their removal is recommended wherever it is found that their design or size restricts the flow of fuel.

Had these experiments been undertaken with a view to finding the most suitable fuel injection system for future construction, a better combustion efficiency than that obtained with the nozzle mentioned was possible. For instance, by reducing the size of the spray holes from ·850 mm. to ·737 mm. the cylinder pressure rise upon injection of fuel was increased 15lb. and the exhaust temperature reduced 12 deg. C., so that, as will be seen by reference to Table 5, the maximum cylinder pressure and exhaust temperature became almost the same as with Diesel fuel, indicating that the combustion efficiency was the same in each case. The fuel injection pressure with this nozzle, however, was well over 10,000lb./sq. in., which was considered too high for existing fuel pump operating gear.

It will be noted that definite injection pressures are not stated, the reason being that, strange as it may seem, a practical, easily manipulated instrument for measuring such pressures of short duration, or what might be termed "punch" pressures, is not available.

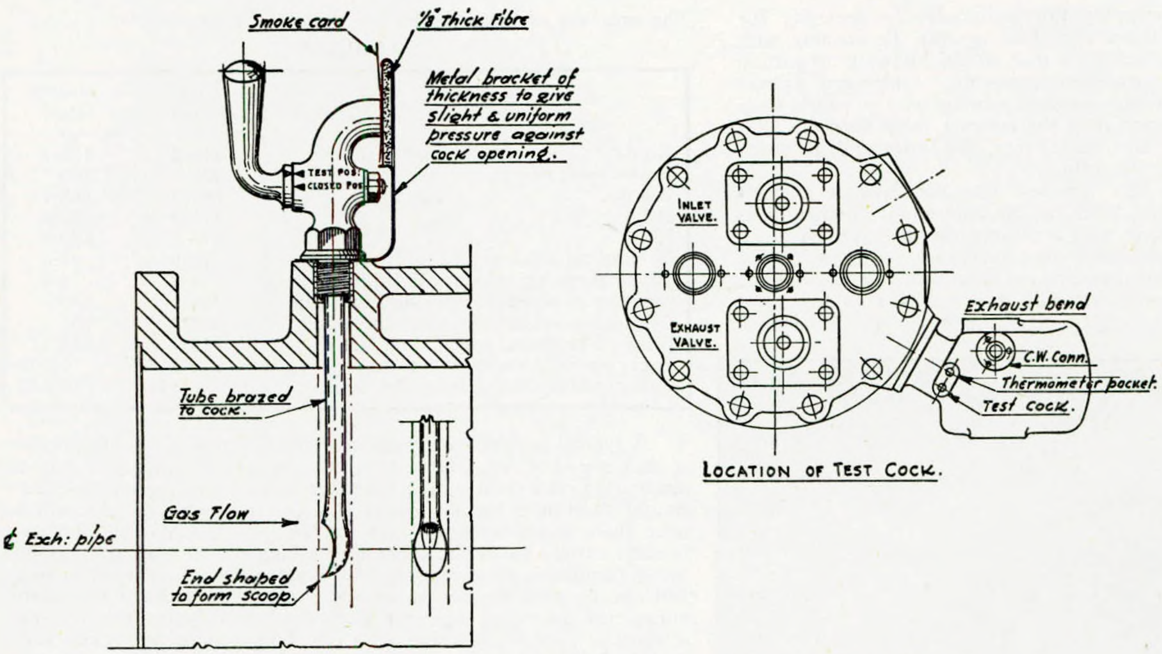


FIG. 12.—*Method of obtaining exhaust-gas smoke cards.*

Various electrical devices were obtained to check the mechanical instrument normally used during these experiments, and in the end it was possible to determine with reasonable accuracy the error in this instrument. All injection pressures given here are correct to within plus or minus 500lb./sq. in., and as it was found that 500lb. either way did not have any material effect upon the degree of atomization or penetration, and consequently the combustion efficiency, no further time was spent in obtaining more accurate recording.

One of the alterations made to the engine prior to this test was to increase the lift of the needle valve from the designed 1 mm. to 2 mm. Finally a lift of 1·5 mm. was decided upon. The lift of these valves was kept at a minimum in order to avoid damage to the faces by hammering, and whilst doubling the designed lift when operating on Diesel fuel had this effect, no such damage resulted when operating on the more viscous fuels, owing, no doubt, to the thicker film of oil left on the valve seat having a cushioning effect as the valve re-seated. The purpose of increasing the valve lift by the amount stated was to remove a slight restriction to the flow of fuel which was found to exist when the lift was 1 mm.

The possibility of gas produced from the fuel when heated to 150 deg. F. having an adverse effect upon the consistent working of the fuel injection pump was carefully investigated, and it was found that with a pressure of 25lb./sq. in. at the pump suction, the pump operated satisfactorily without the slightest variation in the quantity of fuel delivered. Subsequent tests proved that the fuel may be heated to 180 deg. F. prior to injection into the cylinder without any ill effect, and the indications are that a higher temperature still may be employed providing the pressure at the pump suction is increased a small amount.

Upon completion of the seven day test on 1,300 secs. fuel just described, the various parts of the engine likely to be adversely affected by the burning of this grade of fuel were opened up and their condition found to be as follows:—

Fuel Valve. The lower face of the fuel valve housing was thinly covered with a substance which was rough to touch but otherwise would have passed unnoticed. All nozzle spray holes were perfectly clear and the tip free from deposit, but soft carbon had accumulated and filled the annular space between the nozzle and the valve housing, indicated by "A" in Fig. 4. The quantities of deposit were much too small to be analysed, but whilst that removed from the lower face of the valve housing was hard and gritty, that found in the annular space between the nozzle and the housing was soft and easily powdered between the fingers. No importance was attached to the first mentioned deposit as its appearance suggested that it would not build up, and, moreover, similar deposit was found after running on Diesel fuel. The soft deposit, however, appeared to be carbonized lubricating oil, and if accumulation continued it would eventually interfere with the fuel sprays. How lubricating oil could reach this annular space is difficult to explain, but subsequent tests proved that by machining the lower end of the hole in the housing as indicated at "B" in Fig. 4, accumulation of deposit at this point was prevented.

Piston and Cylinder head. The upper surface of the piston head and the underside of the cylinder cover were free from deposit and smooth to the fingers. All piston rings were a free fit in their grooves without showing any signs of wear in a vertical direction. The wear in a radial direction was greater than expected, but perhaps not excessive considering the length of time the engine had been operating and the severe conditions to which the piston rings, as well as other parts, had on occasions been subjected. The cylinder liner wear, however, was surprisingly low. Actual wear rates of such parts in service will be given later.

Exhaust valve. The exhaust valve body was so free from deposit that a clean hand rubbed over any part of it was only very slightly soiled. The ground mitre faces of the lid and seat were in perfect order, the only deposit found on any part of the valve being a small amount on the underside of the seat, the nature and extent of which was similar to that found on the lower end of the fuel valve housing.

During previous tests when scaly matter accumulated on the mitre faces of the exhause valve lid and seat, with tests with varying width of seats were made and it was found that the wide seat, i.e. $\frac{3}{16}$in. on an 8in. dia. valve gave the best results. If the combustion of fuel is such that solid matter is deposited on the mitre faces, a narrow seat does not extend the life of the valve, but if combustion is such that no solid matter is deposited, the wide seat delays the time of routine overhaul.

All parts in use during this seven day full power trial on 1,300 secs. fuel, such as exhaust valve lid and seat, fuel valve nozzle, cylinder liner, piston rings, etc., were of standard Werkspoor material and design. The results obtained during the preceding tests were so satisfactory that it was not considered necessary to try out the parts of special design and material which had been prepared, and the results obtained during the final test justified this course.

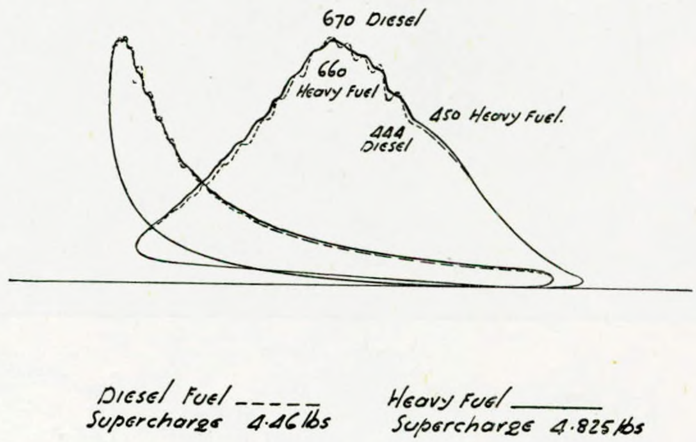


FIG. 13.—*Heavy fuel and Diesel fuel. Indicator diagrams taken when operating under similar conditions.*

This concluded the first stage of the experiments. Sufficient information had been obtained to justify fitting the necessary equipment in a ship which was then under construction, and burning fuels with a maximum viscosity of 1,500 secs. Redwood I at 100 deg. F. As the investigation had proceeded without interruption for more than a year, it will be appreciated that much detail work done has been omitted from this paper. To describe all the tests and how the numerous difficulties encountered were overcome would take considerably more time than is permitted in the presentation of this paper. Starting and slow-running tests for instance, were carried out, and whilst much valuable information was obtained and recorded it was felt that conclusive evidence regarding such operations could only be obtained under normal sea conditions.

The ship selected for the second stage of this interesting experiment was the 12,250 tons deadweight 12 knot single screw tanker "Auricula". The principal particulars of the airless injection supercharged four-cycle Hawthorn/Werkspoor main engine installed in this ship are:—

Number of cylinders	8
Dia. of Cylinders, mm. ...	650
Stroke of pistons, mm. ...	1,400
R.p.m. rated	115
I.h.p. rated	4,000
Cylinder compression pressure lb./sq. in.	490
Cylinder maximum pressure lb./sq. in.	610
Supercharge air pressure lb./sq. in.	5·5

Other information regarding this engine which has a bearing on the experiments is that the cylinders, pistons, exhaust valves and fuel valves are cooled by fresh water, and that the fuel system incorporates a surcharge pump which draws the fuel from the daily service tank and discharges it at a pressure of about 25lb./sq. in. to the main engine h.p. fuel pump suctions.

The engine is of standard design and was constructed to operate on Diesel fuel. A large number of these engines have been and are being installed in exactly similar ships, and the practice is to run the engines in service at 112/113 r.p.m., which corresponds to a power output of 3,700 i.h.p. During fitting-out the fuel purifying plant was installed, and the fuel system modified to permit the engine being started up on Diesel fuel and changed over to heavy fuel without varying the speed after the engine cylinders and pistons had attained normal working temperatures. A pictorial view of the purifying plant and the fuel system is shown in Fig. 15, which it will be assumed is sufficiently clear to be self-explanatory.

The "Auricula" underwent sea trials on the 12th, 13th and 14th of August, 1946, and began the maiden voyage to Curaçao, Dutch West Indies, three days later. The first day of the sea trials was occupied in tuning-up on Diesel fuel,

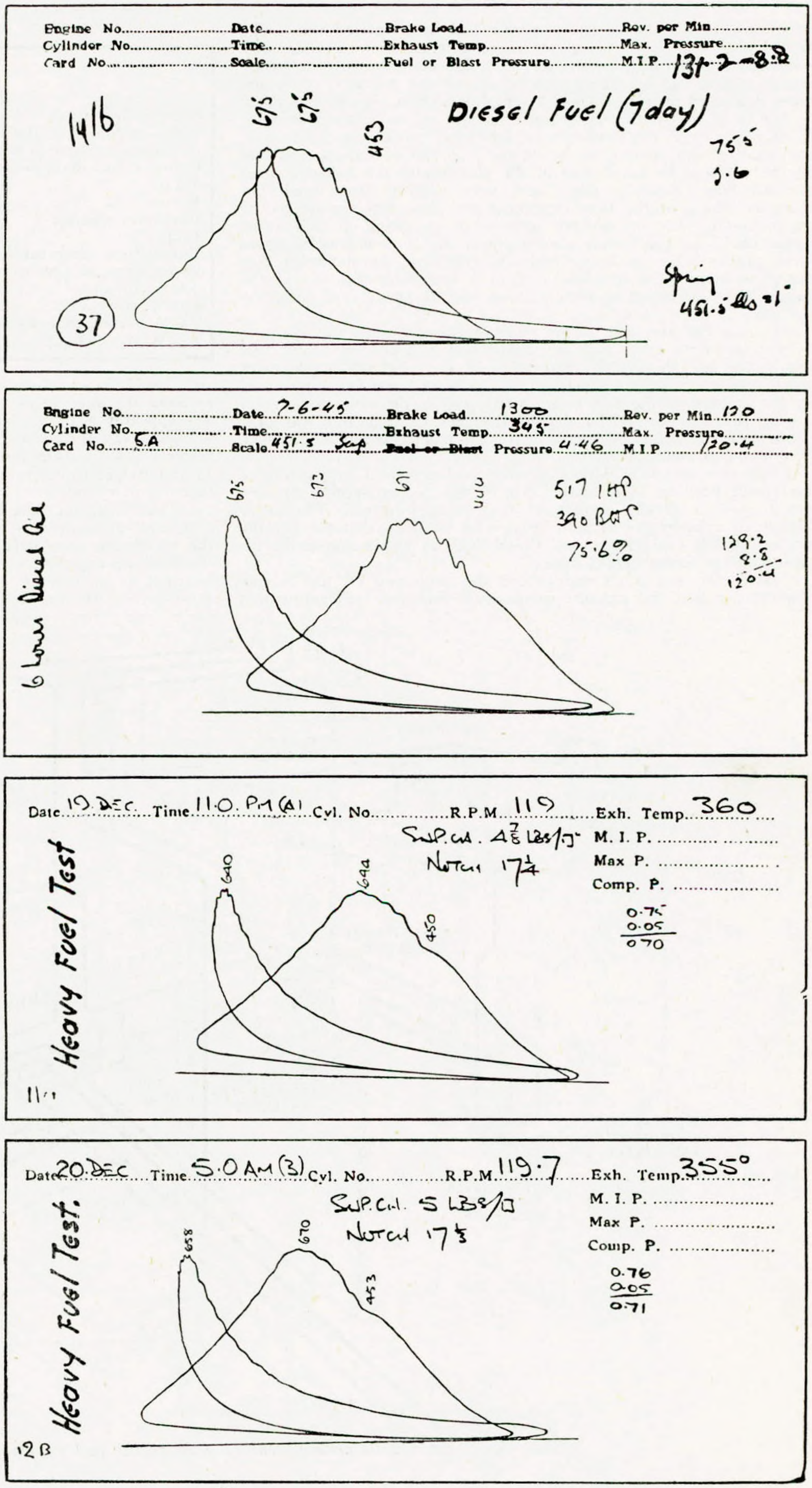


FIG. 14.—*Indicator diagrams taken when operating on Diesel fuel and when operating under similar conditions but on 1,300 sec. fuel.*

which was necessary as no shop test had been carried out. The second day was spent trying out the engine on fuel of 1,225 secs. Redwood I at 100 deg. F., and the third day was devoted to a 6 hour demonstration run before representatives of the technical press and other interested people. The photograph shown in Fig. 16 was taken on the third day of the sea trials when the engine was operating at 4,200 i.h.p., or 5 per cent. above the rated power, on 1,225 secs. fuel purified and injected as during the final test of the experimental engine. It will be noted that in the photograph the exhaust gases are invisible. Actually they were very slightly discoloured, but many on board at the time expressed the view that the degree of discolouration was no greater than when operating at full rated power on Diesel fuel, while some were of the opinion that the gases were clearer when on heavy fuel. In any case, the statement that the gases were quite invisible at 2 to 3 feet above the top of the funnel when operating on either Diesel fuel or heavy fuel cannot be disputed.

During the first and second days of the sea trials the averages of two six hour tests, one on Diesel fuel and one on heavy fuel are shown in Table 6. No alteration of any kind was made after the first test, the power developed on the second test being governed by the position of the fuel lever, which was in the same position as during the first test. The ship at the time of each test was only about half loaded, which accounts for the comparatively high r.p.m. in relation to power developed.

The greater power developed when on heavy fuel with unaltered fuel lever position is accounted for by the higher specific gravity, resulting in a greater weight of fuel being injected. The lower maximum cylinder pressure on heavy fuel indicates that the burning process is less rapid than with Diesel fuel, as was found to be the case with the experimental engine.

After the sea trials and before the beginning of the maiden voyage, two fuel and exhaust valves were removed for examination and found in excellent condition except for a little soft deposit between the fuel valve nozzle and the housing. The deposit had the appearance of carbonized lubricating oil, and after this was scraped away the valves were re-fitted as taken out. The cylinder lubricating oil consumption during the sea trials had averaged nearly 1½ gallons per cylinder per 24 hours, or twice the usual amount for this size of cylinder.

The "Auricula" left the Tyne for Curaçao on the 17th August, 1946, and in accordance with the practice followed for Diesel fuel the speed was gradually increased from 100 to 113 r.p.m. during the first two days, but in order to avoid any suggestion of "nursing", instructions to increase the speed were given and at the end of the third day out the following information was sent from the ship :—

TABLE 6.

	Diesel Fuel	Heavy Fuel
Specific Gravity of fuel at 60°F. ...	0·86	0·95
Viscosity Red. I at 100°F.	43 secs.	1,225 secs.
Cylinder compression pressure ...	531lb.	532lb.
Cylinder maximum pressure	633lb.	605lb.
M.i.p.	109·7lb.	115·5lb.
R.p.m.	120	122
Fuel lever position	14	14
I.h.p.	3,770	3,900
Exhaust gas temperature	309°C.	318°C.
Supercharge air pressure	5·4lb.	5·4lb.
J.C.W. pressure	19lb.	20lb.
P.C.W. pressure	22lb.	22lb.
J.C.W. outlet temperature	130°F.	130°F.
P.C.W. outlet temperature	119°F.	119°F.

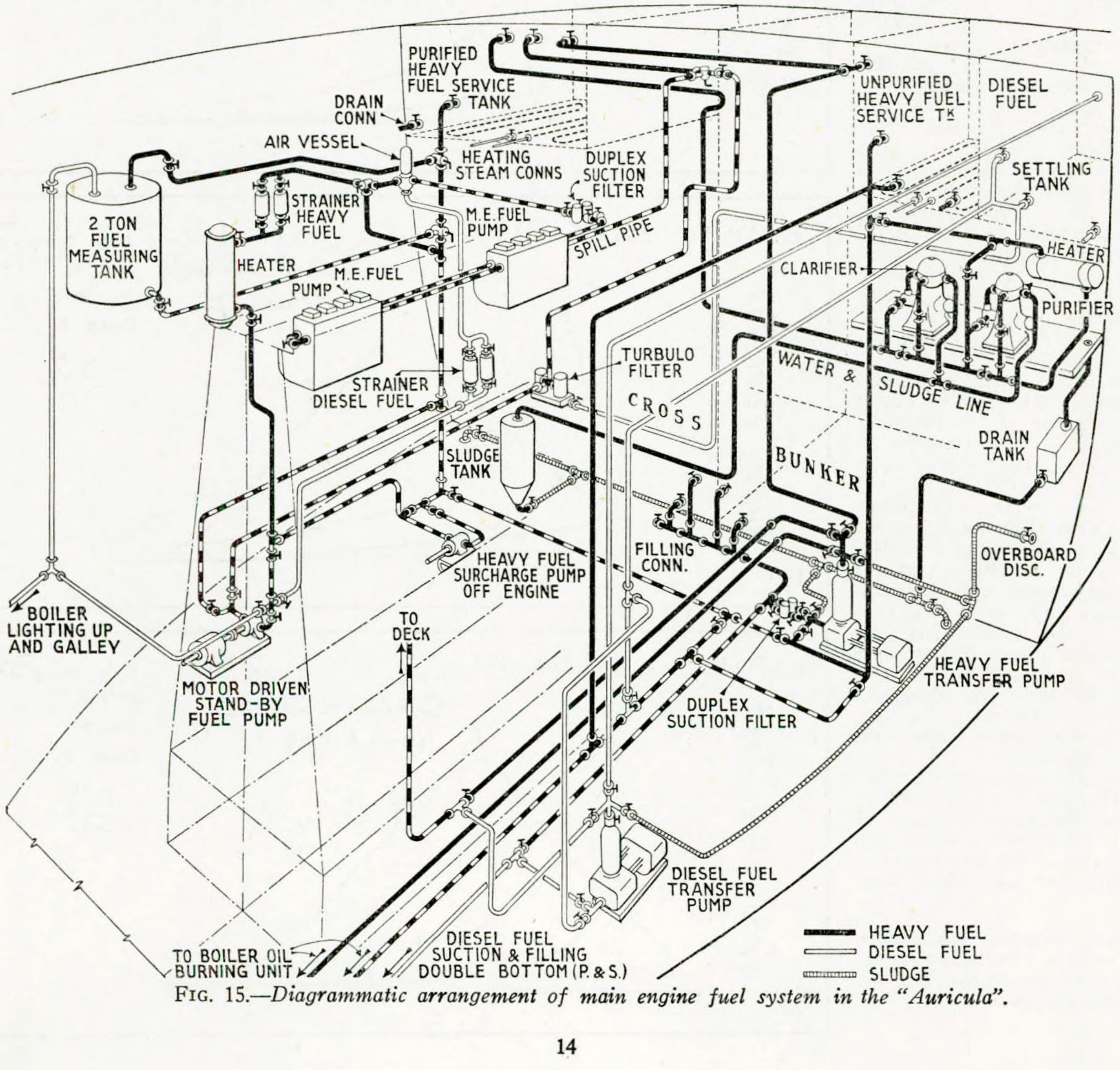


FIG. 15.—*Diagrammatic arrangement of main engine fuel system in the "Auricula".*

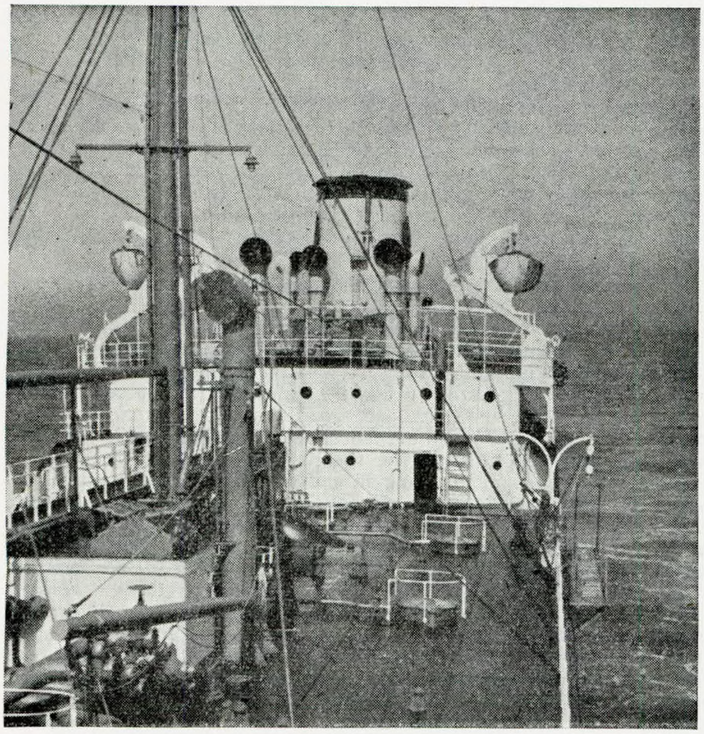


FIG. 16.—*Photograph taken on the "Auricula" when engines developing 5 per cent. over full rated power on 1,225 sec. fuel.*

Hours engine operating	24
Hours fuel purifying plant working ...	7
Average r.p.m.	117·4
Average maximum cylinder pressure ...	610lb.
Average exhaust gas temperature... ...	310 deg. C.
Colour of exhaust gases	Clear
Position of fuel lever	15
Supercharge air pressure	5·4lb.
Average fuel injection pressure	7,500lb.

The telegram giving the above information concluded with:—"No difficulty experienced in burning heavy fuel, boilers on exhaust gases, not yet possible obtain reliable soundings of fuel tanks owing to ship rolling, average speed ship 12·52 knots". The temperature of the exhaust gases is low in relation to the power developed and the temperatures recorded during the sea trials, so that the figure given in the above telegram is in doubt.

The first voyage across the Atlantic was accomplished without incident, the average speed being 12·77 knots, which included 30 hours at varying revolutions owing to fog. On this voyage the fuel injection pressures of Nos. 1 and 8 cylinders only could be checked, and these were higher than expected or desired. Particulars of the fuel used on this occasion are shown in Table 7.

Upon arrival at Curaçao the Chief Engineer reported as follows:—"The engineers are to-day removing all fuel and exhaust valves except No. 7, in accordance with your instructions, and we have already examined the nozzles of the fuel valves and all supercharge pump casings situated under the working cylinders. The condition of the fuel valve nozzles is the same as the two examined after the sea trials, a little carbon in the recess around the nozzle but no deposit round the spray holes. The internal condition of the supercharge casings looks as if the motor had been running on a very good quality Diesel oil and the same can be said of the cylinder liners and piston crowns which have been examined as far as possible. The exhaust valves appear to be in perfect condition but we have not yet had an opportunity to examine the mitre faces of the valves and seatings as this will hold up the work of changing the valves. We will keep all valves in the condition as removed for inspection in the U.K. in accordance with instructions". As anticipated, the exhaust valves were found in perfect condition when examined upon the vessel's arrival home. As regards No. 7 cylinder head valves, it was the intention not to disturb these valves so long as they functioned properly.

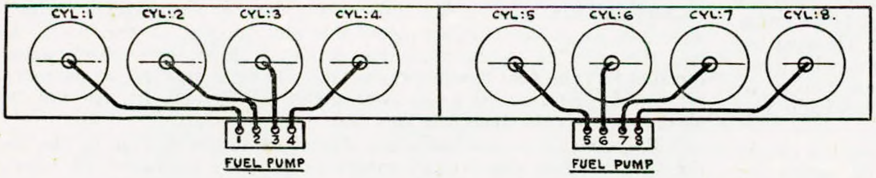
The bunkers shipped at Curaçao for the return voyage had the characteristics shown in Table 7. The only stipulation made was that the viscosity should not exceed 1,500 secs. Redwood I at 100 deg. F.

During the first six days of the homeward voyage the engine operated as on the outward voyage, the daily averages for this period being as follows:—

Hours engine operating	24
Hours fuel purifying plant working ...	14
R.p.m.	118·2
Fuel injection pressure average	8,300lb.
Maximum cylinder pressure average ...	650lb.
Exhaust gas temperature average ...	338 deg. C.
Colour of exhaust gases	Clear
Position of fuel lever	15
Supercharge air pressure	5·7lb.
Speed of ship	12·5 knots

Due note was taken of the increase in the fuel injection pressure since leaving Curaçao but as the experimental engine had been tested to 12,000lb./sq. in. no mechanical difficulties were anticipated. The viscosity of the fuel in use was practically the same as that used during the outward voyage, as will be seen from Table 7, and the fuel was being injected at the same temperature, i.e. 150 deg. F. On the sixth day, however, trouble began to be experienced with pipe connections and other minor parts of the fuel injection system, and it was deemed advisable to change over to Diesel fuel. The only clue to the cause of this increase in injection pressure was that the increase dated from leaving Curaçao. The conclusion reached was, therefore, that there were slight differences between the fuel valves in use on the outward voyage and those fitted at Curaçao, and instructions to refit the original valves were despatched. The effect of this was to reduce the injection pressures to those prevailing on the outward voyage, and the homeward run was continued on heavy fuel but at reduced power as a precaution. As it was apparent that certain parts of the fuel injection system had been unduly strained, it was decided to have new parts of slightly modified form made, and as the new parts could not be made during the time the cargo was being discharged, the ship made the second voyage without incident on Diesel fuel.

During the second voyage of the "Auricula" tests were carried out on the experimental engine at St. Peter's with a view to reducing the fuel injection pressure to the lowest possible without sacrificing combustion efficiency, and it was found that if the size of spray holes in the nozzle, the lift of the needle valve and other factors found necessary and already mentioned, were strictly adhered to, and if the temperature of the fuel at the h.p. pump suctions was raised



FUEL PUMP	Nº1	Nº2	Nº3	Nº4	Nº5	Nº6	Nº7	Nº8
LENGTH PIPE, FT.	11	7·5	5·5	7	7	5·5	7·5	11
PRESSURES LBS/SQ"	6200	5600	5400	5900	5900	5400	5700	6100

FIG. 17.—*Diagram showing effect upon fuel injection pressures of varying lengths of pipe connecting the fuel pumps and fuel valves.*

TABLE 7.

	Outward	Homeward
Specific Gravity at 60°F.	·954	·973
Viscosity Redwood I at 100°F. ...	1,223	1,220
Flash Point Closed °F.	160	185
Carbon Residue Conradson % weight	9·35	8·7
Sulphur ... ... ,, ,,	2·00	2·45
Asphaltenes ... ... ,, ,,	4·70	—
Ash ... ... ,, ,,	0·07	0·04
Sediment by extraction... ,, ,,	0·02	0·06
Water ... ... % volume	0·50	0·25

to 175 deg. F., the desired results could be obtained with an injection pressure of about 6,000lb./sq. in., which is almost equal to the pressure produced when using Diesel fuel. During the first voyage of the "Auricula" the temperature of the fuel at the h.p. pump suction was 150 deg. F. and the result of these tests indicated that the temperature could with advantage be raised to 175 deg. F., which was the temperature employed during subsequent voyages.

Subsequent tests carried out on the "Auricula" revealed that the length of pipe between the fuel pump and the fuel valve had a surprisingly great effect upon the injection pressure, the increase in the injection pressure being shown in Fig. 17. The pressures shown are the averages of readings taken daily over a period of three months, and although the pressure indicator used was correct only to within plus or minus 500 lb., the ratios between the various cylinders are undoubtedly correct.

Whilst investigating this matter tests were carried out to ascertain the effect of varying the temperature, and consequently the viscosity of the fuel at the moment of injection. The speed of the engine was kept constant at 116 r.p.m. by altering the position of the fuel lever, and the effect upon the fuel injection pressure was as follows:—

R.p.m.	*Fuel temperature* deg. F.	*Injection pressure* lb.	*Viscosity* secs.
116	155	6,570	260
116	165	6,400	205
116	175	6,250	165
106	175	6,020	165
60	175	4,260	165

The fuel in use on this occasion had a viscosity of 1,500 secs. Red. I at 100 deg. F. At a temperature of 175 deg. F. the viscosity of this grade of fuel is actually less than Diesel fuel at 60 deg. F., so that with all unusual restrictions removed the pressures with heavy fuel at 175 deg. F. should be about the same as with unheated Diesel fuel. This comparison is made with Diesel fuel having a viscosity of 60 secs. Red. I at 100 deg. F.

When examining every possible source of restriction to free flow it was found that some of the fuel valve springs were not quite straight and were bearing sufficiently hard on the housings to cause wear. This fault would not only increase the injection pressure unnecessarily, but might have an adverse affect upon the prompt reseating of the fuel valves. Sluggish closing of the valves on the "Auricula" was not in evidence, but all such faults are highly undesirable, especially if the injection pressure is not to be unduly high.

When the "Auricula" arrived home at the end of the second round voyage all new parts previously put in hand had been prepared and were fitted. These alterations were of a minor character and comprised the fitting of new pipes connecting the h.p. fuel pumps and fuel valves, each of the new pipes being provided with a pressure indicator connection, instead of Nos. 1 and 8 only as previously, fitting larger bore drain pipes from the drip trays under the fuel pumps, found necessary owing to the higher viscosity of the heavy fuel, checking the lift of all fuel valve needles and adjusting to 1·5 mm. where found necessary, and fitting new covers of modified construction to the h.p. fuel pumps. Better provision was also made for cleaning the purifier and clarifier bowls.

The "Auricula" began the outward leg of No. 3 voyage on the 21st November, 1946, burning heavy fuel having the properties shown in Table 8.

TABLE 8.

	Outward	Homeward
Specific Gravity at 60°F.	·963	·975
Viscosity Red. I at 100°F. secs. ...	1,204	1,472
Flash Point Closed °F.	212	176
Carbon Residue Conradson % weight	8·8	10·8
Sulphur Content ... ,, ,,	2·49	2·59
Ash ... ... ,, ,,	0·03	0·05
Sediment by extraction... ,, ,,	0·03	0·05
Water ... ... % volume	0·05	0·02

During the first half of this voyage across the Atlantic exceptionally heavy weather was encountered, the average propeller slip for the first seven days being over 24 per cent., and although the r.p.m. varied between 70 and 130 because of the pitching motion of the ship, the engine operated as it would have done on Diesel fuel. During the second half of the voyage much fog, necessitating periods of slow running, was encountered, and on these occasions the engine was operated on Diesel fuel, as so far the opportunity to carry out the full pre-arranged slow running tests had not presented itself. The voyage took 449 hours, during 405 of which the engine operated on heavy fuel and the remaining 44 on Diesel fuel.

In view of the severe operating conditions to which the engines had been subjected, a number of fuel and exhaust valves were removed for examination upon the vessel's arrival at Curaçao. The valves in Nos. 6 and 8 cylinders were selected, for no other reason than that they were the most convenient to remove. The fuel valves were found in excellent condition, there being no sign of deposit on the nozzles, while the spray holes were perfectly clear. The exhaust valves were also in clean condition, the mitre faces of the lids and seats being quite free from scale or pitting. All valves were refitted as taken out.

The slow running tests which it was hoped to carry out on this voyage consisted of operating the engine for definite periods at various speeds on heavy fuel, the results to decide if it would be necessary to introduce a closed circulating arrangement in the fuel injection system in order to ensure that the temperature of the fuel at the moment of injection would be maintained at the temperature which had been found to give such good results at normal sea speed, namely 175 deg. F. In any event it was thought that such provision would be necessary to keep the fuel in the system at the required temperature whilst manœuvring in and out of port, and particularly when the engine would be at rest for lengthy periods. Although the bad weather prevented these full scale tests on this voyage, during a short spell of favourable weather it was possible to operate the engine for a period of eight hours at 60 r.p.m., or 19 per cent. of full power. At this speed the engines operated as though working on Diesel fuel, all temperatures and pressures being normal for such conditions of load and the appearance of the exhaust gases unchanged. The only unusual feature noticeable on the indicator diagrams was the beginning of fuel injection, which was later than would have been the case with Diesel fuel in use. During this test the cylinder jacket, piston and fuel valve cooling water outlets were maintained at 130 deg. F. by reducing the quantity of water circulated, and the fuel at the h.p. fuel pump suction was maintained at 175 deg. F.

At the end of this eight hour test the engine was stopped whilst working on heavy fuel, Nos. 1 and 3 fuel valves removed for examination, spare valves fitted and the engine re-started on heavy fuel. A fair amount of deposit was found on the nozzles of these valves, and it was apparent that owing to the smaller quantity of fuel being used in a given time, and consequently the longer time the fuel remained in the pipes after leaving the heater, there was an appreciable drop in temperature and that this had an adverse effect upon combustion: so much so that the conclusion reached was that twenty-four hours operation under such conditions would result in the fuel sprays being effected by accumulation of deposit.

Apart from the loss of heat due to the comparatively slow movement of the fuel at such slow speeds, which might, of course, be partially counteracted by effectively lagging the pipes between the heater and fuel valves, the injection pressure was reduced, which also had an adverse effect upon the atomization of the fuel. It was not possible to ascertain the actual drop in temperature after the fuel left the fuel pump suctions, but the drop in injection pressure from 116 r.p.m. to 60 r.p.m. was about 2,000lb./sq. in., as will be observed from the test just described.

The conclusion reached after this short test was that to obviate the formation of deposit and ensure satisfactory operation on heavy fuel at slow speeds, steps should be taken to maintain the temperature of the fuel at the normal working temperature, i.e. 175 deg. F., and as far as possible to avoid the injection pressure falling as the speed of the engine is reduced. Before taking action, however, it was decided to carry out more extended tests, and the results obtained and the steps found necessary will be referred to later in this paper.

Upon arrival at Curaçoa Nos. 6 and 8 fuel valves were removed for examination. These valves had been in use throughout the voyage and it was interesting to observe that unlike the valves removed at sea after the eight hours slow running test, the nozzles were quite free of deposit. It is reasonable to assume that these two valves were in much the same condition as regards deposit as Nos. 1 and 3 after the eight hours slow running period. If this assumption is correct then this test proved two things, the first being that combustion of the purified fuel was so good at full power that there was no tendency for the deposit to accumulate, and secondly, that the effect of working up to full speed immediately afterwards was to burn off the deposit which had accumulated during the slow running period. The practice at that time of changing over to Diesel fuel for manœuvring into port and the possibility of this grade of fuel being responsible for burning off the deposit was not overlooked.

The photographs reproduced in Fig. 18, of the four fuel valves referred to, clearly illustrate this. Nos. 1 and 3 valves had been

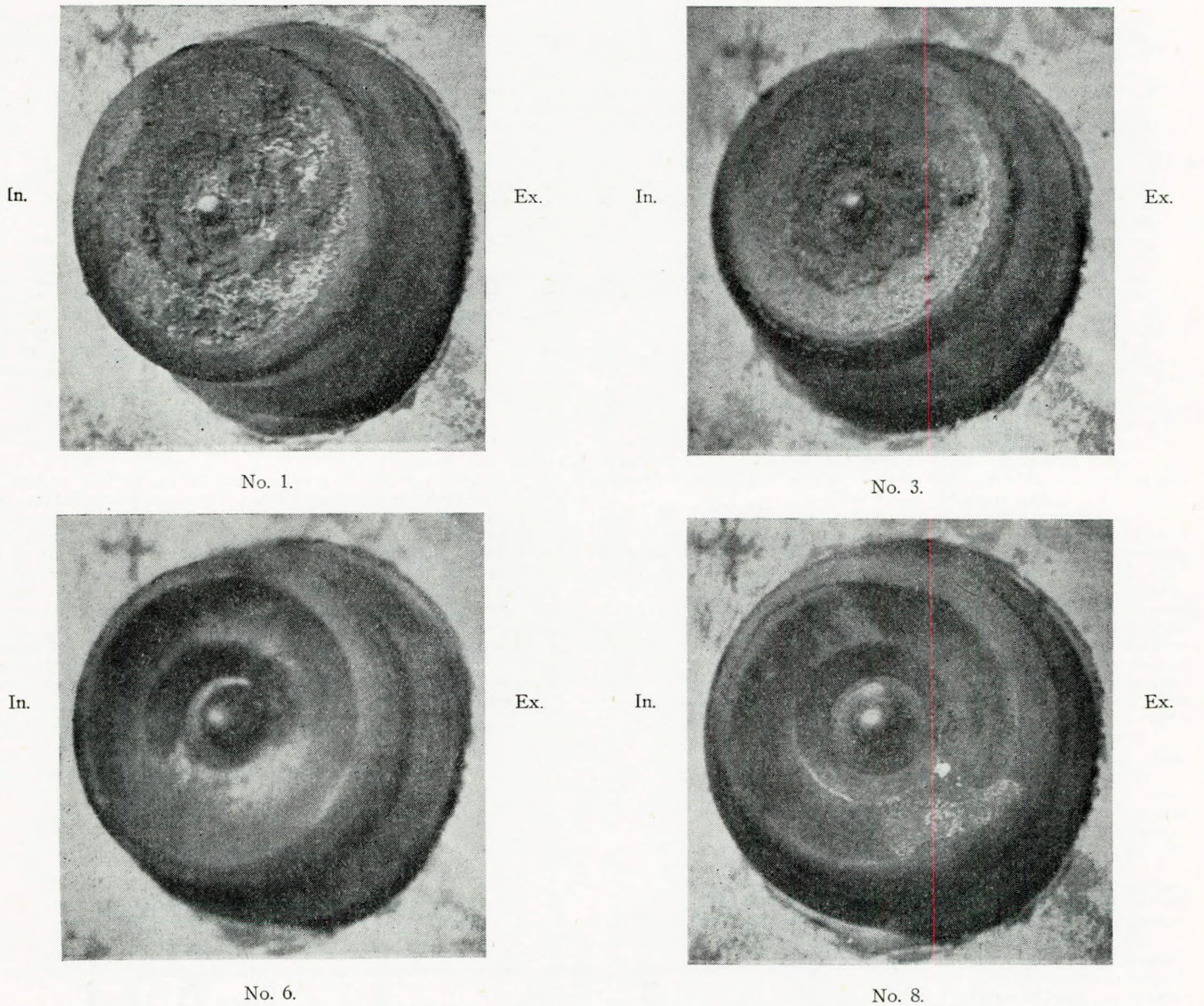


FIG. 18.—*Condition of fuel valve nozzles after slow running test. Nos. 1 and 3 removed immediately after test. Nos. 6 and 8 removed after further period at full power.*

in use a total of 181 hours on heavy fuel, the last eight hours being at slow speed, while Nos. 6 and 8 valves operated for a total of 405 hours, the first 173 hours being on heavy fuel at full power, the next 8 hours on heavy fuel at slow speed, then 123 hours at full power on heavy fuel, and finally one hour on Diesel fuel. During the last hour the engine was being manœuvred. The Diesel fuel might be given the credit for burning off the deposit, but it is not unlikely that the deposit had disappeared completely before the engine was changed over to Diesel fuel, in which case not only is the combustion of specially treated heavy fuel so good at full power that there is no tendency for deposit to accumulate, but the fuel burns so close to the nozzle that any deposit present is burnt off. Accumulation of deposit at any speed is, of course, highly undesirable, so that whilst this interesting point is mentioned, it was realised that before it could be said that the Diesel engine was capable of burning heavy fuel satisfactorily accumulation of deposit in any shape or form must be prevented.

Another interesting feature revealed by the photographs shown in Fig. 18 is that the accumulation of deposit is greatest at the exhaust valve side, as was found to be the case in the experimental engine. No. 3 was in similar condition to No. 1 when removed but some of the deposit was broken off in handling. This is indicated by the small piece still remaining in the direction of the exhaust valve.

The air inlet and exhaust valves removed for examination on this occasion were found in good order and were refitted as taken out. As far as could be seen the piston top and the underside of the cylinder heads were quite free of deposit, while the cylinder liners were reported to be evenly coated with a thin film of lubricating oil. The average consumption of lubricating oil for the last voyage was $\frac{3}{4}$ gallon per cylinder per day.

Whilst the unfavourable weather encountered up to this time had prevented the prescribed slow speed tests from being carried out, it was encouraging to find that so far as full power operation was concerned, the results obtained in service were what the author had been led to expect by the results obtained with the experimental engine.

Reviewing the results so far obtained the position was:—

1. It had been conclusively proved that with practically no alteration a standard four-cycle Diesel engine would operate indefinitely under normal sea conditions on boiler fuel up to 1,500 seconds if treated in the manner described.
2. That the conditions set up by heavy weather, involving constant and wide variation in engine speed, had no detrimental effect upon any part of the engine when operating on heavy fuel.
3. The engine would start satisfactorily on heavy fuel providing the inoperative period prior to starting did not exceed 3 to 4 minutes.
4. Continuous slow running periods were limited to about 12 hours but if provision were made to maintain the temperature right

up to the fuel valve, slow running could probably be accomplished as well on heavy fuel as on Diesel fuel. In addition it might be necessary to take steps to maintain the fuel injection pressure constant.

5. The nature of the deposit formed on the fuel valves by running the engine on improperly heated and atomized heavy fuel is such that full speed conditions on heavy fuel, or reduced speed conditions on Diesel fuel, would burn off the deposit.
6. No reliable check on the fuel consumption had been possible owing to unfavourable weather and to the service tanks in the "Auricula" not being suitable for obtaining accurate measurements under such conditions. The results obtained, however, such as the colourless exhaust gases, the almost normal exhaust temperatures, the absence of unburnt fuel in the cylinders, the shape of the indicator diagram, etc., indicated that the fuel expenditure per unit power developed would be little, if any, different from what it would be when operating on Diesel fuel.
7. The effect of a supercharge air pressure of less than 5lb./sq. in. had yet to be ascertained.

The homeward journey of No. 3 voyage was accomplished without incident, the engine operating perfectly in spite of the very unfavourable weather. The specification of the fuel used on this occasion is shown in Table 8, from which it will be seen that the viscosity and Conradson value are appreciably greater than those of the previous bunkers lifted. The only apparent effect upon the engine was an increase of about 700lb./sq. in. in the fuel injection pressure owing to the higher viscosity of the fuel.

Although the elements had been far from helpful, much useful information had been gained and arrangements were made to have new parts ready so that certain alterations could be carried out when the ship returned. For instance, it was decided that to obtain accurate fuel consumption figures a special measuring tank would have to be installed, and that for slow running and manœuvring on heavy fuel provision must be made to keep the fuel at the required temperature after it left the heater. The indications were that the desired results might be obtained merely by circulating hot water through the cooling jackets of the fuel valves and lagging the pipes, and it was decided to try out this simple remedy before carrying out more extensive alterations.

Alterations were made to the supercharge air system also with the object of enabling the engine to operate on supercharge air pressure varying between 2½ and 5½lb./sq. in. without restricting the flow of air to the supercharge air pump cylinders.

Whilst the ship was discharging cargo the alterations mentioned were carried out, some being of a temporary nature in order to avoid expense and delay. For instance, experience suggested that the fuel valve cooling system should be entirely separate instead of being connected to the piston cooling system as in this case, in order to reduce the time required to preheat the water and to enable the temperature of the cooling water to the fuel valves to be raised to a temperature higher than that advisable for the pistons. Instead of separating the systems, the arrangement provided only for heating the whole of the piston cooling water by steam injection.

When all work had been completed and the ship adequately moored, the steam jets raised the temperature of the cylinder jacket cooling water to 120 deg. F. in six hours and the combined piston and fuel valve cooling water to the same temperature in three hours, the initial temperature of the water in each case being 60 deg. F. The heavy fuel in the service tank was raised to a temperature of 160 deg. F., and circulated through the new heater which had been installed between the service tank and the engine, until the temperature at the main engine fuel pump suction was 180 deg. F. Circulating in this way is possible in the Werkspoor engine, as in most others, by spilling to the service tank. After the fuel valves had been primed with fuel the engine was ready to begin the starting and slow running tests it had been decided to carry out before sending the ship on the next voyage.

Although the temperature of the engine room was not more than 65 deg. F., the engine started up and began working regularly on heavy fuel with the expenditure of no more starting air than would have been required with Diesel fuel. To approximate service conditions as nearly as possible, and to obtain the data required, the speed of the engine was not allowed to exceed 55 r.p.m., and this speed was maintained for 30 minutes during which time every cylinder "fired" with the utmost regularity, and to all outward appearances would have continued doing so indefinitely. The temperature of the fuel at the engine fuel pumps was 175 deg. F. throughout this test, and the estimated drop in temperature before reaching Nos. 1, 4, 5 and 8 fuel valves, which are situated furthest from the fuel pumps, was 10 deg. F.

At the end of this 30 minutes test the engine was stopped and allowed to remain at rest for 1½ hours, during which period the outlet temperature of the cylinder jacket, piston and fuel valve cooling water was maintained at 120 deg. F. by continued circulation. The fuel between the service tank and the engine fuel pumps was also maintained at the working temperature by continued circulation. Without any further priming of the fuel valves the engine was put slow ahead, which manœuvre was accomplished with the utmost promptitude, and during the next 24 minutes the engine was started in alternate directions no less than 64 times, or nearly 2·7 starts a minute. The pressure in the starting air tank at the beginning of this test was 350lb., and 135lb./sq. in. at the end. The lower starting air pressure just set the crankshaft revolving, but although the

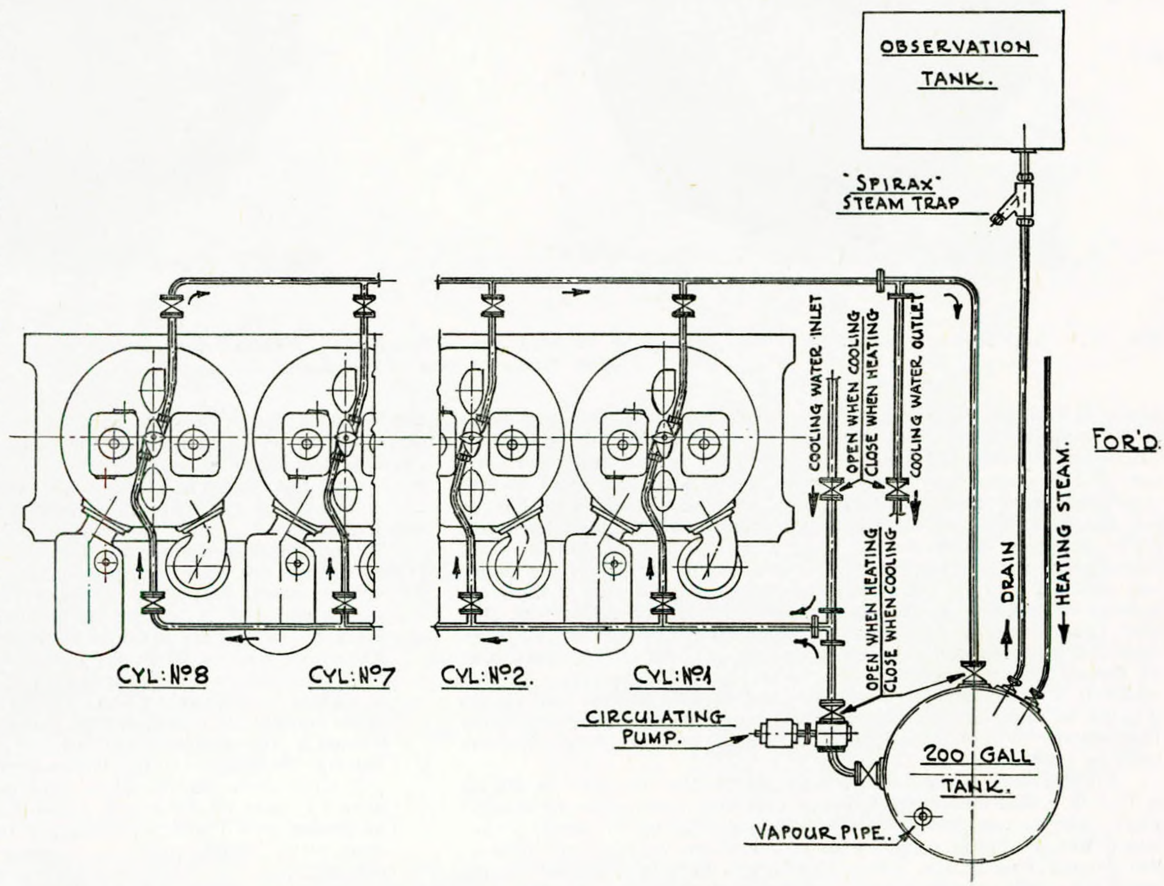


FIG. 19.—*Diagrammatic arrangement for circulating hot water through fuel valves while manœuvring.*

crankshaft moved very slowly the engine "fired" before one revolution had been completed.

No provision was made to register accurately the temperature of the fuel as it entered the fuel valves, but the estimated temperature on first starting after 1½ hours at rest was 100 deg. F. This low temperature and correspondingly high viscosity was evident from the heavier pumping action, which occurred until the engine had made about 20 revolutions and the hot fuel filled the fuel valves and the pipes connecting them to the fuel pumps. The reason for this relatively great drop in temperature will be understood when it is remembered that the temperature of the engine room was only 65 deg. F., and that the fuel from the previous run left in the pipes connecting the fuel pumps and fuel valves could not be heated or circulated. At first it was thought that it might be necessary to jacket these pipes, or arrange for circulation right up to the fuel valves, but the results of the tests just described proved that such major alterations were unnecessary, and that if the pipes were adequately lagged and the fuel valves primed with hot fuel within half-an-hour of starting the engine, the fuel injection pressure upon starting would not be appreciably greater than the normal working pressure.

Calculations were made to ascertain the time required to clear the pipes connecting the fuel pumps and fuel valves, and the results will be given, not because they have an direct bearing upon the problem but because you may find them interesting. Assuming that the engine develops 4,000 i.h.p. at 114 r.p.m., that the consumption is 0·308lb./i.h.p./hr. and that the specific gravity of the fuel is 0·94, the time required to displace completely the fuel in the longest pipe, which has a bore of 6 mm. and a length of 15 feet, is seven seconds. With the same engine developing 750 i.h.p. at 60 r.p.m. the time required is increased to 17 seconds based on a fuel consumption of 0·341b./i.h.p./hr.

After the foregoing manœuvring tests had been carried out Nos. 3 and 6 fuel valves were removed for examination, and while deposit of about 1 mm. thick was found on the exhaust valve side of the lower end of the housings, the nozzles were free of deposit and the spray holes in them quite clear. The nature and location of the deposit were the same as in the case of valves Nos. 1 and 3 illustrated in Fig. 18, and, as already explained, was due to the comparatively cold and viscous fuel not permitting the needle valves to re-seat with the smartness necessary to give a clean cut-off at the end of the fuel injection period, and leaving a thin film of fuel on the nozzle which was caused to spread towards the exhaust valve during the period when the air inlet and exhaust valves were open at the same time.

From these tests the conclusion reached was that circulation of hot fuel right up to the fuel valves was unnecessary if arrangements were made to circulate water at 140 deg. F. through the fuel valve jackets whilst the engine was being manœuvred. The arrangement decided upon is shown in Fig. 19, from which it will be seen that water heated by a steam jet is drawn from a 200 gallon tank, pumped through the fuel valves and returned to the tank until the "full-away" order has been received, when the fuel valve cooling system is connected to the piston cooling system as originally designed.

Time did not permit the alterations decided upon to be carried out, but the results obtained during the recent test with the temporary equipment prompted the decision to let the ship manœuvre out of the River Mersey on heavy fuel. The engine was prepared as for the mooring tests and the Mersey was cleared without incident, the engine responding to the controls with entire satisfaction. After two hours full speed in the open sea the engine was stopped and Nos. 2 and 5 fuel valves removed for examination. The amount of deposit on the end of the valve housing was similar in extent and location to that on the valves removed after the mooring test. The nature of the deposit had undergone a change, however, its appearance suggesting that it was burning off, as it broke away at the slightest touch. The valves were re-fitted and the ship proceeded on her way, making a non-stop run of 405 hours to Curaçao.

It will be remembered that after a previous slow speed test at sea the deposit formed on the fuel valve nozzles during eight hours at 60 r.p.m. had burnt off before the valves were removed for examination at the next port, and it was not possible to say whether the burning off was due to running the engine at full power on heavy fuel immediately after the slow running test, or to the Diesel fuel used to manœuvre the ship into port. This last test, however, proves beyond all doubt that any deposit formed during manœuvring is burnt off when full speed is attained whether heavy fuel or Diesel fuel is used.

During a period of fine weather the speed of the engine was reduced by arrangement to 78 r.p.m. and maintained at this speed for 50 hours, during which all cylinders "fired" regularly and consistently. The outlet temperature of the cooling water was kept at 130 deg. F. and the supercharge air pressure and exhaust temperatures were 3·9lb./sq. in. and 173 deg. C. respectively. Prior to this test it was the practice to change over to Diesel fuel when fog was encountered and a reduced speed was necessary, with the possibility of a sudden stop. The result of this test was so satisfactory that it was decided to discontinue the practice, and henceforth heavy fuel was used at all times and for all purposes.

In an endeavour to obtain accurate fuel consumption figures for both Diesel fuel and heavy fuel, a cylindrical tank 3ft. 6in. diameter and 5ft. long, having a capacity of 48 cubic feet, was installed above cylinder head level. A larger tank could not unfortunately be accommodated in a suitable position in the engine room, so that tests of one hour duration only could be run. The connections provided for filling with either Diesel fuel or heavy fuel, with separate outflows to the Diesel and heavy fuel circuits of the engine, the spill returns being led into the heavy fuel service tank. The tank was provided with a tubular gauge glass with a graduated measuring board close to it. Before being used the tank was calibrated by hand measured quantities of fresh water.

A number of tests, each of one hour duration, were carried out, and whilst the calculated consumption varied slightly the final mean figures were: Diesel fuel 0·295lb./i.h.p./hr., and heavy fuel 0·308lb./i.h.p./hr., a difference of 0·013lb./i.h.p./hr. in favour of the Diesel fuel. This means that in an installation of the size in the "Auricula" the daily fuel consumption when operating on heavy fuel is increased by 1,248lb. (0·56 ton) per day. Part of this increase is accounted for by the difference in calorific value, which for the tests referred to was 18,950 B.T.U's. per lb. for Diesel fuel and 18,600 B.T.U's. per lb. for heavy fuel. After making allowance for this difference it will be found that in the case of the "Auricula" the daily consumption of heavy fuel is 704lb. (0·31 ton) greater than the daily consumption of Diesel fuel.

No attempt has been made to ascertain the quantity of fuel represented by the increase of 12 deg. C. in the temperature of the exhaust gases which occurs when changing over from Diesel fuel to heavy fuel, but there is no doubt that much of the 13,100,000 heat units in 704lb. of fuel will be found in the exhaust gases, in which case they serve a useful purpose if, as is comon practice, the gases pass through a boiler for the generation of steam.

At prices given in Table 1 for Diesel fuel and No. 2 heavy fuel, i.e. 83s. and 61s. per ton respectively, the daily consumption of heavy fuel of a 4,000 i.h.p. Diesel engine could be 4.56 tons greater than that of Diesel fuel before there would be no advantage—all other considerations being equal—in changing over a ship to heavy fuel. In other words, if the consumption of Diesel fuel is 12·6 tons per day, the consumption of No. 2 heavy fuel would require to be 17·16 tons per day before the fuel bills would be equal. Actually the consumption of heavy fuel in such an installation would be 13·16 tons per day, so that the saving amounts to 4 tons per day, which in cost is over £200 on each Atlantic crossing. In an 8,000 i.h.p. installation this saving would, of course, be doubled.

The only outward indication of this 2·5 per cent. increase in fuel consumption is a lower cylinder maximum pressure and a higher exhaust temperature. As a relatively high exhaust temperature indicates that a lower proportion of the heat in the fuel is doing useful work, and as an increase in the cylinder maximum pressure is accompanied by a reduction in the exhaust temperature, it is to be expected that the intention to advance the timing of the h.p. fuel pumps on the "Auricula" will result in the fuel consumption being reduced for a given power developed.

It will be recalled that during experiments at St. Peter's it was found that better thermal results were possible with a fuel valve nozzle which was not adopted, solely because it caused the injection pressure to be greater than was considered safe for the fuel pump driving gear of existing engines. This restriction could be obviated at very small extra cost in the case of engines specially designed to burn heavy fuels, so that the probability is that the heavy fuel consumption of such an engine would be no greater than it would be on Diesel fuel, neglecting the slight difference in calorific values of the two grades.

In common with all Werkspoor type four-cycle engines, the engines of the "Auricula" are provided with the under-piston supercharge system which is so simple in construction, reliable in service and economical in upkeep. The normal supercharge air pressure at full speed is 5¼lb/sq. in., and an adequate amount of air for efficient operation is automatically provided at all speeds, so that in order to operate at full speed with supercharge pressures below the normal figure it was necessary to arrange controls which would return a proportion of the discharged air to the suctions of the supercharge air pumps. To have throttled the pump suctions would have affected the mechanical efficiency of the engine, besides tending to draw lubricating oil out of the crankcase. Tests with a lower supercharge air pressure than 5½lb./sq. in. were carried out because some makes of engines are not designed for such high pressures, and it would be useful to know how the Werkspoor engine would be affected in the event of some fault occurring which reduced the pressure. Particulars of the tests carried out at sea are shown in Table 9.

TABLE 9.

Supercharge air pressure lb./sq.in.	5·5	4·5	3·5	2·5
Fuel lever position	13·2	13·2	13·2	13·2
R.p.m....	113·5	113·4	112·6	112·6
Exhaust temperature, °C. ...	312	325	340	357
I.h.p.	3,920	3,877	3,791	3,759
M.i.p.	120·6	119·4	117·6	116·6
Compression pressure lb./sq.in.	543	521	494	469
Maximum pressure lb./sq.in.	714	698	685	673
Engine room temperatures, °F.	100	101	98	96

When this test was carried out the engine had been operating continuously at about 4,200 i.h.p. for six days, and at the time of the test a light to moderate head sea was running. The fuel was injected at a temperature of 175 deg. F., and as the revolutions varied only slightly no noticeable change occurred in the fuel injection pressure. As regards the colour of the exhaust gases, the Chief Engineer, Mr. Lewis, reported "the colour of the exhaust gases coming from the funnel, although difficult to judge, did I think become slightly discoloured at the lowest supercharge air pressure, but no difference could be observed at the test cocks on the exhaust manifold when blowing on to indicator cards".

To ensure the information recorded being as accurate as possible the engine was allowed to run for 45 minutes after the supercharge air pressure has been stepped down and before indicator diagrams were taken and temperatures and pressures obtained. The test occupied seven hours, during which the only part of the engine altered in any way was the bye-pass valve which regulated the pressure of the supercharge air entering the engine cylinders. As will be seen from Table 9, the alterations registered in the principal pressures and temperatures as the supercharge air pressure was reduced are what would be expected, the only item which is at variance being the r.p.m. The author does not doubt that the revolutions were carefully counted during the test and it may be that during the second and third test the helm movement was less or more active respectively than during the first and fourth tests. The r.p.m. recorded for the first test can be proved to be correct and, in relation to the power developed, the r.p.m. recorded for the fourth test can be assumed to be correct.

The fall of almost one r.p.m. due to reducing the supercharge air pressure from 5·5 to 2·5lb./sq. in. is mainly accounted for by the drop in compression pressure of over 74lb./sq. in. and a corresponding drop in the maximum pressure, in which case it is reasonable to assume that if in the "Auricula's" engines the compression clearance volume was reduced to give the same terminal compression and maximum pressures there would be no reduction in thermal efficiency and, consequently, revolutions as a result of the supercharge air pressure being reduced from 5·5 to 2·5lb./sq. in. In the case of the exhaust gases, however, such a reduction in pressure would result in an increase in temperature owing to a lower weight of air entering the engine cylinders, but since 400 deg. C. is considered the safe limit for exhaust gases it will be seen that there is a good margin.

Although the "Auricula" always shipped bunkers at Curaçao, except for the sea trials and the first voyage for which the fuel was received in the U.K., the amount of matter extracted by the purifying plant varied, the purifier's portion ranging from ½lb. to 2lb., and that of the clarifier from 2 ozs. to 5 ozs. per ton of fuel treated. Consequently the frequency with which the bowls require to be cleaned varies also, the intervals between each operation being anything from 12 hours to 48 hours. In the case of the separators on the "Auricula" the dirt spaces of the bowls have a capacity of 10½ litres, so that the accumulation would require to be about 20lb. before separation would be adversely affected.

On the seventh voyage of the "Auricula" the bunkers shipped at Curaçao made it necessary to clean both the purifier and clarifier bowls every two hours, the total amount of matter extracted averaging 25lb. per ton of fuel treated. Although it was obvious that the fuel was "breaking-down" under the treatment, the ship was allowed to proceed as the engines were operating perfectly on the purified fuel. The thorough investigation which followed revealed that this particular shipment was derived from mixed paraffin base crudes and asphaltic base crudes, and that whilst such a mixture was stable at normal atmospheric temperatures, "break-down" occurred at 175 deg. F. It is most unusual refinery practice to mix such crudes and, the author is informed, quite unnecessary.

During the voyage when the need to clean the bowls became much too frequent it was found that running hot fresh water through for about five minutes, in place of the fuel, softened the deposit in the purifier bowl and caused much of it to pass out of the sludge outlet. Illuminating oil introduced in the same way produced even better results. With a normal grade of 1,500 secs. fuel and the introduction of one to two gallons of illuminating oil at about 12 hour intervals, the bowls will run for several days before requiring to be opened up. The best results will be obtained if the illuminating oil is introduced very slowly. The same applies, of course, if hot water is used. The construction of the clarifier bowl does not permit such treatment, but as the quantities of material separated by this machine are so small compared with the quantities extracted by the purifier, the clarifier will operate at full efficiency for days, probably a week, before opening up for cleaning becomes necessary.

Excepting for the voyage when unstable fuel was shipped, the practice on the "Auricula" was to open up the bowls once daily, and the time taken to carry out the operation was roughly half-an-hour. Much can be done to make this work less unpleasant and reduce the time to carry it out if during installation of the plant due regard is given to the size and position, relative to the machines, of the bench and receptacles for the extracted material, as well as arranging for all necessary tools to be within reach when in their rightful positions. A further advantage is to have the purifier and clarifier so arranged that it is possible for the operators to work at them from all sides. In view of the close proximity of fuel heaters, etc., the space occupied by the purifying plant should be well ventilated if situated in some corner of the engine room.

The usual practice in marine Diesel engines is for the fuel to flow by gravity from the service tanks to the main engine h.p. fuel pumps. In some cases a surcharge pump is provided, as on the Werkspoor type engines. With Diesel fuel and where a reasonable pressure head can be produced at the fuel pump suctions, mechanical means of creating the requisite pressure is unnecessary, but with heavy fuel such means may be advisable, particularly if the distance between the service tank and the fuel pumps is great and/or indirect. On the "Auricula" it was found that a pressure of 25lb./sq. in. at the pump suctions ensured 1,500 secs. fuel following up the pump plunger satisfactorily at full speed. A test carried out with a pressure of 45lb. at the pump suctions caused the engine revolutions to be increased 1·9 r.p.m., which indicates "slack" oil at the pump suction with a pressure of 25lb., but the engine operated with perfect regularity at the lower pressure. A higher pressure is not, therefore, advocated unless in some particular installation the desired results cannot be obtained.

As in the case of all other parts, the design of the main engine h.p. fuel pumps of the "Auricula" was in accordance with standard practice. During the early stages of the experiment the spring load on the plungers was increased to overcome a tendency to stick, due to the film of heavy oil adhering to the rubbing surfaces being thicker than would be a film of Diesel fuel. Later the spring load was reduced to normal as it was found that sticking could be prevented by making the plungers a slightly easier fit. The tolerance which was found to obviate sticking, while at the same time prevent ing leakage when the heavy fuel was heated to 175 deg. F., was between 0·00015in. and 0·00020in. The finish of the contact surfaces of plungers and bushes must be perfectly smooth and free from "holidays", otherwise certain resinous substances from the hot fuel will deposit and may eventually cause the plungers to stick.

Turning now to the cost to equip a ship for the burning of heavy oil, the "Auricula" had all her machinery installed and was within a month of completion when it was decided to convert that part of the installation concerned. Moreover, this ship was provided with experimental gear and equipment which would not be required in subsequent conversions. Even so the total extra cost to fit out the "Auricula" was £7,259, which includes the cost of the two centrifugal separators, heating coils in storage and service tanks, etc. So far no existing ships have been converted, owing solely to the difficulty of obtaining the electrical portion of the separators, but several new ships have been fitted out and even at present day inflated prices the cost is under £4,000. The cost to convert existing ships will vary according to the arrangement of fuel storage and service tanks, but if the arrangement follows general practice it is estimated that the cost will not exceed £5,000, which is approximately the saving effected during one year's operation of a 4,000 i.h.p. installation. The cost to convert will not be materially affected by the power of the installation, so that for an 8,000 i.h.p. installation the initial outlay will be recovered after six months' service.

The equipment for a 4,000 i.h.p. installation comprises the following:—

1. Steam heating coils in storage and service tanks capable of maintaining fuel at 120 deg. F.
2. One purifier with self-driven suction and delivery pumps. One clarifier with self-driven delivery pump only.
3. One multi-tubular heater located between service tanks and purifier capable of heating fuel from 100 deg. F. to 180 deg. F. at 200 gallons an hour.
4. One multi-tubular heater located between service tank and h.p. fuel pumps and of similar capacity to item 3.
5. One effective strainer located between heater, item 4, and h.p. fuel pumps.
6. One work bench and tool rack situated close to separating machines with two 10-gallon receptacles, one for cleansing oil and one for sludge.
7. One receptacle for water and sludge discharged by purifier whilst operating.
8. Hot water circulating system for fuel valves.

Between the 17th August, 1946 and the 13th August, 1947 the "Auricula" accomplished the following:—

Distance covered between pilot vessels ... 68,715 miles
Hours main engine operated at full speed 6,136 hours
Total revolutions made by main engine ... 42·33 million

At the end of this period Nos. 3, 4, 5 and 6 cylinders were opened up and the cylinder liners, piston rings and piston ring grooves gauged for wear, but before giving figures the author would mention again that the second voyage (8,483 miles, 722 hours, 5 million revolutions) was made on Diesel fuel. Also, that the cylinder liners, piston rings and piston ring grooves were not, unfortunately, microscopically gauged during the construction of this engine. The question of opening up and obtaining accurate measurements of these parts after the sea trials was considered, but owing to the urgent need for the ship's services the seven to eight days' delay that would be incurred could not be allowed, so that when calculating the wear rates now to be given it had to be assumed that the parts concerned were machined to the exact dimensions given on the working drawings.

The upper ends of all cylinder liners were entirely free of deposit, as was the underside of the cylinder head excepting for a patch of deposit between the fuel valve and exhaust valve pockets. This deposit was obviously the result of running the engine at slow speed and the fuel valves at too low a temperature, reference to which was made earlier in this paper.

With the exception of No. 4, the bores of all cylinder liners examined on this occasion were perfectly smooth and polished, and it was apparent that no gritty matter had been present in the cylinders and that the normal grade and quantity of lubricating oil used was efficient and adequate. Moreover, the surfaces were more greasy than is generally the case with Diesel fuel and the appearance raised the hope that the use of heavy fuel had assisted lubrication of the cylinders, and that consequently the amount of wear would be found to be very small. The oil used was Shell C3, and the quantity ¾-gallon per cylinder per day. The surface of No. 4 liner was equally smooth but dull and dry, due to water having accidentally entered this cylinder whilst the head valves were being removed.

The original diameter of these liners was 650 mm. and the construction is shown in Fig. 20. This illustration also indicates the points at which the wear was gauged, while the gauge readings after one year's operation are shown in Table 10.

TABLE 10.

	Cylinder No. 3		Cylinder No. 4		Cylinder No. 5		Cylinder No. 6	
	F. & A.	P. & S.	F. & A.	P. & S.	F. & A.	P. & S.	F. & A.	P. & S.
A	650·52	650·73	650·70	650·63	650·61	650·93	650·45	650·54
B	·42	·75	·31	·53	·47	·82	·32	·50
C	·57	·80	·45	·49	·57	·87	·42	·51
D	·69	·69	·49	·53	·61	·93	·45	·54
E	·69	·75	·46	·61	·66	·76	·23	·43
F	·35	·52	·30	·34	·41	·43	·14	·14

From the foregoing gaugings it will be seen that the mean wear at the point A, where the greatest wear usually takes place, is:—

No. 3 Cylinder 0·665 mm. No. 4 Cylinder 0·664 mm.
No. 5 Cylinder 0·770 mm. No. 6 Cylinder 0·495 mm.

The mean wear of these four cylinder liners is 0·648 mm., and as the ship had covered 68,715 miles the engine operated for 6,136 hours and made 42·33 million revolutions, the wear rates per thousand miles, per thousand hours and per million revolutions are as follows:—

Per thousand miles ... ... 0·0093 mm. or 0·00036in.
Per thousand hours ... ... 0·1040 mm. or 0·00409in.
Per million revolutions ... 0·0150 mm. or 0·00059in.

It goes without saying that the wear rates of cylinder liners and piston rings depend as much, if not more, upon the materials of which these parts are made as upon the proper burning of the fuel, so that if the difference due solely to running on boiler fuel is to be ascertained, the wear rates just given should be compared with the four cylinders of an exactly similar engine which had operated for the same length of time on Diesel fuel.

The "Goldmouth" is propelled by an exactly similar engine, and when Nos. 2 and 7 cylinders were opened up and the liners gauged for wear the engine had operated 5,161 hours at full speed and made 33,549,300 revolutions on high grade Diesel fuel. The average wear of these two liners at the point indicated by "A" in Fig. 20 was 0·505 mm. and the wear rates are:—

Per thousand hours ... ... 0·0980 mm. or 0·00386in.
Per million revolutions ... 0·0150 mm. or 0·00059in.

It is usual to speak of wear rates as so much per thousand hours, but as this basis varies according to the rotational speed of the engine and to the nature of the voyage, the steaming time being calculated between pilot vessels, the wear rate per million revolutions gives a more accurate comparison, and as will be observed from the figures just given, the wear rates of the "Auricula" cylinder liners are exactly the same as those of the "Goldmouth", notwithstanding the former ship having operated on boiler fuel and at 5 per cent. greater power output.

Assuming that the average revolutions made by an engine burning boiler fuel is 40 millions per annum, and that the maximum allowable cylinder liner wear is 6 mm., the engine will operate over 10 years before renewal of liners becomes necessary when conditions are similar to those prevailing on the "Auricula". These conditions were of necessity far from ideal, since apart from running the engine for quite long periods with reduced fuel injection pressure, low fuel temperatures, etc., the weather encountered for eight months out of the twelve was the worst possible. Furthermore, there is every reason to believe that the wear-resisting qualities of the piston rings employed were not of the best.

Nos. 3, 4, 5 and 6 pistons were disconnected from the piston rods

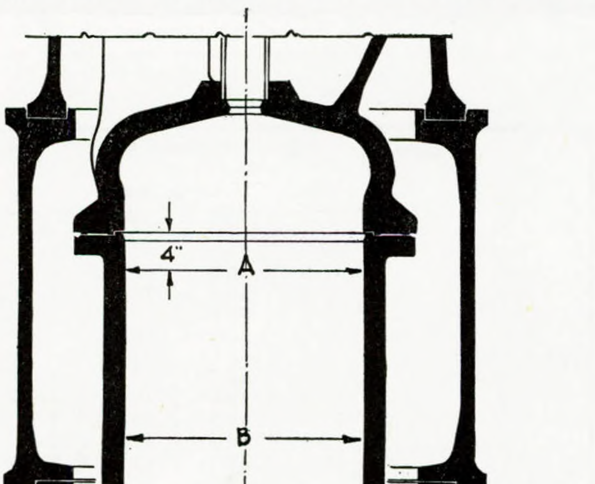


FIG. 20.—*Points at which liners of "Auricula" were gauged for wear.*

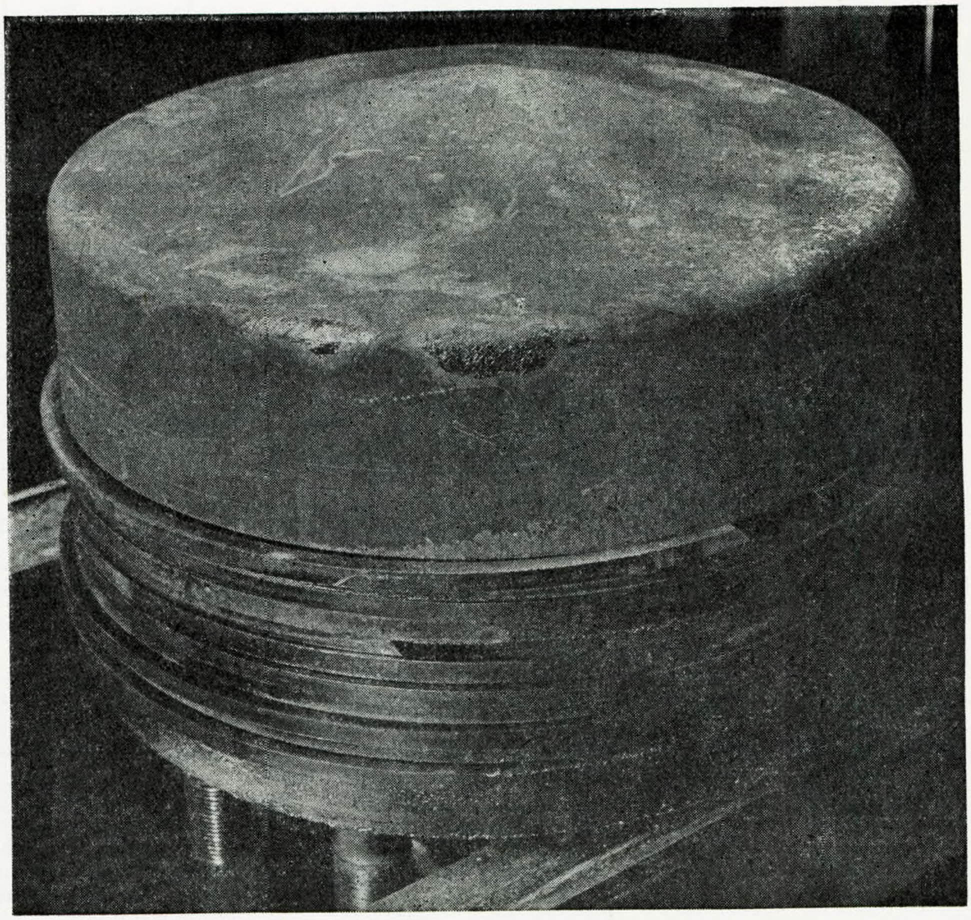


FIG. 21.—*No. 5 piston as removed from cylinder after one year in use.*

and every part carefully examined. The nuts of Nos. 3 and 5 pistons were found to have slackened slightly, and it was evident that water had got between the joining surfaces. Water could only emanate from leaking piston cooling telescopic pipe glands, and water from this source would also find its way on to the cylinder liners. Moreover, it was evident that these two pistons had been rubbing lightly against the liners, so that how much these two faults were responsible for liner wear can only be surmised.

All four pistons were entirely free from deposit of any kind and their remarkably clean condition can best be illustrated by the statement that after wiping with a paraffin soaked rag they were ready to be refitted. No. 5 piston, shown in Fig. 21, is typical of the pistons, as they were removed after one year's operation, and the author thinks it will be agreed that so far as fouling is concerned there would be no need to examine pistons between special surveys.

Every piston ring (24 in number) in each of the four pistons examined was free to the extent that in addition to being easily moved in and out of the grooves they could be moved circumferentially in their grooves with ease. The original width of the piston ring grooves as given on the working drawing was 14·05 mm. for the top groove and 14 mm. for all the others, the corresponding dimensions of the piston rings being the same less an allowance for working clearance, and when gauged after a year's operation the widths of the grooves were found to be as shown in Table 11.

From these measurements it will be seen that, on the assumption that the grooves were machined exactly to drawing size, the enlargement was from 0·1 mm. to 0·2 mm. Generally, however, it is the upper grooves which show the greatest enlargement due to there being less lubricating oil at the upper end of the piston, and as the wear in the case of the "Auricula" pistons was more or less uniform it is just possible that the original width was not exactly to drawing size. This was supported by the absence of any sign of a ridge at the bottom of any of the grooves, and the top piston ring and groove of each piston were well covered by lubricant.

TABLE 11.

Grooves	Top	2nd	3rd	4th	5th	Bottom
No. 3 Piston ...	14·15	14·15	14·15	14·10	14·10	14·15
No. 4 „ ...	·15	·10	·10	·10	·10	·10
No. 5 „ ...	·15	·15	·10	·10	·15	·10
No. 6 „ ...	·20	·15	·15	·10	·10	·15

In regard to the piston rings, however, the results were not quite so good. The original depth (vertical dimension) of the rings fitted was 14 mm. less 0·15 mm. for working clearance, and of the 24 rings gauged for wear the maximum and minimum measurements were 13·8 mm. and 13·65 mm. respectively, indicating from 0·05 mm. to 0·20 mm. wear, the greatest wear taking place at the top ring in each piston. In the case of the "Goldmouth" engine which had operated for roughly five-sixths of the time of the "Auricula" engine, the corresponding figures were nil to 0·06 mm., so that if the "Goldmouth" figures are taken as a standard, the wear of the "Auricula's" piston rings in a vertical direction was greater than it ought to be.

The original radial thickness of the five upper piston rings was 21 mm., and when those in Nos. 3, 4, 5 and 6 pistons were gauged after one year's operation the radial thicknesses were found to be as shown in Table 12.

Each piston ring was gauged at nine points, and the greatest wear was found to have taken place directly opposite the gap. The opening between the ends (gap) of each ring when inserted in an unused cylinder liner is shown in Table 12, the original opening being 2 mm. The wear of the sixth ring is not given in Table 12 as this is the oil scraper ring and is chamfered for half its depth in accordance with general practice.

TABLE 12.

	Radial Thicknesses			Mean Wear	Gap
	Max.	Min.	Mean		
No. 3 Piston				mm.	mm.
Top Ring ...	16·2	14·2	15·20	5·80	35·5
2nd „ ...	17·6	14·3	15·95	5·05	33·0
3rd „ ...	17·7	15·6	16·65	4·35	26·0
4th „ ...	18·7	16·6	17·65	3·35	22·0
5th „ ...	19·1	17·9	18·50	2·50	16·5
No. 4 Piston					
Top Ring ...	17·3	14·7	16·00	5·00	32·0
2nd „ ...	18·0	15·0	16·50	4·50	27·5
3rd „ ...	18·6	14·7	16·65	4·35	25·5
4th „ ...	18·6	16·5	17·55	3·45	20·0
5th „ ...	18·8	17·1	17·95	3·05	18·5
No. 5 Piston					
Top Ring ...	16·6	14·3	15·45	5·55	35·0
2nd „ ...	17·9	15·5	16·70	4·30	27·0
3rd „ ...	18·1	16·1	17·10	3·90	25·5
4th „ ...	18·6	17·0	17·80	3·20	21·5
5th „ ...	18·8	17·5	18·15	2·85	19·0
No. 6 Piston					
Top Ring ...	18·2	15·1	16·65	4·35	27·5
2nd „ ...	18·2	16·5	17·35	3·65	23·0
3rd „ ...	18·1	16·4	17·25	3·75	21·5
4th „ ...	19·0	17·1	18·05	2·95	19·0
5th „ ...	18·9	17·6	18·25	2·75	17·0

After the "Auricula's" piston ring wear had been tabulated, the results obtained in numerous other ships, some with similar engines and some with other types but all of about the same age and operating on Diesel fuel, were carefully investigated and the

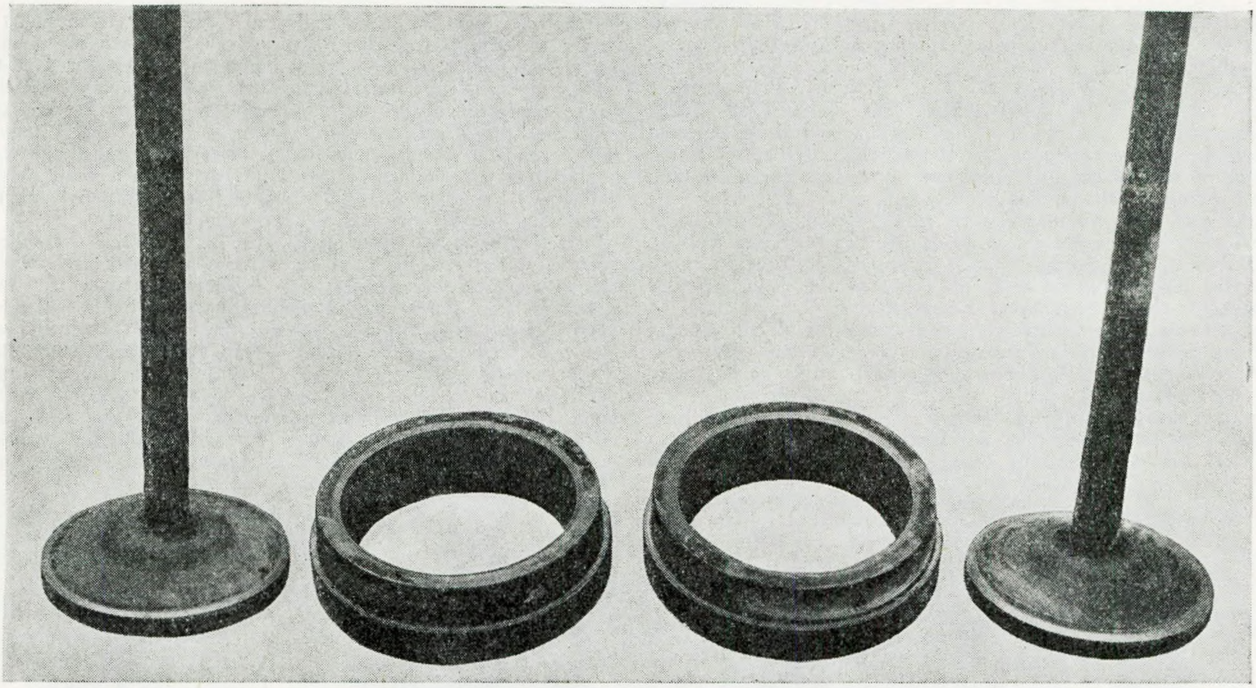


FIG. 22.—*Nos. 1 and 7 exhaust valve lids and seats after 2,022 and 4,768 hours' service respectively.*

conclusion reached was that piston ring wear not only varied in a line of cylinders but varied just as much in different ships.

It was found that the wear in a radial direction varied from 0·73 mm. to 0·32 mm. per thousand hours, and this was confirmed by comparing the indents received in a given time from the different ships. Even after making due allowance for factors other than the composition of material which affect piston ring wear, it was apparent from this investigation that there is a considerable difference in the wear-resisting properties of piston rings, and that the matter is sufficiently serious to justify the immediate attention of piston ring specialists. A reasonable expectation is 2 mm. wear during the first year in the case of top rings of the size with which we are concerned here. This figure is derived from the results obtained with the experimental engine and some ships in service.

It would seem that the wear-resisting qualities of the piston rings supplied to the "Auricula" and some other ships for which the author is technically responsible, are far from satisfactory. The rings appear to be too soft, and whether a Brinell hardness figure higher than 200 would give better results the author is not yet in a position to say. Some hold the view that piston rings should be slightly softer than the cylinder liner so that the rings rather than the liner will wear. The author's view is that both parts should have the highest possible wear-resisting properties consistent with resistance to breakage.

The metal removed in powder form, whether from the liner or the piston rings, is bound to mix with the lubricating oil and form an abrasive paste to the detriment of both parts. Piston rings of different compositions are now being tried out on the "Auricula" and when the results come to hand they will be made known.

It will be observed in Table 12 that the wear of each of these concentric rings is very uneven, the difference being nearly 4 mm. in some rings. In every case the greatest wear occurred at a point opposite the gap and the least at each side of the gap. This proves the earlier statement that all piston rings were found quite free in their grooves, and that the cause of this uneven wear is due entirely to the uneven outward pressure of the rings.

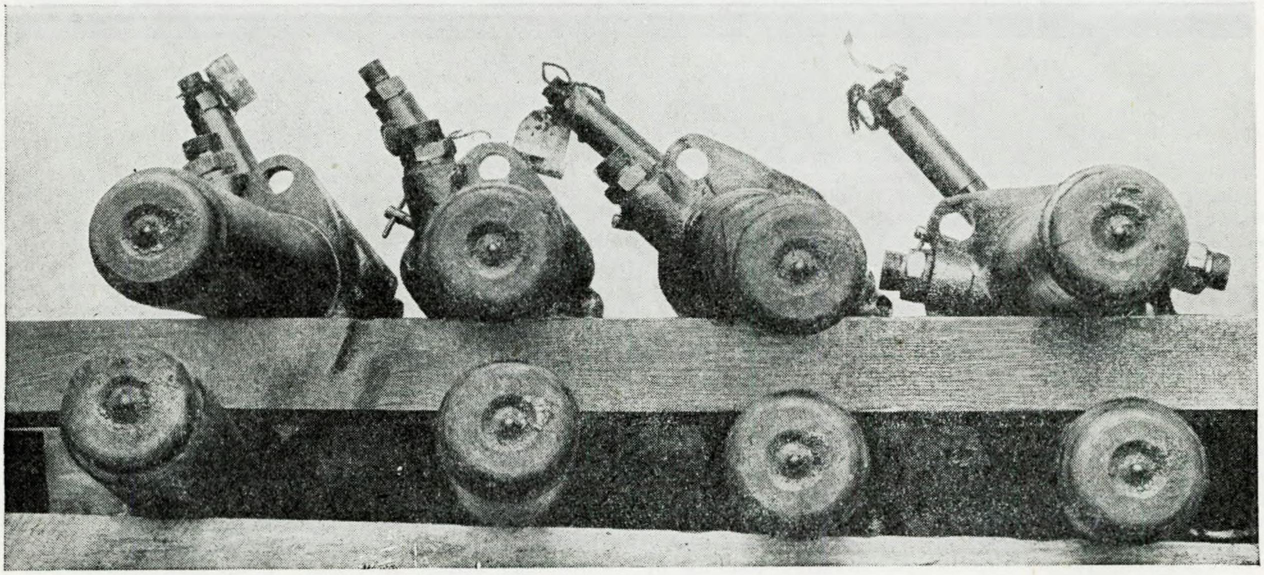


FIG. 23.—*Fuel valves as taken out of "Auricula's" engines after varying periods of service.*

When the exhaust valves were removed they had been in continuous use for the following full speed running periods, the manœuvring time being additional:—

Valve No.	1	2	3	4	5	6	7	8
Hours	2,022	1,400	1,400	2,516	560	2,516	4,768	2,022

All valve housings were in the condition that would be expected had the engines been operating on Diesel fuel, the only deposit found being on the outside at the lower end and extending for about 2in. above the landing. All spindles were an easy fit, and after the securing nut had been removed were easily withdrawn by hand. All lids and seats were in perfect order as will be seen from Fig. 22, the two valves shown being typical examples. Although every endeavour was made to avoid disturbing any of the deposit before the photographs were taken, it will be observed that portions of the upper surfaces of the seats have been rubbed with the fingers when carrying them or setting them up for photographing. However, the finger-marks illustrate very clearly the soft nature of the very thin layer deposited.

The mitre faces of all lids and seats were in the condition illustrated in Fig. 22. In no case was it necessary to do more than rub the mitre faces together with fine carborundum paste and clean other parts with a paraffin soaked rag before re-fitting. These two valves were selected for photographing because No. 7 valve had been in service 9½ months, or nearly two-and-a-half times longer than No. 1 valve, and as will be seen there is no difference in respect of deposit or condition of mitre faces, which are entirely free of pitting or scoring.

No deposit of any kind was found in the exhaust gas manifold, the internal surface of which was evenly covered with a very thin film of dry soot which could be removed with the fingers.

When the eight fuel valves were removed they had been in continuous use for the following full speed periods, the manœuvring time being additional:—

Valve No.	1	2	3	4	5	6	7	8
Hours	990	2,678	1,596	560	560	1,380	4,768	990

Particular care was taken when removing the valves from the cylinder heads to avoid disturbing any deposit that might have formed on the lower ends, and the condition of this part of the valves when taken out is shown by the photograph reproduced in Fig. 23. As will be observed, there is practically no difference in the amount of deposit even though some of the valves had been in use for a period over eight times longer than others. Further evidence of this is shown in Fig. 24 in which is illustrated a close-up of Nos. 1 and 7 nozzles and needle valves, the former having been in use for 990 hours whilst the latter had seen 4,768 hours continuous service. After removal No. 2 fuel valve, which has been in use for 2,678 hours, was connected to the test pump and tested for fluid-tightness and spraying with Diesel fuel. This test proved the needle valve to be perfectly fluid-tight and not only all spray holes clear but that the sprays had the same form as those from a valve which had never been in use. The lifting pressure of the needle valve was found to be 3,700lb./sq. in. or 150lb./sq. in. less than the designed pressure. Whether this difference existed originally or represents weakening of the spring in service cannot be stated.

Referring again to Fig. 23 it will be noted that the deposit occurs on the same side of the nozzle in every case, which is the side nearest to the exhaust valve. This peculiarity has been mentioned several times in this paper and this final evidence proves beyond doubt that the theory as to the cause previously advanced is the correct one, namely, that deposit occurs only when the engine is running at slow speeds and is due to the temperature of the fuel being reduced before it reaches the fuel valves. With effective lagging of the pipes connecting the fuel pumps and fuel valves and circulation of water at 140 deg. F. through the fuel valve jackets on occasions when an engine is operating at reduced speeds or manœuvring, there is no doubt that formation of deposit will be obviated.

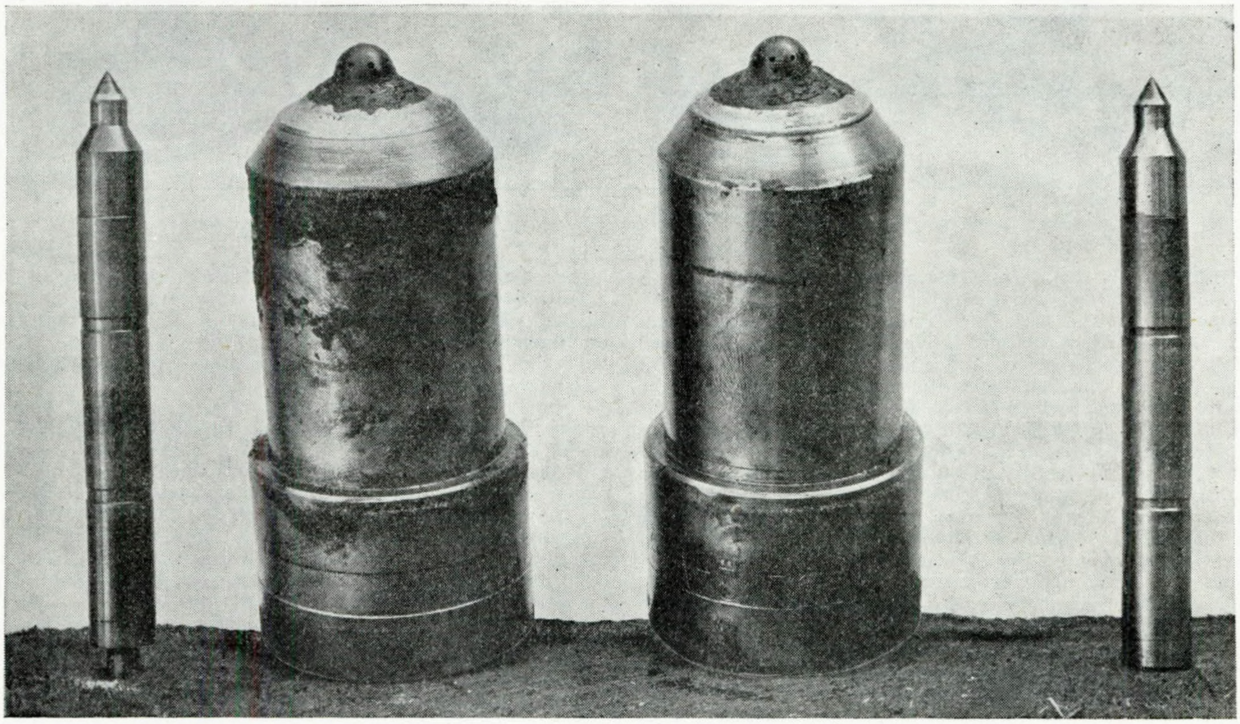


FIG. 24.—*Fuel valve nozzles and needle valves after 990 and 4,768 hours' service.*

The author contends also that the photograph reproduced in Fig. 23 proves that the deposit found on the ends of the fuel valves accumulated only during the 10 hours slow running period made necessary owing to fog encountered immediately prior to the ship entering port, where the valves were removed for inspection. He is quite sure that had this ship, which is not fully equipped for preventing the formation of deposit on these valves, not encountered fog but had entered port in the ordinary way, the valves would have been found entirely free of deposit and would have been re-fitted as taken out.

The whole of these experiments have been carried out with Werkspoor four-cycle type engines, and the question which will naturally arise is "will similar results be obtained with other makes of four-cycle engines, or even two-cycle engines?" This question cannot be answered yet, but the author sees no reason why similar results should not be obtained with other makes of four-cycle engines or even two-cycle engines, providing the undesirable matter in the fuel used is extracted as efficiently as was done on the "Auricula". The author claims, and thinks it has been proved, that so far as composition is concerned heavy fuel treated in the manner here recommended is no more harmful to the vital parts of a Diesel engine than is Diesel fuel. If this is so then the only difference between purified heavy fuel and Diesel fuel is in respect of viscosity, in which case it is only engine details that might require to be adjusted or altered. The heavy fuel may not burn so rapidly as Diesel fuel unless the injection system is altered to increase the degree of atomization, but it is suggested that the evidence here put forward proves that the formation of the fuel sprays differs only slightly, if at all, and that the whole of the fuel is burnt in the allotted time. If it were otherwise, would not deposit be found in the cylinders and/or the exhaust gas passages?

Discussion

Mr. C. J. Lugt, of Werkspoor, Amsterdam (Visitor), in opening the discussion, said they were highly indebted to the author for his complete and comprehensive paper, and for the many useful details which he gave on what he had been doing in connection with the burning of boiler oil of this viscosity in Diesel engines. He was, of course, particularly interested, as he was the designer of the special type of engine which the author had used for these experiments. He thought that the paper was so complete that the information given was ample to allow every other engine maker to run similar tests on his own special make.

He could only be thankful that the author did it for him on the Werkspoor engine as it released him from this duty, at least as far as the four-cycle supercharged Werkspoor engine was concerned. As he did not have the presumption to think that his engine was the only "pebble on the beach" he felt certain that the other four-cycle types of engines would show up equally well. But the new Werkspoor-Lugt engine was quite different from the old one, and he had felt it his duty to show that also this new two-cycle supercharged engine could be made to run satisfactorily on boiler oil of the same kind and viscosity as was used in the "Auricula". He keenly wanted to give at this meeting a positive answer to the last query in the paper, and after receipt of the advanced copy, he had quickly organised the trials on boiler oil of this new type of Werkspoor engine. Unfortunately he had at the works only a purifying installation, but not the very essential clarifier. However, the Delft Laboratory of the Royal Dutch were kind enough to help him out in record time. Just before leaving Amsterdam for this meeting the test engine completed a 10 hours test, of which 5 hours were on Diesel oil and 5 on boiler oil. Fig. 25 showed the injector after the first period of 5 hours and Fig. 26 after the second period. It could be seen that there was practically no difference.

A more detailed description of the new Werkspoor engine, shown in Fig. 27, would be published shortly. It was designed by the speaker, practically single-handed, during war time, in great secrecy on account of the German occupation, and he continued this work until the cold, darkness and hunger of the 1944/45 winter put a stop to all work. When the war was over, the drawing office at once started work on the two-cylinder full scale test engine of 600 b.h.p. per cylinder. This engine had now been on the test bed for over a year and had given complete satisfaction. Notably weight and encumbrance of the new engine were much inferior to what was usual. The old 3,600 b.h.p. engine weighed about 315 tons, the new one as shown in Fig. 27, only 155 tons. The mechanical efficiency was expected to be close on 90 per cent. for a multiple cylinder engine and the fuel consumption well below 0·35lb. per s.h.p. One of the remarkable features of the new engine was that every cylinder was entirely self-contained, as the movement of the fuel pump and of the exhaust valves was derived from the piston rod of the scavenging pump. There was no camshaft and no reversing motion, and the entire construction was of the utmost simplicity and straight forwardness.

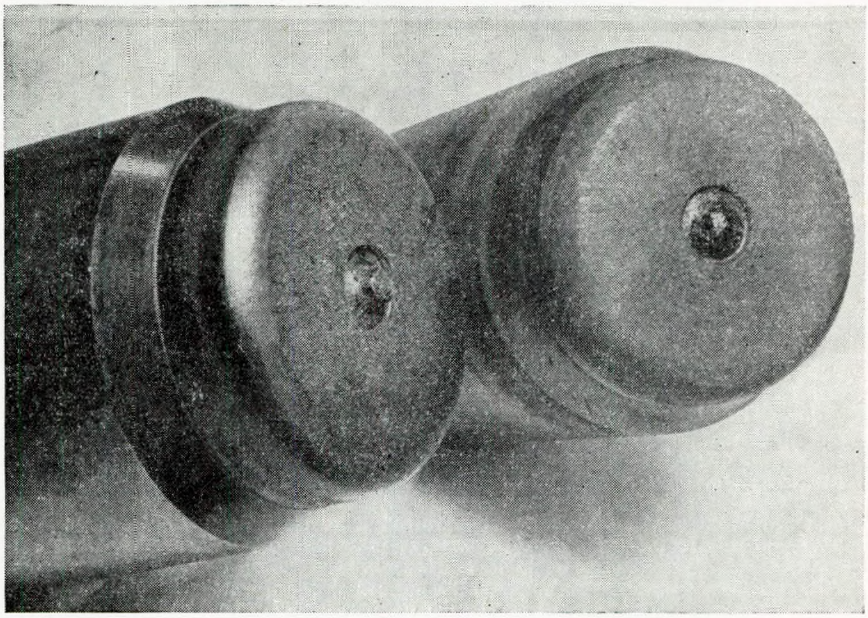


Fig. 26.

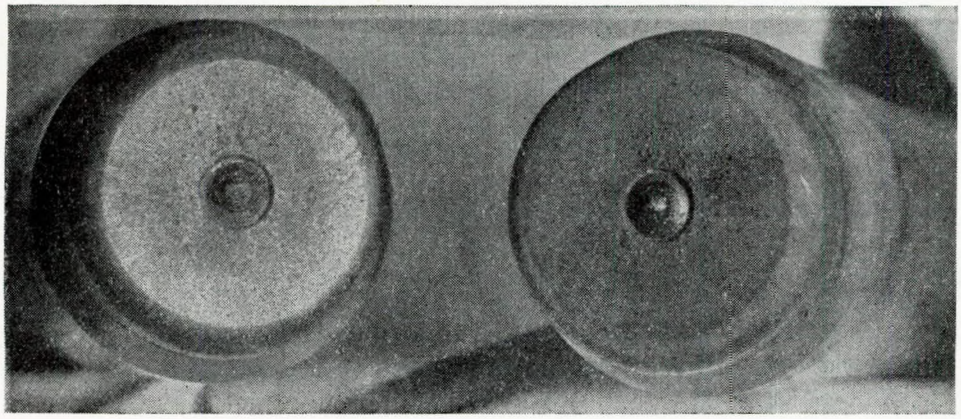


Fig. 25.

After running this preliminary test on boiler oil, the speaker was able to give a provisional affirmative answer to the author's query, as far as the new Werkspoor-Lugt two-cycle supercharged Diesel engine was concerned, but it was the speaker's intention to make this engine run for a considerable time on Ordoil, and he hoped to be able to give the results in a written contribution to the discussion in due time.

Mr. P. Jackson, M.Sc. (Visitor) congratulated the author on the persistence with which he had carried out the experiments on the use of boiler fuels and on the methodical manner in which the tests were undertaken and analysed.

He remarked that the cost of running such large engines for long period trials was almost prohibitive. Many attempts had been made over the past 25 years to use heavy boiler oils, but after relatively short periods these had usually been abandoned owing to the increased maintenance required to the pumps and injectors, and also due to the increased wear of the pistons, piston rings and cylinder liners. Air injection engines had been more successful in using boiler oils than airless injection owing to the injection gear being less sensitive, and also due to the fact that the injection was not accomplished by spraying heavy fuels through small holes, but by blowing the fuel into the cylinder through relatively big holes. In the airless injection engine, difficulties had been experienced, not only due to the formation of trumpets around the nozzles, but also due to the scoring of fuel pump plungers and the choking and wear

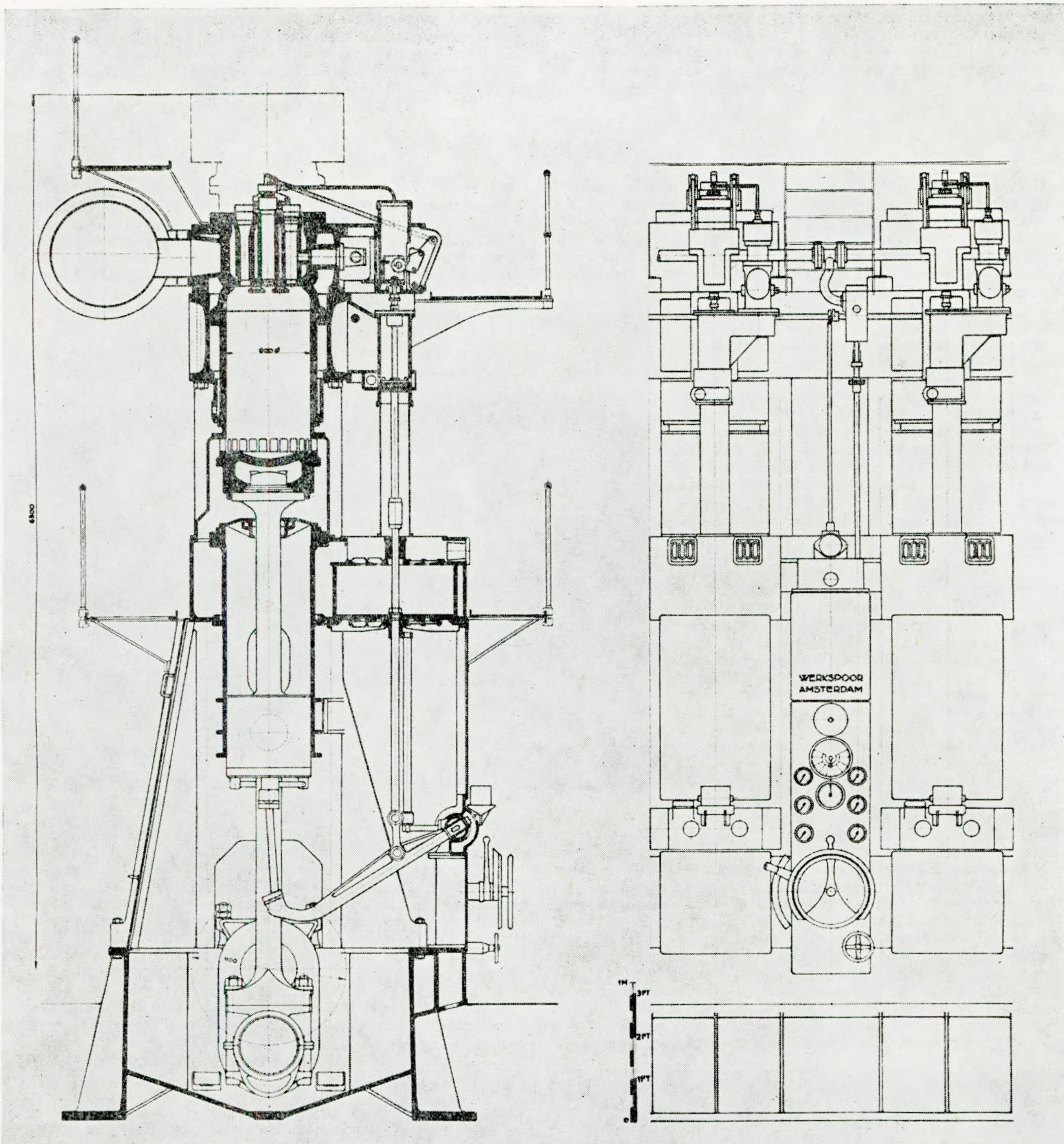


FIG. 27.

of the piston rings.

The speaker found the author's opening statement, that there was a demand for light Diesel fuels 50 years ago, rather surprising, as surely 50 years ago was rather the date of birth of the Diesel engine, and it was not until high speed engines began to be developed that light distillate fuels were really demanded. In this connection he thought the oil companies had really done considerable pioneer work in helping the development of the high speed engine by developing light oils with high octane values and consequent absence of Diesel knock. If the modern high speed engine were run on the heavy oils of 25 years ago, there would again be the old pronounced Diesel knock to such a degree as to make the engine impossible.

The use of boiler oils in marine engines in particular was to be encouraged, because such oils were obtainable in many parts of the world at relatively low prices. There were many varieties of these fuels having varying viscosities, and with different characteristics. In Sunderland, the speaker had a cupboard full of oil samples collected throughout the world over the past 30 years, and many of these had been tried with success on Doxford engines. In this connection he held that the "common rail" system of the Doxford engine with its relatively large holes was more in line with the air injection engine, and was better adapted to the use of boiler fuels than systems employing the "jerk" type of injection pump. With the latter type of pump any small particles of ash or abrasive would cut a line or groove down the surface of the pump through which leakage could occur, and the efficiency of the pump was in consequence diminished.

This was particularly the case with the pump having the byepass controlled by a scroll as in the well known Bosch type. With such pumps exceptional care would have to be taken with filtration.

The author had mentioned a test which he had carried out on a Doxford engine using Ordoil. The speaker was present when this test was made at the works of the Wallsend Slipway and Engineering Co., Ltd., and he would not have called it an adequate test. The engine had been tuned up on marine fuel oil and then changed over to Ordoil without any adjustments being made. The engine continued to run as if there had been no change, the combustion was perhaps slightly quieter, the colour of the exhaust was much the same, maybe slightly more visible, and the maximum pressure had fallen by about 30lb./sq. in. The Ordoil was heated to 185 deg. F. by steam pipes coupled and lagged together with the fuel pipes. After about 12 hours the engine was shut down as the supply of fuel was exhausted. The standard sprayers in the Doxford engine for ordinary marine Diesel fuel had 5 holes of ·022in. diameter, and with these the injection pressure was about 6,000lb./sq. in. On Ordoil the injection pressure had increased to 8,200lb./sq. in., and this, together with the drop in maximum pressure indicated slower injection. Larger holed nozzles, having six ·025in. holes had been supplied but these were not tried. It was suggested that these larger holed nozzles should be tried, and also the fall of maximum pressure showed that the fuel cams might be advanced with advantage.

With regard to the tests described in the paper, in connection with the centrifuging of the fuel oil, Table 3, column 2 showed an analysis of the Ordoil before and after centrifuging. The results appeared to show that centrifuging was of no advantage, in fact rather the reverse, since the viscosity was increased and also the percentage of ash content. Nevertheless the author persisted with centrifuging, and later evolved what was in effect two-stage centrifuging, which had apparently made it possible to use this type of oil. In order to illustrate the effect of two-stage centrifuging, could the author give an analysis of the oil before and after, for comparison with the figures given in column 2 of Table 3, Secondly, with regard to the tests described in Table 2, the fuel consumption of the Werkspoor engine was given as ·49lb./b.h.p./hr. and ·38lb./i.h.p./hr. on Admiralty fuel oil. These figures were not very good, and did not do justice to the Werkspoor engine; nevertheless the maximum pressure was lower than on Diesel fuel, and in addition the characteristics of the burning card showed that the injection could have been advanced with advantage. The exhaust temperatures recorded were distinctly low, even for a super-charged engine of the Werkspoor type.

In connection with the author's remarks concerning there being no difficulty with the sulphur content of the fuel, the speaker would advise taking this conclusion with a degree of reserve. He had known the sulphur content in the fuel to cause considerable difficulties with corrosion in exhaust pipes, and also should any of the sulphurous acids get into contact with salt water, corrosion of any part in contact would be accelerated to an alarming degree. The sulphur content of the fuel was also responsible for the excessive liner and piston ring wear which could occur in engines when using these heavy boiler fuels.

The results given on page — showed that engines in the "Auricula" had a liner wear of ·0038in. per thousand hours which was nearly four times the normal rate of wear of a slow speed Diesel engine, usually taken at ·001in. per thousand hours. At Doxford's it was their usual practice to consider the average life of a liner as 50,000 hours operation, but if this were reduced to one quarter by the use of boiler oils, a considerable proportion of the saving on the fuel oil would be spent in renewing cylinder liners. To overcome this disadvantage, which had been found on trials previous to those conducted by the author, chromium plating of the cylinder liners had been tried and had given encouraging results. A still better and more encouraging line of development was that of chromium plating the top two piston rings.

The speaker concluded with the remark that he hoped the author's endeavours to use boiler oils would be continued even to the point of using oils up to 3,000 seconds viscosity, for as he had remarked previously there were many types of boiler oils relatively easy to use, such as those supplied by the Anglo-Iranian Oil Co. ("Persoleum") and by the Shell Petroleum Co. ("Britoleum") or Admiralty Fuel Oil, but to use the really heavy 3,000 seconds oils was another matter.

Com'r (E) L. Baker, D.S.C., R.N. (Member) thought that a small historical note might be of interest; whilst transferring offices recently he came across a report on the history of the Diesel engine in the Royal Navy, which included the following statements:—

"A satisfactory trial was carried out in September 1907 on Broxbourne oil, the engine (a Vickers 500 b.h.p.) being also proved capable of running on Texas oil, although with a reduced power and foul exhaust".

"In December 1918 satisfactory trials were run with this engine (Cammell-Laird two-stroke opposed piston) and further trials on Texas oil in 1919".

With the cessation of hostilities, however, interest in heavier fuels seemed to have lapsed, and the development of high speed Diesel engines for submarine propulsion was based on the highest grade of gas oil available.

The interest in this excellent paper lay more in the wider significance of the results obtained than in the reduced operating costs of the "Auricula". From a national and strategical aspect the supply of high grade Diesel oil might be said to be already in short supply, and the possibility of using a high percentage of residuals in slow running Diesel engines, and the consequent reduction in high grade gas oil was of major importance.

Without wishing in any way to deprecate the result obtained in this series of experiments, he felt that it should be pointed out that the slow running Diesel engine was designed for marine Diesel fuel, which consisted of approximately 20 per cent. residual fuel added to 80 per cent. high grade gas oil, and it was not surprising, therefore, that it continued to run satisfactorily when the percentage of residual was increased to approximately 70 per cent. The value of the experiment, therefore, lay not so much in the proof that the engine would run with this fuel, but in the method by which the results were obtained. It would be of considerable value in considering extensions of this principle to learn what was the percentage of ash and its composition remaining after purification and clarification. It would also be of value to learn whether the effect of a small percentage of a wetting agent to assist the removal of the water content was investigated; also whether any steps had been taken by the oil companies concerned to prevent effectively the recurrence of the supply of unstable fuels.

The logical development of this process would be for the oil companies to supply ready centrifuged boiler fuel which might well then have an application for gas turbine work, and for a greater use in slow running Diesel engines, in which case the additional complication to ships' machinery would be negligible.

The figures quoted for wear were surprisingly good, and the additional piston ring wear, which in any case might not have been due to the fuel, would be a small price to pay for the high grade fuel saved. It would, however, be valuable to have more concrete information of the total percentage, over a period, of the fuel paid for but rejected in either purifier or clarifier.

It was to be hoped that the experiments would continue with other types of slow running Diesels, and would be extended to include medium speed types of engines.

Mr. E. MacKinnon (Visitor) said that the author's details of the fuel system were very interesting, and it would have been thought that a larger amount of re-designing of this system would have been necessary to effect the complete atomisation of the higher viscosity fuels.

The purifying of the fuel now became a major problem, and could hardly be carried out with standard centrifuges. The author stated that on the "Auricula" deposits in the purifier bowl after lengthy runs were small. From reports it was learnt that this was not the case, and further that the purifiers needed constant attention. The author appeared to have allowed for this by having fitted purifiers with a capacity very much in excess of requirements.

From reports available on the Compagnie Auxiliare de Navigation vessels using boiler oil as a Diesel fuel, particular importance was paid to the purifying of the fuel oil with a view to reducing wear in the various parts of the fuel system, and also to eliminate the tedious operation of manually cleaning the bowls, and having the purifiers under the constant observation of the engine room personnel. This company fitted a purifier of the self-cleaning type, which assisted greatly towards the above objective, and was able to maintain an adequate supply of clean oil. The cleaning of the bowl of this type of purifier occupied ten to fifteen seconds only (the purifier continuing to run at full speed), as against thirty minutes for cleaning the ordinary standard centrifuge.

The author's cost for his initial purifier installation would appear to be low. However, the additional cost of a self-cleaning centrifuge would show considerable saving in operating cost, and would be recovered in a comparatively short period of running.

Mr. H. J. Hetherington (Member) said that his remarks were made mainly from the viewpoint of the operating engineer, and also to give some account of earlier experiments in this field. Some years ago he served as chief engineer in an ex-German vessel built in 1924, with engines designed to burn boiler fuel. He gave the following further details from memory.

The main engine was a Krupp type 10 E.V. 6 cylinder, 4-stroke single acting, non-supercharged, 1,950 b.h.p. at 120 r.p.m. Blast pressure at full load was 65 atmospheres.

The fuel was treated by first warming to about 100 deg. F. and passing to a settling tank through a filter. From this settling tank it was sent to a second settling tank, thence through a second heater heated to about 150 deg. F., thence through another filter and centrifuged. From the purifier the fuel was again heated to about 180 deg. F., and thence passed to the service tank, which held about four hours supply of fuel.

The fuel heaters were supplied with steam from an exhaust gas boiler. The life of the cylinder liners was about four years, and their cost £40 each. From the reports of the German engineers who had been in the vessel when new, there was no difficulty with the burning of the boiler oil, and the experiment would, he felt sure, have been quite successful but for the trouble with the engine itself when running on any fuel. For one thing the m.i.p. was 7·5 atm. unusually high for a non-supercharged engine even of the present day. There were other faults of design, chiefly a bad compressor, and too complicated starting and cooling water systems. He felt sure, however, that boiler fuel could have been used in the standard Burmeister and Wain engine 20 years ago.

He added that he burnt fuel, which, although classed as Diesel oil, cost only 30s. per ton, and had a specific gravity of 0·940 without any difficulty from the fuel itself. One interesting fact about the vessel mentioned was that no trouble whatever was experienced when burning boiler oil in the auxiliary engines. In order that any false impressions may be avoided, he stated that the conditions were much more favourable with blast injection, and that the blast pressure was higher than that used in most contemporary engines. Starting and manœuvring on heavy fuel was not contemplated, and a higher rate of liner wear expected and allowed for.

When a number of engines were running on the grade of fuel mentioned in the paper, would this not become the Diesel oil of the future? As chief engineer of steam tankers chartered by an oil company, he found that, although when he started, he was supplied with fuel of a fairly good quality, after some time, and the installation of a new washing plant at Curaçao, the grade of bunkers supplied became worse and worse. In fact the best fuel he had in the latter stages was a mixture of creosote and fuel oil with a specific gravity of 1·1.

In conclusion he would like to emphasize one of the author's points, and to advise any superintendent or owner wishing to follow in his footsteps not to skimp the centrifuge, but to have plenty of capacity, and if in doubt, to adopt a larger size.

Mr. H. Mackegg (Member) said that his company had been associated with this work from the centrifuge point of view throughout, and he had been rather in the position of the "old gentleman sitting in the back of the bus", and had been able to watch the progress of these experiments from quite a favourable angle. He very greatly admired the frank and candid manner in which the author had detailed the results, be they favourable or unfavourable, and he ventured to suggest that such frank treatment of this very complicated subject considerably enhanced the value of this paper.

When first approached he thought they were able to give a certain amount of quite valuable information, because quite a number of people in the past had endeavoured to run Diesels on heavy fuel, but none of them very successfully. The principal reason for the success of the present experiments, from the point of view of the extraction of the deleterious solid matter, had been due to the fact that the author had followed the line that it was first of all necessary to determine the correct design and size of separator to be used, and the early tests had produced valuable information upon which to base decisions. The De Laval organisation, who were the original designers of the high speed centrifugal separator, had knowledge of the efficiencies which could be obtained by all existing designs, and after reviewing the whole range and carrying out a considerable amount of experiments therewith, the author decided that the large diameter medium speed disc type bowl, of the design shown in figure 9 in the paper, should be used in the "Auricula" experiments.

The purifier bowl indicated was the standard De Laval high efficiency disc type purifier bowl, fitted with a modified top disc to ensure that the water seal was maintained under all conditions when dealing with high gravity fuel.

The clarifier bowl was of practically standard construction, and whereas in existing machines the clarifier bowl was fitted with perforated discs which were screened at the top and bottom disc assembly, it should have been possible to slightly increase the efficiency of this bowl by using blank discs throughout and possibly modifying the distance between them.

Consideration was given to the possibility of using one of the several forms of self-discharging bowls, but the experiments were primarily to obtain the highest possible degree of separation in both machines, and it was an inherent feature in centrifuge design that any modification of the standard bowl indicated, such as provision of self-discharging facilities, tended to reduce the separating efficiency of the unit. This followed directly from the fact that, for any given bowl speed, the maximum dimensions of the bowl were limited by mechanical considerations, thus, if part of the volume of the bowl was utilized for devices to automatically discharge the solid, then the space left for clarification of the liquids was reduced, with consequent reduction in efficiency.

On the question of bowl cleaning, the author said that during the "Auricula" tests the bowl cleaning did not present any great difficulties, and even when the unstable fuel had been treated and the bowl cleaning became too frequent, it was found that hot fresh water when slowly passed through the bowl caused the sludge to pass out through the sludge outlet, and by using this method it was possible to run the purifier several days before shutting down for bowl cleaning.

Additionally, the large type centrifuge used provided a solid holding capacity in the bowl which was quite considerable, and, therefore, the conclusions were that this high efficiency purifier was the suitable type for this problem.

It should be borne in mind that if a slow feed of hot fresh water be provided this could be applied continuously if particularly dirty oil was encountered, thus ensuring continuous operation. The same question in relation to the clarifier did not arise, because the solid which was removed in that machine was very finely divided matter, and because of the adequate sludge holding capacity of the bowl this machine would run for probably a week without stoppage for cleaning.

It was found that the other critical features of the centrifugal treatment were throughput and temperature.

The position could, therefore, be summarised by stating that the results obtained by the author may always be attained, and would in the future be improved upon, by using the correct size of disc type bowl running with relatively low throughput at correct temperatures, at each stage. It was his company's considered opinion that such equipment as was installed in the "Auricula" was, per unit, entirely suitable for vessels of considerably higher power.

In dealing with the question of installation cost as it affected the centrifuge equipment, it should be borne in mind that the centrifuge purifiers which were usually fitted in motor ships using Diesel oil would not of course be installed in vessels which might be fitted with the combined purifier-clarifier heavy fuel oil separation unit, and, therefore, the cost of the Diesel oil separator equipment should be offset against the total cost of the combined unit equipment.

He stated that the whole question of obtaining high separating efficiency was dealt with in a paper entitled "Oil purifying with continuous lubrication" by Professor Forsberg of the De Laval organisation, which was published in the TRANSACTIONS in February 1940. Whilst this paper dealt with the purification of lubricating oil, the same principles expounded therein, of course, applied to fuel oil or any other comparable separation problem, and those who cared to investigate the theory laid down would find ample justification for the decision which the author made, relating to the size and design of the equipment which he decided to use, in the experiments under consideration.

He concluded by saying that research on this problem was continuing and it was hoped to place at the author's disposal still more effective separation equipment in the future.

Mr. J. F. Alcock (Visitor) said that he felt that the author might have underestimated the effect of supercharge in aiding the combustion of residual oil. In a recent experiment at the Ricardo laboratories, a small high speed engine, 5in. bore × 5·5in. stroke, Ricardo Comet Mk. III combustion chamber, was tested on Venezuelan Admiralty boiler fuel, similar to the No. 1 boiler fuel of Table 1. This had been centrifuged in the ordinary way but not clarified. The engine ran at 1,250 r.p.m., and had the standard fuel injection gear, with pintle self-cleaning nozzle, normally used with gas oil. Without supercharge the performance on boiler oil was very poor. Compared with gas oil the power (at the clean-exhaust limit) was 15 per cent. down and the minimum fuel consumption 12 per cent. up, while the exhaust was grey at all loads. Next 10lb. supercharge was applied, and the picture was completely transformed. Comparing again with the performance on gas oil under the same conditions, the power was only 3 per cent. down and the fuel consumption 3 per cent. up, the latter difference corresponding to the difference in heat value of the two fuels. At powers below the clean exhaust limit the exhaust was quite invisible.

Increase in air pressure, rather than in temperature, seemed to be the main cause of improved combustion, since the performance was the same with both hot and cold supercharge apart from the effect of the reduced volumetric efficiency with hot supercharge; this reduced the b.m.p. at the clean exaust limit from 192lb./in.^{2} gross with air at 30 deg. C. to 158lb./in.^{2} with air at 90 deg. C. In the cold-air test 78 per cent. of the air in the cylinder was burnt at the clean-exhaust limit.

These tests were only of a few hours duration, so they gave no clue as to the long-term endurance of such an engine on residual fuels, but they did show that these fuels could be burned efficiently even at engine speeds ten times greater than those of the author's engines.

Had the author any information as to the maximum size of solid particles left in the fuel after clarification? Very small particles seemed to be harmless. In an experiment made some years ago, "artificial dust" was fed to a petrol engine by mixing an organo-silicon compound with the fuel. On combustion this produced enough silica to render the inside of the exhaust system white instead of black, but the bore wear was if anything reduced. Even the ball and roller bearings in the crankcase did not object.

It would be of interest to know whether the fuel pumps had spill valves or spill ports; the latter type was more sensitive to plunger wear owing to the short sealing length.

On the voyage mentioned on page 20, when frequent bowl-cleaning became necessary, it was not clear how the need for bowl-cleaning became apparent. Was there some quick method of determining, e.g. by colour, whether an oil was properly clarified?

Mr. A. H. Ysselmuiden (Holland) (Visitor) said that for the tests described in this paper Admiralty boiler fuel oil and Ordoil had been used. The preparation and combustion of this last fuel oil were the real subject matters of the paper. Ordoil was specified in Tables 1 and 3, but not as completely as was necessary for an exact definition of this fuel. For instance what were the ignition qualities, how was the distillation-curve, what was the Cetane number, etc.?

There were several kinds of Diesel fuel oils and certainly not every Diesel fuel oil could be burned in every Diesel engine, not even in every marine Diesel engine. In the same way not every boiler fuel could be burnt in any marine Diesel engine, even if the viscosity was not over 1,500 secs. Redwood 1 at 100 deg. F.

The author said that boiler fuel oils were a mixture and that the proportions of its constituents, residual oil and distilled oil, were determined by specification requirements. Whose and which requirements were they?

Tests of boiler fuels with a viscosity above 1,500 secs. Redwood 1, 50 deg. F., though very attractive regarding price, were not mentioned in the paper. Was there any physical, chemical or other reason for the restriction to that limit?

If the ash could be extracted from the boiler fuels, there was every reason to hope that distilled fuels would no longer be necessary for Diesel engines. Were difficulties already encountered in centrifuging heavier boiler fuels or were they to be expected? One difficulty may have been that by heating the heavier fuels to the higher temperature required for centrifuging, lighter constituents may have been driven out, would that be in a higher degree than with the lighter Ordoil at the lower temperature?

The author had shown two phases of the problem, the technical and the economic one. He was right in doing so for what was the good of engineering not directed by economy? The profits calculated out of the use of Ordoil were based on a whole year's service. That meant that ships going all over the world must be offered the opportunity to bunker Ordoil anywhere and at any time. As soon as this was not the case the calculation may be affected seriously, or the ship must be confined to certain routes. Moreover, if the Ordoil supplied had proved to be not of the same quality as used for tests done by the author, the consequences may have been disappointing. Not only Diesel engine users, but the makers of such engines must be sure of the specification of the oil proposed to be used in their engines. Finally, the speaker asked if Ordoil was a special product of the Royal Dutch Shell group, or was it a product generally known in the oil trade, and would it be produced for a long time to come?

Mr. R. J. Welsh (Member) considered that this paper marked a milestone in the development of the heavy oil engine and that the principles it described would find application to engines of other makes and other sizes and, indeed, to prime movers of other forms. The author might well feel satisfied merely to record the very successful practical results achieved, but for the sake of considering the wider applications it would be most helpful if additional data and explanations could be given. For example, the analysis of the materials recovered from the purifier and the clarifier shown at the foot of page 9 would have their value considerably enhanced if corresponding figures could be given for the ash present in the original fuel. Without such comparative figures it was impossible to deduce what percentage of the various impurities had been removed, and it was, therefore, impossible to assess the exact reason for the "Auricula's" success.

The author's table indicated that in the case of vanadium oxide, for example, the extraction had been only a minute fraction of the quantity in the original oil, and it would be interesting if anyone could explain why the removal of so small an amount of the ash had produced so tremendous an improvement. It might be, as Mr. Alcock had suggested, that the question was one of particle size, but in this connection the speaker asked if the inorganic ash in the fuel was actually all present in the form of solid particles or whether, as he had always understood, much of it was in the form of oil-soluble salts which became ash only after the process of combustion.

It was clear that unstable fuels could not yet be tolerated, as the cost of cleaning purifiers every two hours might easily wipe out the difference in the fuel bill, besides making the ship thoroughly unpopular with her engineers. Compared with the usual Diesel fuel specification it was a big simplification to ask merely for "a stable oil of not more than 1,500 secs. viscosity at 100 deg. F.". It was difficult to believe that the oil companies would regard this as a specification so onerous that they could not undertake to abide by it.

In regard to the actual experiments in the "Auricula", he was very surprised to note the high fuel consumption which was apparently accepted without perturbation. In considering the merits of multi-engined ships it was commonly argued that one grave disadvantage of the scheme was the relatively high fuel consumptions of small engines, which might be as much as ·37lb./b.h.p./hr. In view of this attitude, it was difficult to understand the author's complacence with fuel consumptions of the order of ·48lb./b.h.p./hr.

The rates of wear accepted on these large engines were also somewhat surprising to anyone used to the more highly developed small engine types on which, with units running at 600 r.p.m., a figure of ·001in. per thousand hours was regarded as quite a heavy rate of wear. In comparing wear per million engine revolutions the author was perhaps a little unfair to his large engine, as on this million rev. basis it was not unusual to find engines of, say, 10in. bore, having wear rates about 1/60th of those given in the paper. Wear per million feet of piston travel might be a more equitable criterion.

At the foot of page 4 the author suggested that the volume of fuel injected was the same during the comparative tests on Diesel fuel and Admiralty fuel oil. A comparison of the consumption figures in Table 2 and the specific gravities shown in Table 1 indicated, however, that the volume with the Admiralty fuel was about 2½ per cent. greater, which indicated that the fuel pumps had a higher volumetric efficiency with the Admiralty fuel. This was rather surprising in view of the higher viscosity, and it would be interesting to know if there was any apparent reason for this.

The speaker concluded by asking the purpose of the Lolos strainer shown in Fig. 8. In view of the treatment the oil had received before reaching this filter, its function was not entirely obvious.

Mr. J. Calderwood, M.Sc. (Member of Council) said that he would like to refer to Mr. Welsh's comments regarding the rates of wear mentioned in the paper. Mr. Welsh, he felt, had made a comparison which was unfair to the author of the paper in that he had compared rates of wear of a stationary engine on industrial duty with the author's rates of wear on a direct coupled marine engine. It was always found that a marine propelling engine had a much greater rate of cylinder liner wear than a similar engine on industrial duty in a power station. This was no doubt largely due to the manœuvring, and cases had been known of industrial engines which were started up for periods of a few minutes at a time frequently during the day having rates of wear 10 to 15 times as high as those on engines running continuously. The actual rates of wear quoted by the author seemed very reasonable, particularly considering the grade of oil being burnt.

On page 2 of the paper the opinion was expressed that in the two-cycle type of engine if heavy fuel were used the sulphurous gases blowing past the piston rings would cause serious mechanical troubles. In fact in the past quite a number of two-cycle engines had run in service with heavy grades of fuel, in some instances with heavier fuels than those referred to by the author, and so far as was known, mechanical trouble in the crankcase had not arisen due to this cause. In fact in some respects the two-stroke engine was less likely to suffer in this way than a four-stroke, as the scavenging ports produced a belt of clean air at a pressure higher than the exhaust pressure, so that there was a tendency to blow any gas leakage into the exhaust ports.

Cases where corrosion trouble had occurred in the crankcase had been experienced with both two-cycle and four-cycle engines, and had not been confined to engines burning high sulphur oils, even petrol and gas engines having been known to experience trouble of this kind.

It was realised that the paper was only a brief report of a very extensive series of experiments, but from the description it appeared that between the first tests on Ordoil and the next series of tests, there had been changes in more than one condition, so that it was difficult to distinguish which of the alterations was responsible for the satisfactory running. The first test was tried without clarification at a low compression pressure and with low oil temperatures, whereas the second test was with clarified oil with an increased compression pressure and with heated oil, and from the paper it was not possible to say with certainty which of these factors had given the good results. Clarification no doubt was an important factor in engine wear, but would not seem to be likely to have any influence upon combustion.

Perhaps the author could add something to this question, and give some more explanation as to the influence of each of the factors, as, no doubt, intermediate tests had been carried out in addition to those described in the paper.

The problem of burning heavy fuel oils in a Diesel engine was not primarily one of combustion. Many engines had run in the past with the heavy grades of oil, and he felt that the main contribution of the paper was in the direction of reduction of engine wear when burning the heavier grades of fuel oil. It was hoped that information would be given in future of further experience with other grades of heavy fuel.

Mr. H. F. Jones (Visitor) referred to page 20 where the author stated: "On the seventh voyage of the 'Auricula' the bunkers shipped at Curaçao made it necessary to clean both the purifier and clarifier bowls every two hours, the total amount of matter extracted averaging 25lb. per ton of fuel treated". No doubt the author was concerned about this when he continued; "The thorough investigation which followed revealed that this particular shipment was derived from mixed paraffin base crudes and asphaltic base crudes, and that whilst such a mixture was stable at normal atmospheric temperatures, 'breakdown' occurred at 175 deg. F. It is most unusual refinery practice to mix such crudes, and, the author is informed, quite unnecessary".

If, as stated in the paper, it was quite unnecessary to mix such crudes, it should not also be assumed that mixing of residual fuels from such crudes in bunker installations was unnecessary or most unusual.

Even if such mixtures were unusual, there was still another factor to take into account. The operator might have had no option but to take fuels at whichever ports his ships had to call, and therefore, he might be unable to keep to exactly the same fuel. With this in mind, it was suggested that operators should refrain from leaving the discussion under the impression that periods of excessive cleaning of purifiers and clarifiers could be easily avoided.

Mr. H. F. Sherborne, M.C., M.A. (Associate) said that it was with considerable diffidence that he wished to take part in the discussion. He hoped that he would not be deemed so ignorant and ill-advised as to attempt gratuitously to drag his particular subject into the discussion before so experienced and critical an audience, but the point he wished to establish was a practical one as he would soon show. He thought that the paper bore the authentic hallmark of applied scholarship, and was likely to be the standard work of reference on the subject with which it dealt for some time to come. In these circumstances he wished to refer to the paragraph on page 13 in which occurred the following: "Other information regarding this engine which has a bearing on the experiments is that the cylinders, pistons, exhaust valves and fuel valves are cooled by fresh water, etc.".

The fresh water in question was no doubt in its turn cooled by sea water, which presumably was brought in at the side of the ship, conveyed through pipes to the heat exchanger where the fresh water was cooled, and having there done its work was discharged overboard. The temperature of the sea water on its way up to the heat exchanger would be that of the sea, on its way overboard some degrees higher. It was common knowledge that one of the things the war had revealed was that in naval vessels copper tubes were not reliable for the conveyance of salt water. When salt water passed through copper tubes the conditions as regards speed of flow, turbulence, aeration, and the like, were such as to produce the same type of corrosion attack of the metal as used to be observed years ago in condenser tubes when these were of brass. See Figs. 28-31.

There was nothing new in this type of attack on copper pipes, but the war had made it more generally observed, due to the universal speeding up of the flow of water through pipes in naval vessels

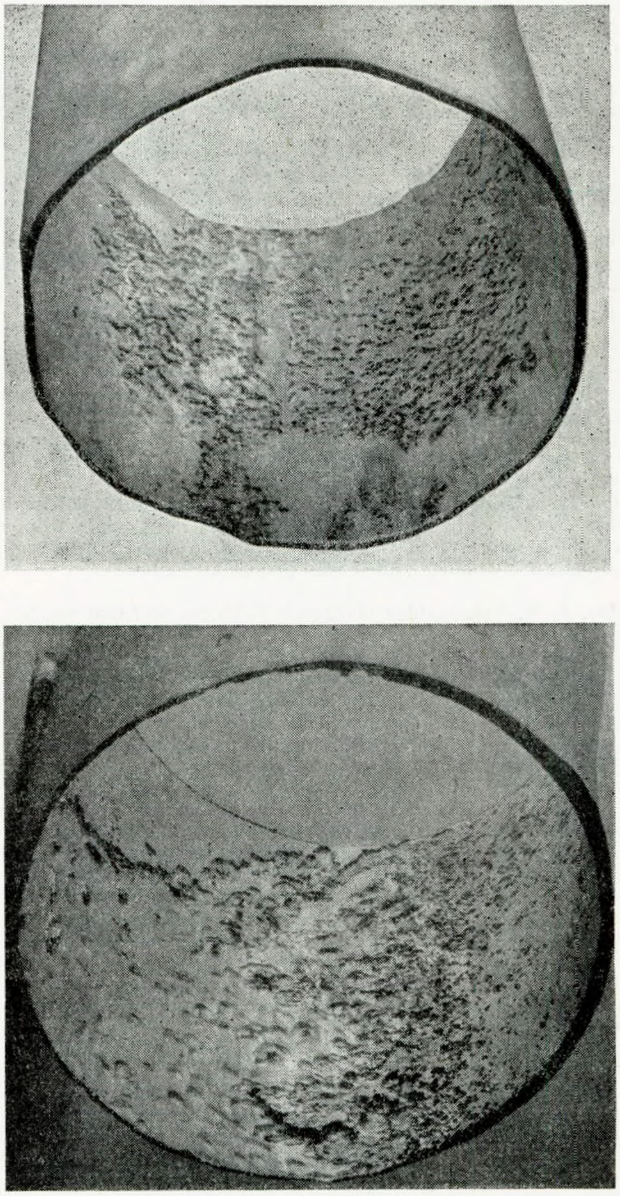


FIG. 28.—*Corroded eroded copper discharge pipes.*

and often enough in other ships as well. The speaker had been looking up some records, and had found that about eleven years ago, the author's company had been specifying aluminium brass, 76 per cent. copper, 22 per cent. zinc, and 2 per cent. aluminium, also a copper aluminium nickel silicon alloy approximately 81/85 per cent. copper, aluminium ·7/1·2 per cent., nickel ·8/1·4 per cent., silicon ·8/1·3 per cent. for the material of the pipes for the conveyance of salt water for the cooling of the fresh water in these engines. The accompanying photographs were of copper tubes corroded in the manner indicated, also of brass condenser tubes, to illustrate the similarity of the attack. If the author thought fit to ascertain the actual service performance of these pipes, also the opinion of those who had the job of fitting them, and publish his findings in his reply to the discussion, he would be performing a further public service.

The speaker was a member of the Corrosion Research Committee of the British Non-Ferrous Metals Research Association, on which the Institute was represented. Much money was being spent and effort being put forth by many people to determine the most suitable alloy for this very purpose, namely the conveyance of salt water through pipes. The author's company had specified and used aluminium brass pipes up to 9in. diameter, certainly as far back as 1936. If in fact these had proved entirely satisfactory in service, and the results could be published, such information would constitute a valuable contribution to what was known on the subject.

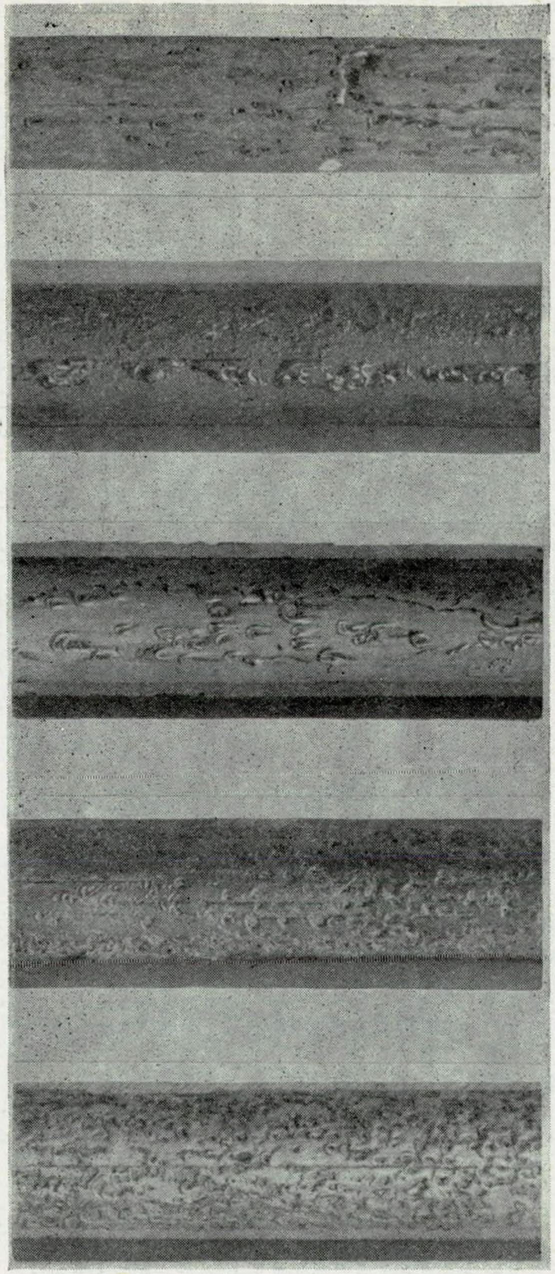


Fig. 31.—*Typical corrosion erosion or air impingement attack on old fashioned brass condenser tubes—completely inhibited by the use of aluminium brass tubes.*

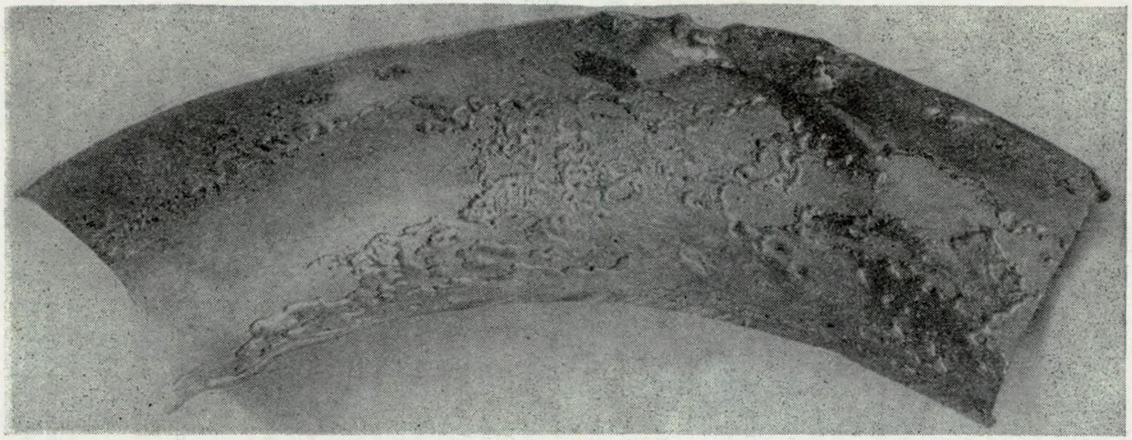


Fig. 29.—*Corrosion erosion or air impingement attack. Effect of salt water on copper tube under certain conditions of flow.*

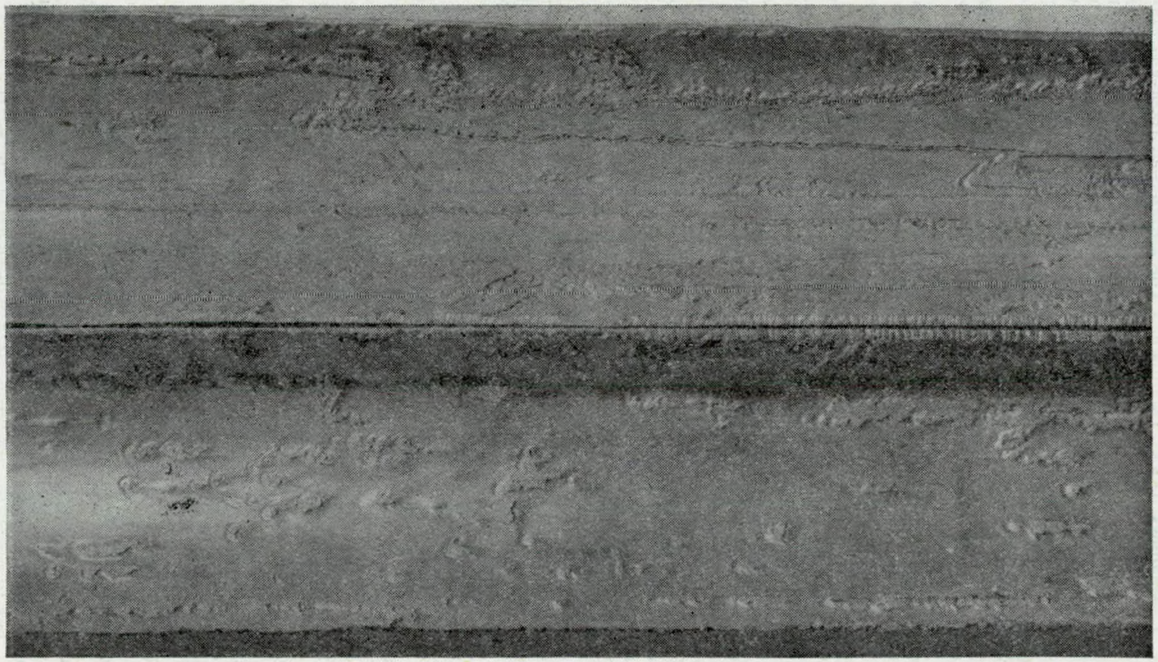


Fig. 30.—*Corrosion erosion or air impingement attack. Effect of salt water on copper pipe under certain conditions of flow.*

Mr. H. T. Meadows, D.S.C. (Member): The author had received the congratulations of many distinguished engineers, but it was felt that the occasion demanded some little recognition for the chief engineers of the "Auricula" and their staffs, without whose devotion to duty such a complete paper would not have been possible.

The question of contamination of the crankcase lubricating oil with sulphurous exhaust gases had quite rightly not been mentioned in the paper, as it did not arise. The combustion chambers in the engine of the "Auricula" were very effectively sealed from the crankcase. The author had however, told them of a short test with a Doxford engine using heavy fuel; they have also been told of tests on an experimental Werkspoor two-stroke cycle engine. These engines, in common with most two-stroke cycle engines, had combustion chambers which were separated from the crankcases only by piston rings. Tests on samples of crankcase lubricating oil over many years showed that such engines were much more prone to formation of soot in the oil, than were engines in which a positive piston rod gland was fitted. The finely divided particles of carbon found their way past the piston rings to the crankcase. By the same token then, would any particles of sulphur travel, and, unlike the inert carbon, produce sulphuric acid, given proper conditions. That there was a possibility of some sulphur remaining in the fuel was admitted by the author when he told them of the presence of a yellow streak on one of the pistons, and of the formation of sulphuric acid on the lagging around a leaking exhaust pipe joint. It would, therefore, appear that there was a possibility of contamination of the lubricating oil with sulphuric acid, with consequent corrosion troubles. Could the author give his views on this, and whether in his opinion this danger was very real, or whether such contamination would be taken care of by using a rust inhibited crankcase lubricating oil?

Mr. E. C. Warne (Member) pointed out that in the paper attention was drawn to the absence of smoke when the engine was running on boiler fuel. It seemed obvious that if there was any indication of smoke at the funnel of a motor ship, the combustion was poor, and this would mean that the fuel consumption would be so high as to demand immediate investigation.

The author was asked to amplify his description of the purifying installation which was used, as the speaker thought there was quite a lot left to the imagination. He referred especially to the clarifier, which went a long way towards making a success of the undertaking. The author suggested that the decision to use the centrifugal type of purifier was made because the static type of fuel filter would occupy too much space in the engine room. It would have to be a small engine room which would not take a suitably-sized static fuel filter, judging by the ships he had seen of much lower power than the "Auricula". He thought the author might give some more information about the purifier and clarifier design and what led to the decision to turn this type of purifier into a clarifier.

Mr. C. W. C. Martin (Visitor) said that they had been told several times that the author had not attempted anything new, but that it had all been tried before. He agreed that it had been tried previously, but this was the first time it had been tried successfully.

References had been made by other speakers to fuel oil from Curaçao, but this was not the only source of heavy fuel; there were, and would continue to be, many different types of fuel oil, of varied origin, and with all of them the user must be prepared for ash in some proportion. Perhaps some of these speakers had forgotten the old Mexican fuel oils.

Mr. Ysselmuiden had asked the question "What is Ordoil?" This, the speaker said had been a trade name for a very long time. It was simply an ordinary grade of commercial fuel oil but lower in viscosity than bunker "C" grade.

Commander Baker had said quite a lot about the type of boiler fuel which was being supplied to "the unfortunate marine engineer", and had suggested that the oil companies should do something with regard to the centrifuging of this oil. The speaker said that he imagined the total consumption of boiler fuel for steamers was about 30,000,000 tons a year; he thought this an awful lot to put through centrifuges, and asked "Where would it be done?" He doubted very much whether there was any point in doing this at the refinery, even if it were possible. The oil might be shipped half-way across the world in a tanker before the ship's engineer even saw it. It might also have been some time in shore storage before it got into his own tanks. Obviously, if centrifuging were to be done at all, it must be done at the last possible moment before the fuel was burnt, and this was the way the author had approached the problem.

Mr. E. L. Harland (Visitor) said that the question he wished to ask had been suggested by an earlier speaker who seemed to be under the impression that to obtain successful operation on Pool Diesel fuel represented a useful intermediate stage between restricting a big engine to the use of gas oil and feeding it on boiler oil. This illustrated a misapprehension which at such a meeting should be corrected, for in this country there was nothing whatever to choose between Pool Diesel fuel and gas oil so far as large engines of the type under consideration were concerned. Admittedly, overseas, a grade referred to as "Diesel fuel" might, and frequently did, contain a significant residual component. But the designations adopted by the Petroleum Board had not by any means the same implication, and the speaker thought the Board would agreed that their 100 per cent. distillate grade, Pool Diesel, was in most respects indistinguishable from a "gas oil". Manufacturers, therefore, who had only tested their engines on this grade had a *very* long way to go before tackling under-boiler fuel oils.

The grade specifically manufactured for motor vessel use, and usually containing a significant percentage of residual fuel was Pool *marine* Diesel fuel—with its equivalents at overseas ports. This was what all motor vessels should have used successfully before their owners aspired to taking under-boiler fuel oils; and yet, allegations of difficulty with such grades were still heard.

Had the author ever experienced difficulty in using marine Diesel fuel in his fleet? If not, to what extent did he consider these reports pointed to inherent sensitivity of some engines, and to what extent might they be due to unsatisfactory conditions of operation and maintenance? Might some of them simply indicate an unnecessary fear of what had not been really seriously tried?

Mr. B. P. Fielden (Member) wrote that this paper was one more contribution towards the advance of science and practice of marine engineering. He thought the paper was a very valuable one and was presented at a very difficult time for British shipping.

He considered Newcastle was an ideal place for an engine to be installed to test oil. He then referred to the price of boiler oil at West Indian ports as being between 56s. 11d. and 65s. 8d., and the calorific value as between 18,300 and 18,750 B.T.U.s, and then house coal which had increased from 86s. 8d. per ton in 1946 to 101s. 8d. in November 1947, and he thought the calorific value was probably less than 13,000.

Under present conditions it was assumed that where oil was obtainable for ships it was more economic than coal. He thought the prospects for firemen and trimmers were not good, and recommended young marine engineers to study closely the information given in the paper.

Mr. E. F. Souchotte (Member of Council) stated that the paper under discussion, being an account of successful endeavour, resulting from much clear thinking, forethought and resourcefulness, must command admiration; this was especially true of the author's approach to the work. Since similar experience was limited it presented a problem to those who wished to make a useful contribution.

A full scale experiment, directed towards the same ends as the author's work, was carried out some years ago in the motorships of the fleet with which the writer was associated, but was brought to an end by the outbreak of war. Since the ships concerned were bunkering at a number of stations throughout the world, the information collected on their performance was often conflicting, and they had some difficulty in arriving at conclusions whose bases would satisfy them. They formed some conclusions which were borne out by the author's work and were somewhat as follows:—"Furnace fuels contain abrasive solids which, unless removed, make mechanical operation of the fuel injection equipment impossible. They also, because of their varying content of cracked residues, include matter which is reluctant to burn completely, though trifling quantities which are completely incombustible. Complete combustion can be attained if the fuel is delivered to the cylinder in the right condition and into intimate contact with air at the right temperature, there being adequate time allowed".

When a furnace fuel was difficult to burn, the addition of varying amounts of Diesel oil wrought an immediate improvement in combustion. It was impossible to say whether the improvement was due to the lowered viscosity and improved atomisation or to a better rate of flame propagation, arising from the presence of the greater quantity of distillate, and the consequent more rapid attainment of the maximum temperature of combustion, thus overcoming the reluctance to burn, of the cracked residual components. The author's experience was that these latter were thrown out during centrifuging under proper conditions, or were made amenable by pre-injection heating.

The writer's experience was that after-burning occurred to a widely varying extent with furnace fuels of quite low viscosities (250-350 secs. Redwood 1 at 100 deg. F.), and that many oils bunkered as normal Diesel fuels had been much more troublesome in the engine cylinders than was the heaviest fuel used in the "Auricula". There were two conclusions which might be drawn from this, one comforting. He was not sure which one to draw.

The data presented showed some differences in maximum cylinder pressure which were not explained in the text, of Tables 4, 5, 6 and 9. Would the author comment on these, please? The writer had not previously observed that indicators, using such springs as those used when taking the cards shown, responded to variations in cylinder pressure (Figs. 13 and 14). Could it be confirmed that they did so?

The work done on injection pressures indicated that effective fuel injection did not necessarily commence at the moment when the fuel valve spring load was overcome by hydraulic pressure, but at some later time determined by nozzle resistance. This being so, precise timing of injection, fundamental to good combustion, demanded a relationship between fuel pump acceleration or cam profile fuel viscosity and the number and diameter of the nozzle openings. The existance of a critical relationship of the latter had been observed, a relationship between fuel pump acceleration or cam profile, fuel injection systems than was common, if the range of fuel viscosity demanded by world wide bunkering was to be acceptable. The viscosity of a satisfactory fuel for Diesel engines would then be limited only by the temperature at which it could be handled safely in the centrifuges and by the fuel injection equipment. The cooled nozzle had an advantage in this respect, too.

Comparisons between the rates of wear in single acting four stroke and double acting two stroke engines showed that while the incidents of wear accompanied the temperature gradient in the cylinder wall, the rate was generally proportional to the heat released per unit of cylinder area. It was influenced by a number of other factors, amongst which it had been noted that an abundance of scavenge air had a marked beneficial effect in the cylinders. It was to be expected that the supercharged engine would be more flexible in its fuel requirements than the naturally aspirated, and this factor might be expected to influence the two-stroke engine in a comparable way. Having regard to the lower temperature of the exhaust gases of the latter and the tendency of the di- and tri-oxides of sulphur to raise the dew point of these, some additional care and/or modification of cooling systems might be necessary, in order to maintain temperature at reduced loads, especially at the end of long passages when the mechanical condition of the engine had deteriorated.

Irregular piston ring wear of the nature described occurred from time to time, the cause being elusive; there seemed to be a connection between such wear and the combustion conditions associated with ignition delay. A free gap of two millimetres might be insufficient for such cylinder conditions.

The author had tackled and solved his problem in an eminently practical way, and their thanks were due to him for his informative paper. The economics of steam and oil engine operation have been influenced by his work; the oil engine designer had an important new problem and a contribution to make. Would not some of the preparation of the oil be done more economically at the refinery?

Mr. A. T. Webb (Member) stated that it would be interesting to know the composition of the metal used in the engine concerned, for both levers and piston rings and the treatment, if any, given to the working surfaces when fitted. In other words the statement "standard Hawthorn Werkspoor" did not convey very much to those who did not know this firm's practice.

Experience compelled one to offer a word of criticism quite irrelevant to the direct object of the paper submitted. Great stress was laid on the treatment of the fuel oil before use in the engine, yet the machines used to accomplish this end were perched literally "on the shelf" with a system of pipe lines which spelt trouble for the operating engineer.

The merit of a layout was judged by its failings, and whilst the majority of fuel supplied to a ship would not give trouble from a sludge point of view, the odd quantity of sludge which would be encountered, such as described in the paper, would cause considerable work in the disposal of the waste cast out from the purifier. In short the position of the purifying plant should be nearer the critical eye of the senior engineer on watch, and the waste discharge open to view, so that in the event of failure, usable oil would not run to waste, nor would heavy sludge clog the pipes and so shorten the period of effective purifying between cleanings of the machines. The writer had handled Diesel fuel of the recognised type which, in the process of purifying, had caused considerable trouble due to the clogging nature of the waste from the centrifuge. He would, therefore, suggest that a better position adjacent to a pump could be found, arranged so that the platform on which the purifying plant was seated would form the sludge tank top, with open conical shaped pipes from waste outlets to sludge tank. The sludge tank outlet should then be coupled direct to a pump suction chest. The purifying plant should not be located any higher in the ship than would allow a head of sludge from sludge tank to pump suction. It was suggested that this would greatly assist ships engineers to maintain the standard of purification called for in the burning of the fuel described in the paper.

Mr. H. R. Williams (Member) and **Mr. M. M. Hallett, M.Sc., F.I.M.** (Visitor) expressed the opinion that the paper would surely be regarded as a classic, dealing as it did with an investigation of the highest importance, carried out with the greatest care and thoroughness. It was seldom that a study of this type led to such outstandingly successful practical conclusions.

The author appeared to be entirely satisfied with the performance of all the engine components except the piston rings, and even with these, his dissatisfaction was directed to piston ring wear in general service, rather than to increased wear as a result of burning boiler fuel oil.

The writers agreed that many of the wear figures quoted in the paper were unsatisfactory, and warranted immediate attention. This applied even when due allowance had been made for the unavoidable variations in operating conditions inherent in marine Diesel practice, and for the difficulty in maintaining constant material characteristics, in these days of pig iron shortage.

The paper suggested that piston rings with a Brinall hardness higher than 200 might have superior wear resisting qualities, and it might be interesting to consider some of the possibilities in this direction. In the first place, it must be emphasized that wear resistance was not an inherent and constant quality in a given material, nor was Brinell hardness a safe indication of wear resistance.

Secondly, in any case involving wear resistance, both the contacting members must be considered, and the operating conditions, especially lubrication, borne in mind. For example, the evidence given in the paper suggested that liner wear was small. It was by no means impossible that a change in liner material might cure piston ring wear without an increase in liner wear. It was, of course, preferable for the rings to wear before the liner, rather than for the reverse to occur.

Wear resistance was a function, not only of hardness, but also of bearing or running properties as well as of a number of other factors. Many of these were related to the microstructure of the material. The rings employed in these tests were of a sand cast grey iron of fairly high total carbon and low silicon contents, leading to a microstructure of comparatively coarse graphite flakes in a tough fully pearlitic matrix. The writers attached considerable importance to the presence of an adequate amount of graphite in the structure because of its beneficial influence on self lubricating properties; the elimination of the soft ferrite constituent was well recognised, and was important.

Hardening could be effected either by decreasing the size or quantity of the graphite flakes, or by refining and hardening the matrix. A simple method of decreasing the size of the flakes without altering the total quantity of the graphite was by centrifugal casting, though some doubt existed as to whether the structure so produced had such good wearing properties.

Addition of alloys to the iron tended to refine the matrix as well as the graphite. Again it might be that the abrasion resistance was improved at the expense of the self-lubricating qualities. Full hardening of the rings was also a possibility, but the hardened rings tended to be so brittle as to lead to serious difficulties in production and possibly in operation. Consideration must also be given to changes in the phosphorus content, and to various surface treatments designed to increase the hardness, corrosion resistance, or running properties of the rings.

Surprisingly little work had been done in the marine Diesel field on a systematic investigation into the influence of metallurgical factors on piston ring performance. Material specifications were based too much on empirical data or even on guesswork.

The writers, therefore, welcomed very much the opportunity afforded them by the author to co-operate in his tests. They believed that the installation of the experimental engine represented a most important step forward, since it would enable such factors as those outlined above to be investigated under constant reproducible conditions, and would lead to the ideals aimed at, namely maximum efficiency of engine operation, with minimum wear of all working parts.

The projected experimental programme thus included tests under the same conditions (preferably in a well run-in liner, since with a new liner initial ring wear might be high).

(a) Centrifugally cast grey iron rings, with a Brinell hardness of about 240

(b) Centrifugally cast chrome molybdenum grey iron, with a Brinell hardness of about 280

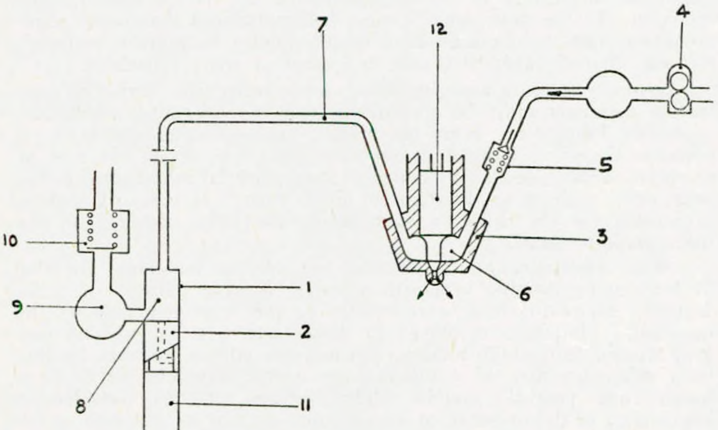
(c) Sand cast good quality rings of about 190 Brinell, i.e. the type which has given generally good service in the marine Diesel field

(d) A slightly harder sand cast ring, perhaps of a higher phosphorus content.

Such a programme, carried out with similar variations in liner materials, would enable definite answers to be given to a number of outstanding questions.

Professor ir. J. J. Broeze (Holland) (Visitor) stated that the matter of burning cheaper grades of oil in Diesel engines had received much attention by him over a long period of time, and several of his publications had tried to draw the attention of fuel users and engine builders alike to this obvious way of economizing. Although there always was interest from technical levels, the practical effect expressed in numbers of installations converted remained small, apart from the very economically minded countries like France and Italy. There, several ships were operated on fuels similar to or even heavier than that described by the author and present policy was to proceed along these lines. The great significance of the paper was that the author had worked out the technique of dealing with heavy fuel to such great detail and had been so accurate and complete in describing it.

Three points of interest may be mentioned with a view towards further development. First, apart from proper design and cooling of the injector, a proper functioning of the injection system as a whole was required giving a sharp, clean cut-off at the end of the injection period. This condition allowed of calculating injection pressures and valve lifts to a high degree of accuracy, and in recent years they had also been checking up the injection system operation of several motorships with the aid of simple tools which stood up to the difficult conditions of working aboard ship. It would appear from the results obtained that the conditions of injection in the author's Werkspoor engines were very good, and the calculations made confirmed this.



1.—Fuel pump.
2.—Piston slide.
3.—Atomiser.
4.—Low pressure cooling pump.
5.—Back pressure valve.
6.—Fuel space.
7.—Pressure line.
8.—Pumping space.
9.—Chamber.
10.—Spring loaded valve.
11.—Fuel pump plunger.
12.—Spring loaded differential needle valve.

FIG. 32.—*"Pilgrim" Fuel Injector for a combustion engine.*

As to the "simple tools" for checking injection pressures and injector valve lift, the writer said he would describe them fully within a short space of time. They had gone back to "plain mechanics" for this sort of thing, with one small exception, i.e. an electric neon flash light indicator. The idea was as follows: the upward movement of a pressure membrane (for the pressure indicator) or needle valve at a certain position of the crankshaft, say 15 deg. before t.d.c., was observed by feeling for its position with a micrometer screw having a spring contact. If the contact was made, the flash light registered it, and the micrometer reading was taken. The crank angle position, which was obtained from a contact on a protractor, was then changed to, say, 14 deg before t.d.c and the next reading was taken. In this manner the fuel pressure and valve lift diagrams were taken at the same time, by point-by-point method. It took some time, it was true, but had the advantage that the readings were obtained in the most direct way and without intricate electronics. The result was very accurate and dependable, both type of diagrams being reproducible down to small detail, which went a long way to make direct comparisons with calculation possible. The valve lift limitation was checked acurately to less than *1/2,000in.*, which had resulted in finding out errors in its setting, and so on. He would like to present full details, even working drawings, as soon as he could, but just now he could not do much more than produce two photographs of the pressure recorder shown in Figs. 33 and 34.

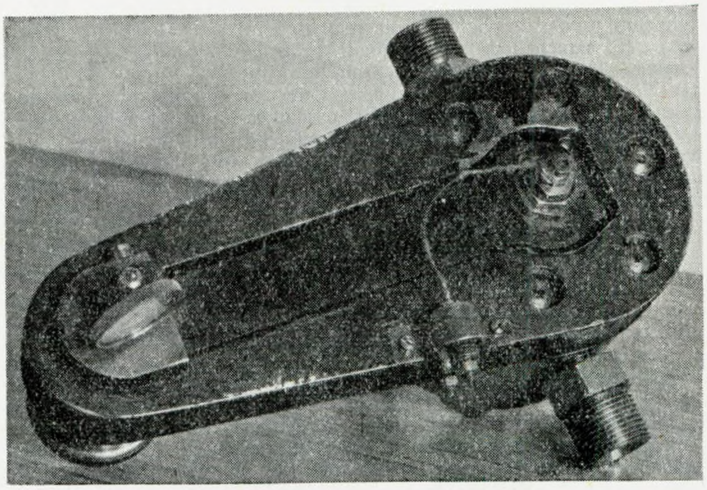


FIG. 33.

Second, the importance of keeping the fuel at its proper temperature under all conditions had been stressed by the author. In this respect, the writer would like to draw attention to the "Pilgrim" injection system, shown in Fig. 32. This was mainly intended as a system which provided for injector cooling by means of the fuel, and which allowed of circulation of fuel at its proper temperature through the injector and pipe system even before starting the engine. The "Pilgrim" injection system was fully described in the June, 1947 issue of "The Motor Ship".

Third, it had been our general experience, particularly when dealing with heavy fuels, that the rate of piston ring wear, which was still relatively high, was reduced very much indeed in conjunction with chromium plated cylinder liners. A reduction of 90 percent might, in effect, be expected.

They have had some, admittedly, short runs on C-grade fuel in a small four-stroke engine in their laboratory and described them in a paper "Diesel Engines and the World's Fuel Supply" to the D.E.U.A., 1938 (S.147). The result of chromium plating the cylinder was a reduction of ring gap increase from 4 (0·16in.) to 0·1 mm. (0·004in.) in 200 hours at an exceedingly high b.m.e.p. (vide "Fuel and Wear in Diesel Engines", "The Motor Ship", September, 1938).

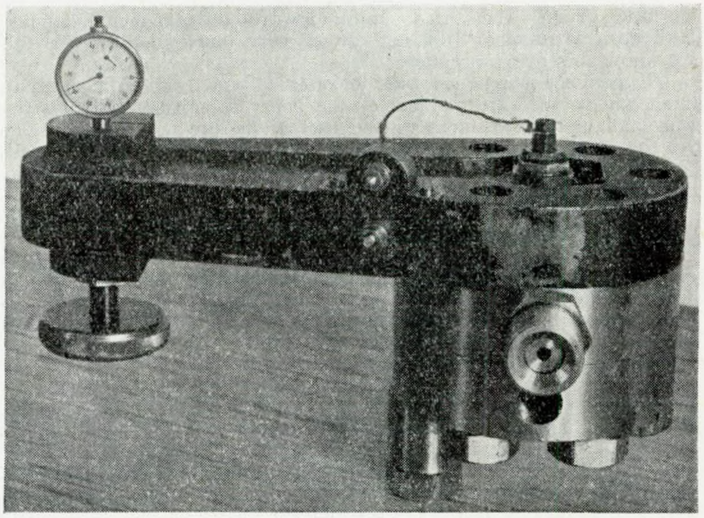


FIG. 34.

The Author's Reply to the Discussion

The author, in reply to Mr. Jackson, said that it was generally known that the late Mr. Keller gave some thought to the burning of heavy fuels in Doxford opposed piston engines and his understanding was that this eminent engineer achieved some measure of success, but for reasons unknown to him the attempts were abandoned. Mr. Jackson mentioned that in airless injection engines trumpets formed around the fuel valve nozzles, fuel pump plungers became scored and piston rings stuck and wore excessively. As no such difficulties were experienced in the "Auricula" when the heavy fuel was treated in the manner recommended by the author, he presumed that the troubles mentioned were the cause of the attempts to burn untreated heavy fuel in the Doxford engine being abandoned. Mr. Jackson's useful contribution would have been of even greater value had he told them something of Mr. Keller's experiments.

The author could not agree with Mr. Jackson's statement that the "common rail" system of the Doxford engine was better adapted to the use of boiler fuels than systems employing the "jerk" type of injection pump. He saw no reason why the Doxford engine could not use boiler fuel successfully provided the fuel was first treated as recommended in the paper, but the facts were that at the moment several engines with the "jerk" type of pump were operating on boiler fuel with entire satisfaction, and so far as he was aware the first Doxford engine had yet to operate at sea with equal results. The first would probably be in a ship now nearing completion and for which he was technically responsible.

Regarding the test-bed trial of a Doxford engine referred to by Mr. Jackson, the author stated that the engine was first tuned up on Pool Marine Diesel fuel, not marine fuel oil, and then changed over to fuel of 1,500 sec. Redwood I at 100 deg. F. after it had been purified in the same manner as the fuel in the "Auricula". The results of this short test suggested that after some minor adjustments had been made to the fuel injection and atomising devices there was reason to hope that this opposed piston two-cycle engine would operate successfully on specially treated heavy fuel. Mr. Jackson's recommendations in this connection were appreciated.

To Mr. Jackson's query regarding the analysis of fuel before and after treatment, the author could but refer him to the third and fourth paragraph on page 10 of the paper.

The fuel consumption of the experimental engine was admittedly high when operating on Admiralty fuel oil. This was pointed out in the second paragraph on page 4 of the paper. It was realised that a better fuel consumption figure would be obtained by injecting the fuel earlier, but this alteration was not made for two reasons, the first being that the engine at that time started and finished each run on Diesel fuel which produced a much higher pressure rise upon injection, and secondly, the tests referred to in Table 2 were run to obtain comparative data and not the least fuel consumption per unit power developed.

Regarding the effect of sulphur in fuel, the author could only state that the "Auricula" had now operated continuously for 17 months on fuels having a sulphur content of between 2·5 and 3 per cent. and there was absolutely no indication whatsoever of any deleterious effect.

Mr. Jackson stated that the cylinder liner wear in the "Auricula" was four times greater than normal and that Doxford's practice was to consider the average life of a liner as 50,000 hours. If the wear rate was ·001in. per thousand hours this meant that the large and costly Doxford liners would require to be renewed when the maximum wear was .050in. or 1·25 mm. The normal maximum enlargement of other types was 6 mm. He could assure Mr. Jackson that the normal wear rate of cylinder liners of all types of Diesel engines, including several Doxford engines, under his charge was very much greater than the figure quoted by him.

The satisfactory burning of 1,500 sec. fuel was only the first stage of these experiments. The burning of 3,000 sec. fuel was already being proceeded with, and if these tests proved as successful as the one described in the paper, the next step would be an endeavour to burn "C" grade fuel in a manner that would justify the continued use of such fuel.

Mr. Lugt's brief reference to his new two-cycle engine, the principal features of which were a considerable saving in weight and space for a given power developed, was most interesting, and he was to be congratulated upon giving this matter such intensive study under conditions that must have been extremely difficult.

Mr. Lugt had run the prototype of this new engine on 1,500 sec. fuel, purified as recommended in the paper, and although the test was of short duration owing to the limited time available between making the decision to try out the engine on heavy fuel and the reading of the paper, the results given in his contribution to the discussion were encouraging.

Upon such a test no conclusions could, of course, be reached as to cylinder liner wear, but from the photographs of the fuel valve nozzles taken immediately after the test, and after examining the pressures and temperatures produced, together with the absence of discoloration of the exhaust gases, the indications were that this two-cycle engine would have no difficulty in burning purified boiler fuel satisfactorily.

The question raised by Mr. Harland was irrelevant to the matter under discussion, but the author thought he would have difficulty in finding a marine Diesel engine designer or builder who would agree that his engine could not operate satisfactorily on so-called marine Diesel fuel.

Regarding Mr. Meadows's opening remark, the author would confirm that the chief engineers of the "Auricula" did what was expected of them, but it would be quite wrong to create the impression that a super chief engineer was necessary to operate Diesel engines satisfactorily on heavy fuel in the manner recommended in the paper. Anticipating this possibility he purposely changed the chief engineers after the "Auricula" had been six months in commission, and no attempt was made to hand-pick either chief. The chief engineer during the second six months was only 28 years of age, and the "Auricula" was his first chief's job. When questioned by a representative of the technical press regarding the performance of the engine this chief engineer remarked "So far as my work is concerned it makes no difference whether the engine is running on Diesel fuel or heavy fuel".

Mr. Meadows was apparently not fully conversant with the construction of the under-piston supercharge system, as he stated that the combustion chambers of the "Auricula" engine were very effectively sealed from the crankcase. In this respect the "Auricula's" engines were the same as any other four-cycle engine. The bottom of the cylinders might be enclosed but any gases passing the piston rings were only prevented from reaching the crankcase by the gland through which the piston rod reciprocated. Actually there was more chance of gases from the combustion chamber reaching the crankcase with under-piston supercharge than when the undersides of the cylinders were open. In neither case, however, would the crankcase oil be contaminated with sulphur laden gas unless the piston rings were allowed to leak. This applied also to engines of the two-cycle type.

Any fuel which was the direct cause of piston rings jamming could not be considered satisfactory, and had this difficulty not been overcome when burning 1,500 sec. fuel the claim that these experiments had been completely successful would not have been made. The statement in the paper that after 12 months' operation under arduous conditions every piston ring of the "Auricula" was not only quite free, but so free that they could be rotated in their grooves by the fingers, should convince anyone that combustion had been all that could be desired.

Regarding the effect of the 2·5 to 3 per cent. sulphur content of the fuels used in the "Auricula"', the author's remarks which were supplementary to the paper were that during the whole of the 12 months' operation there was no evidence of the high sulphur content. Towards the end of that time, however, one of the exhaust manifold joints began to leak and a yellow sulphur-like substance was deposited on the asbestos lagging in the vicinity of the joint. Chemical examination of this substance disclosed that it was composed of vanadium pentoxide V_2O_5 (yellow), traces of soluble sulphates, and a very small amount of free sulphuric acid. Free sulphur was not present. The report upon this examination concluded with the statement that the results of this analysis did not indicate abnormal combustion conditions. Further remarks regarding the effect, or rather the absence thereof, of a high sulphur content, would be found in the author's reply to Mr. Jackson.

The fact that sulphur was a combustible was not realised by some. Being a combustible, if the combustion in the cylinder of a Diesel engine was perfect the whole of the sulphur content in the fuel should be consumed. It was known, however, that the combustion was not absolutely perfect, so that traces of the sulphur in the form of sulphurous fumes passed to the atmosphere with the exhaust gases. The quantity of sulphurous fumes, however, was so small and their nature such that so long as their temperature was maintained well above the condensing temperature of steam, they had no effect whatsoever upon the ferric metal parts of the exhaust passages. The condition when sulphur in fuel was likely to have a detrimental effect was when piston rings were allowed to leak. Under such a condition the sulphurous fumes were released before combustion was complete, and moreover, were allowed to leak into the atmosphere, which was at a temperature that would allow the sulphurous fumes to mix with water and form sulphuric acid. In the event of this sulphuric acid entering the crankcase and mixing with the lubricating oil, corrosion of the steel parts in the crankcase could only be expected.

The general opinion among marine engineers was, the author thought, that in most cases when corrosion of steel parts inside the crankcase was found, the cause was salt water mixing with the lubricating oil. In a few cases the cause had been traced to burning gases (not exhaust gases) passing the piston rings and finding their way into the crankcases. This of course occurred mostly in two-cycle engines. If, therefore, the ill effect of a high sulphur content in the fuels used was to be avoided either in the exhaust passages or the engine crankcase, the simple remedy was to pay proper attention to the piston rings and renew them before the wear was so great that leakage of gas occurred.

Messrs. Williams and Hallett's contribution was very welcome, and it was to be hoped that they would continue to apply their expert knowledge to a problem that was causing shipowners no little concern.

If the reciprocating piston engine was not to succumb to the competition of a power producer of the rotary type at a much earlier date than many anticipated, the cost of operating reciprocating engines must be reduced very substantially. Apart from the higher prices charged for spare parts such as piston rings, which was to a certain extent understandable, the cost of fitting such parts had increased three to four times in the past 10 years, and unless something could be done to give various wearable parts longer life, so that less frequent opening up was required, the passing of the reciprocating engine was assured.

The author's thanks were due to Mr. Souchotte for his interesting contribution, and for providing the author with the results of certain pre-war experiments at a time when he was engaged upon drawing up plans for his own experiments.

Regarding the effect of adding Diesel fuel to boiler fuel, the author, too, found that such an addition wrought an immediate improvement in combustion. The reason was, he thought, that the Diesel fuel resulted in the ignition and burning being accelerated. During his experiments it was found that as the proportion of low viscosity fuel in the mixture was decreased the pressure rise upon injection of fuel became proportionately less. The effect of adding Diesel fuel was, of course, to reduce the viscosity of the mixture, and Mr. Souchotte was possibly right when he suggested that the improvement in combustion might have been due to better atomisation. This could only be to a small extent, however, as when heavy fuel was heated to a temperature sufficiently high to reduce its viscosity to that of Diesel fuel, the rate of combustion, i.e. the pressure rise upon injection, on heavy fuel was still less than it was on Diesel fuel. In view of this the conclusion reached was that the addition of low viscosity fuel reduced the proportion of the slower burning constituents in the heavy fuel, and in consequence combustion was accelerated. These remarks referred to untreated heavy fuel.

It had been conclusively proved that in slow-speed Diesel engines there was sufficient time for the slower burning constituents to burn completely without the addition of low viscosity fuel, and the reason why Mr. Souchotte did not get the desired results was doubtless due to the heavy fuel not having the ash and the certain slow burning constituents removed before it was delivered to the engine.

The lower pressure rise upon injection when using heavy fuel would be reflected in the fuel consumption per unit power developed, so that in order to obtain the best results in this direction it was advisable to advance the timing of the fuel injection pumps when converting an engine to burn heavy fuel.

The reason for the differences in the cylinder maximum pressures would be found in the varying supercharge air pressures. As regards the pressures shown in Tables 4 and 5, the maximum pressure in the former was recorded when the experimental engine was operating with a compression pressure of about 500lb./sq. in. and a supercharge air pressure of 5½lb./sq. in., whilst the corresponding pressure in Table 5 was recorded when the compression pressure was about 450lb./sq. in. and the supercharge air pressure 4½lb./sq. in. It should be mentioned that the difference in these compression pressures was not due to the difference in the supercharge air pressures. Varying the supercharge air pressure would have this effect, but the difference in this instance was mainly due to having a smaller compression clearance volume when the pressures recorded in Table 4 were taken.

The greatest differences in maximum pressures were found when comparing Tables 6 and 9. Those shown in the former Table were recorded on the sea trials, and those in Table 9 after the ship had been in commission about ten months. On the sea trials the ship was in ballast trim, and fully loaded when Table 9 was compiled. This was indicated by the i.h.p. developed and the r.p.m. Although the powers developed on each occasion were the same, the revolutions varied by 7·5 per minute. Even so the author was of the opinion that the pressures recorded in Table 6 were below the actual, and the only explanation that could be given was that for this test a new indicator was used.

Mr. Webb desired to know the composition of the metal used for the cylinder liners and piston rings in the "Auricula", and if the rubbing surfaces of these parts were treated in any way before being fitted.

As mentioned in the paper, this engine was not built for the author's company, and the decision to instal the fuel purifying equipment to enable the ship to operate on boiler fuel was taken within a month of the ship being ready for sea. There was, therefore, no time to treat specially the rubbing surfaces of the parts mentioned or even to obtain accurate gaugings. Without having had conclusive experience he felt that chrome hardening of the wearing surfaces of cylinder liners and piston rings would have beneficial results, provided that the surfaces were plain and unbroken such as the bore of a four-cycle engine cylinder liner.

As regards the composition of the metal used in the "Auricula", the author regretted that as the engines in question were not built to his company's specification he was not at liberty to divulge this information, which, no doubt, could be obtained from the makers of the engine. The statement in the paper that in material and design the "Auricula's" engine followed standard practice was made merely to indicate that in these respects the engine was exactly the same as would have been the case had it been intended to operate on Diesel fuel. The purpose of the paper was to show that the extent of wear when operating on boiler fuel was no greater than when operating on Diesel fuel, irrespective of the composition of the material used, and not to prove the effect of varying the composition of the material. This was quite a different subject upon which volumes had been written.

He fully agreed with Mr. Webb when he stated that the location of the fuel purifying plant and the facilities provided to dispose of the extracted matter were of importance. Ample space around the machines should also be provided and the plant should be located in a well ventilated position. All these points were mentioned in the paper, and as regards the location of the purifying plant in the "Auricula" he could assure Mr. Webb that although the decision to fit the purifying plant in this ship was not made until all other machines had been installed, the plant was not "perched literally on the shelf". Actually, the plant was located in a 'tween deck, and the engineers had not the slightest trouble in becoming familiar with the pipe arrangement. It was evident that Mr. Webb based his conclusions upon the diagrammatic sketch shown in Fig. 15 and overlooked the fact that the sketch was, as stated, purely diagrammatic, and drawn solely as was the usual practice, to show clearly the pipes and connections, and how the various parts were connected.

In reply to Mr. Sherborne's enquiry regarding the use of special metals used in sea water circulating systems, the author stated that they began to use aluminium brass (76 per cent. copper, 22 per cent. zinc, 2 per cent. aluminium) for the first time in the horizontally located piston water coolers of Diesel engines because the copper tubes in these coolers became wasted and began to leak after having been in service for about 4 or 5 months.

As an experiment one cooler in their ship was removed from the main engine and placed in a vertical position. At the same time new tubes of aluminium brass were supplied to similar vessels, and since that time no serious trouble had been experienced with cooler tubes. The copper tubes gave slightly better results after the cooler was placed vertically, but much better results were obtained with aluminium brass tubes. It was now their practice to fit the condensers of all ships with aluminium brass tubes, and the results had been very satisfactory when located in either a vertical or horizontal position.

In many of their ships they had experienced serious trouble with wastage of copper pipes of salt water systems, especially in recently built ships. Some of the pipes lasted only 6/7 months. For the sea water services of ships built in the years immediately before the last war, they specified tungum for some and aluminium brass for others, and in both cases the results had been very satisfactory. No wastage of any account had been reported in pipes made of these materials.

The author had some slight knowledge of the Admiralty experiments referred to by Commander Baker in his interesting contribution, and thought he was correct in stating that the experiments were abandoned because the difficulties to be overcome were found to be too great, rather than to lapse of interest upon the conclusion of hostilities in 1918. The engines used for the experiments were of the high speed type used in submarines, and on no occasion did an engine "run round the clock" before the fuel nozzle spray holes became choked, and the exhaust so black that a submarine on the horizon would have been spotted in the middle of the night!

The statement that "as marine Diesel fuel is composed of about 20 per cent. residual fuel and 80 per cent. high grade gas oil, it is not surprising that it (the engine) continued to run satisfactorily when the percentage of residual was increased to approximately 70 per cent." was not understood.

The percentages of ash in the fuel before and after treatment in the purifying plant was recorded in Table 3 on page 8 of the paper. The quantities of ash remaining were found to be so small that when the analysis was made, the differences fell within the analytical error, and accurate determination of the proportion removed was not possible. The fact remained, however, that before extraction the fuel was unsuitable, and that after treatment it was wholly satisfactory for use in the engine.

No wetting agent was used to facilitate the removal of water from the fuel; any water which was in the fuel was separated out by the purifier.

To date the "Auricula" had been in service 17 months, during which time she had received 12 separate consignments of bunkers, and on no occasion had bunkers been rejected. The only stipulation made, was that the viscosity should be limited to 1,500 secs. Redwood I at 100 deg. F., and the chemical characteristics in the various consignments had varied without having any effect whatsoever upon the running of the engine. On one occasion, as stated in the paper, the ship was supplied with fuel oil which turned out to be unstable, but even with this parcel of fuel the engine operated with entire satisfaction.

The author did not agree that the logical development of this purifying process would be for the Oil Companies to supply ready centrifuged boiler fuel, because of the enormous quantities that would require to be treated in a given time. It was much better for the fuel to be treated as required on board, particularly as the additional complication to the machinery in ships and the extra work entailed was negligible.

On the assumption that by this purifying process all matter in boiler fuel which was objectionable in Diesel engines was removed, there should be no difficulty in adapting high speed engines of this type to operate satisfactorily on this cheaper fuel, and before the end of 1948 he hoped to prove that this could be done.

The author was glad to know that Mr. Calderwood considered the wear rates quoted by him very reasonable, considering the grade of oil used. Further information upon wear rates had since been obtained and would be given at the end of this reply to the discussion.

The claim that Diesel engines had previously operated on heavy grade fuel oils, some even heavier than those used in the "Auricula", had been made periodically, but the technical information divulged on such occasions had been either incomplete or inconsistent, and, therefore, valueless. The author had this in mind when he started his experiments, and when the time arrived to put forward a claim, every endeavour was made to present a clear picture of how the problem was tackled, the progress made, and the results obtained, in a manner which would enable the reader to decide for himself whether there was actually anything in this idea of using the cheaper fuel oils.

For his views upon the merits of two and four cycle engines to resist contamination of crankcase lubricating oil when the fuel used had a high sulphur content, the author would refer Mr. Calderwood to his reply to Mr. Meadows. No such contamination would take place in either type if the piston rings were maintained in an effective condition.

In regard to the alterations effected between the preliminary and later tests with the experimental engine, the objects in the beginning was to determine whether the engine would operate satisfactorily on Admiralty Fuel Oil, and having established this, to work progressively up to the cheaper commercial fuels. After observing that the unusually low cylinder compression did not seriously interfere with the burning of Admiralty fuel, it was decided to decrease the clearance volume in order that the experimental engine would have similar combustion space characteristics to those existing in a large number of engines already in service.

The increase in the temperature of the fuel prior to injection was made necessary due to the more viscous nature of the fuel as the tests progressed. Apart from the maximum fuel injection pressure, no pronounced differences were noted during tests carried out with the fuel at various temperatures. It was, therefore, decided to base the temperature of the particular grade of fuel upon the known viscosity of Diesel oil at the normal operating temperatures, as by this method no undue load would be put upon the h.p. fuel pump driving mechanism.

Tests were now being carried out with even more viscous fuels than those already quoted, and it would appear that the deduction to work at the equivalent Diesel oil viscosity still held good.

Mr. Hetherington's remarks regarding a German built engine that was intended to use heavy fuel, and the treatment given to the fuel before it was supplied to the engine, were interesting, and would have been of value had he been able to give us some information concerning the fuel used and the reasons for three-stage filtering before finally centrifuging. To filter heavy fuel at 100 deg. F. must have been a very slow process if the viscosity of the fuel was in the region of 1,500 secs. or similar to that used in the "Auricula". The fact that the life of the cylinder liners was about four years was doubtless the reason why nothing had been heard of these endeavours until now.

The opinion expressed, that boiler fuel could have been used in a standard engine of propriety make 20 years ago, could best be answered by the question—why wasn't it? And what advancement had been made over this long period by the enterprising makers of the engine quoted? The answer was probably that due to bad combustion, and excessive wear of costly parts, the monetary advantage of the cheaper fuel was outweighed by the greater wear and tear.

The author was indebted to Mr. Mackegg for amplifying his (the author's) reasons for deciding upon the particular make and type of centrifugal separator to be installed in the "Auricula". His contribution also provided answers to questions raised by Mr. MacKinnon.

Mr. MacKinnon's reference to the amount of deposit removed from the purifier and clarifier bowls implied unintentionally no doubt, that the quantities were found to be greater than were given in the paper. Mr. MacKinnon could be assured that the purifiers in the "Auricula" did not require constant attention, but if, as a centrifugal separator expert, he could show how the same results could be obtained with less attention the author would be very interested. The author's understanding was that self-cleaning centrifugal separator bowls had certain disadvantages. He thought it was made quite clear in the right-hand column of page 6 of the paper that the decision to operate the purifier and clarifier at half the rated capacity of the machines was not influenced by the frequency with which the bowls required to be cleaned, the reason being the higher proportion of ash extracted when the throughput was reduced.

Mr. MacKinnon's very brief reference to the Compagnie Auxiliare de Navigation ships using boiler fuel as Diesel engine fuel was interesting. An article upon this shipping company's activities appeared in the October issue of "La Révue Nautique", but as was usual when such claims were made, the information given was so scanty as to be of no practical use to any who wished to profit by their experience.

The author was glad to have the views of such an authority as Mr. Welsh regarding the possible development of his (the author's) efforts to successfully burn heavier and cheaper fuels in Diesel engines than was at present the case. The successful practical results so far achieved applied only to slow running marine engines, but he foresaw the time when all road and rail transport would be driven by high compression engines operating on so-called boiler fuel. A large proportion of such engines were already running on Diesel fuel, and it was surely not beyond the capacity of this age to overcome the difficulty of burning high viscosity fuels if the objectionable matter was first removed from such fuels. It would of course be impracticable for road transport and, to a lesser degree, rail transport, to purify the fuel immediately before use, as described in the paper, but in view of the relatively small quantities required, and the fact that such transport returned to its base daily, there was no reason why purifying plant could not be installed at bases, and the fuel purified before it was "put on board".

The analysis of the materials removed by the purifier and clarifier, and given at the foot of page 9 of the paper referred to No. 2 fuel, the characteristics of which were shown in Tables Nos. 1 and 3.

With regard to the size of the particles remaining in the fuel after treatment, the author would refer Mr. Welsh to the reply given to Mr. Alcock, and in addition would state that about 35 per cent. of the *total* ash only was removed, the remainder being soluble and not extractable by centrifugal means. This 35 per cent. consisted mainly of the hard solid matter which was far more destructive in the cylinders than the soluble portion.

When the consignment of unstable fuel was shipped by the "Auricula" during the seventh voyage there was no extra cost incurred for additional cleaning of the purifiers. The frequency of cleaning (every two hours at the peak period) was considerably reduced when it was realised what was taking place, and during the return passage, when hot water was introduced to the purifier bowl as a de-sludging agent, the machines could operate for periods nearly equal to those required with the stable fuel shipped at all other times.

Mr. Welsh appeared to be confusing the fuel consumptions of the experimental engine and the "Auricula". In the first case the recorded fuel consumption, which was considered unusually high, was fully discussed and reasons given in paragraph 3 column 1 page 4 of the paper. The fuel consumption in the "Auricula", namely 0·308lb./i.h.p./hour of heavy fuel was a reasonable figure for this type of engine. It should, however, be pointed out that when the consumption trial in question was run, the combustion pressures were lower than those necessary for best fuel economy, and with the fuel cams advanced to produce higher combustion pressures, the fuel consumption would show an even lower relative figure. It should also be remembered that in order not to raise the injection pressure unduly the fuel nozzles which gave the best results in respect of fuel consumption were not used in the "Auricula". Had the engine in this ship been built to burn heavy fuel it would have been a simple and inexpensive matter to arrange for a better consumption figure.

Regarding Mr. Welsh's criticism of the cylinder liner wear in the "Auricula", the author would refer him to his concluding remarks at the end of this reply to those who took part in the discussion.

The reason for the higher volumetric efficiency when using Admiralty fuel, instead of Diesel oil, was that the fuel surcharge pump delivery pressure into the main pump suctions was higher when the surcharge pump was handling the more viscous oil. With the "Auricula's" engine operating at service power the relative pressures were 12lb./sq. in. for Diesel oil, and 25lb./sq. in. when operating on Ordoil. The results of this pressure difference at the fuel pump suctions were described in paragraph 4, column 2, page 20 of the paper.

The "Lolos" strainer was provided between the treated oil settling tank and the fuel valves as a safeguard against foreign matter which may be left in the tank or pipes after inspection or repairs, from reaching the fuel valve atomisers.

From Mr. Warne's opening remark he seemed to think that the author's reference to the absence of smoke when running on boiler fuel was superfluous. It may have been, but he was sure Mr. Warne would forgive him for pointing out one of the most ready indications of good combustion in his endeavours to convince the audience that, so far as this indication was concerned, the conditions prevailing in the cylinders with both Diesel fuel and boiler fuel were much the same.

Mr. Warne was of the opinion that the detailed description and sketches given in the paper did not adequately cover the fuel purifying plant. The last paragraph in column 2, page 6, of the paper, when read in conjunction with the sketch shown in Fig. 9, did, the author thought, clearly reveal the differences between the purifier and carifier.

The decision to use centrifugal type separators in preference to the static type, was made after taking into account the relative efficiencies, throughput rate, and space available in the ship.

Mr. Martin's contribution provided the answer to the question raised by several speakers about centrifuging the fuel oil at the production centres, and the author agreed that the fuel should receive the prescribed treatment on board ship for the reasons given.

Mr. Ysselmuiden was correct in stating that the real subject matter of the paper was the preparation and combustion of Ordoil (ordinary fuel oil of 1,500 seconds Redwood I at 100 deg. F.). That being the case, therefore, those points of analysis which appeared to have a very minor bearing upon the subject, could, to a large extent be ignored. Having proved beyond doubt that Ordoil could be successfully used, the characteristics such as cetane number, and the distillation range of such fuels, were not considered of sufficient importance to justify investigation. The author had no doubt that these varied somewhat from one delivery to another, as did other characteristics and, moreover, that they were probably in many cases of an order which would previously be considered as most undesirable in a Diesel engine fuel.

Mr. Ysselmuiden stated that there were several kinds of Diesel fuel, some of which could not be burnt in every marine Diesel engine. The author suggested that this was a statement which required verification, and asked who could say whether, if conditions were right, any given Diesel fuel could not be made to burn satisfactorily?

Mr. Martin had already answered Mr. Ysselmuiden's question regarding Ordoil. This fuel complied with the internationally accepted requirements for bunker "C" grade in respect of water, sediment and flashpoint, but in the case of Ordoil, the viscosity was restricted to 1,500 seconds Redwood I at 100 deg. F. In fact it would perhaps have been better to disregard the code-word "Ordoil" and simply call it what it really was, 1,500 seconds fuel oil.

The only reason for limiting this viscosity was that one must walk before one could run. The experiments described in the paper were already of the past, and fuels of higher viscosity were now being tried. When these later experiments were completed, it would be known whether there was any limit to the viscosity of the fuel oils which could be used in this way, and whether they would present the centrifuging problems visualised by Mr. Ysselmuiden.

Mr. Ysselmuiden stated that the extraction of the ash from boiler fuels gave reason to hope that distilled fuels, by which we inferred gas oil was meant, would no longer be necessary. In the author's opinion, they never had been necessary for the vast majority of marine Diesel engines. It was a fallacy to suppose that there was any inherent requirement which necessitated such fuels. After all, the original Diesel engine was designed to run on residual fuel or even pulverised coal.

It was the opinion of the author that too much importance was attached to the physical specification of a fuel. Many engine builders now realised that they had been unnecessarily restrictive in regard to fuel specifications. Mr. Ysselmuiden visualised disappointing results if Ordoil proved to be of varying quality in different parts of the world; the Ordoil shipped by the "Auricula" varied appreciably in viscosity, Conradson, sulphur, etc., yet there was no noticeable difference in the combustion efficiency. The viscosity of boiler fuels varied over a wide range, and the importance of these tests and others which the author was already conducting lay in demonstrating that there was no essential merit in any one particular viscosity. He would, therefore, like to disclaim any suggestion that his efforts were directed to burning one solitary grade which might thereby limit the operation of a ship to one restricted range of ports.

Mr. Jones desired information upon the unstable parcel of fuel shipped in June 1947 by the "Auricula", but as the behaviour of this particular parcel was rather mystifying, the very thorough investigation started at the time was not yet completed, and the author was afraid, therefore, that he was not in a position to give a complete answer to Mr. Jones' queries.

He would however, repeat his statement that although this parcel of fuel broke down during the purifying process, the operation of the engine was in no way affected, in other words, there was no reduction in the power developed for the normal speed control lever position, and the various parts inside the cylinders remained perfectly clean as with all other parcels of fuel shipped.

Since the "Auricula" was commissioned in August 1946, twelve consignments of heavy fuel of blended varieties had been shipped, and excepting for this seventh voyage no breakdown of fuel, or even abnormal precipitation occurred. The breakdown of this particular parcel was all the more surprising because exactly similar fuel had been supplied to steamships where temperatures as high as those reached in the "Auricula" had been employed, without breakdown occurring. This being so the chemists who were working upon this problem, very rightly assumed that the fuel which was supplied to the "Auricula" and proved unstable had some peculiar characteristics.

The theory that the breakdown occurred owing to a combination of circumstances was being investigated, but all the evidence so far collected suggested that this was an extremely unusual occurrence, and that it may never happen again.

Replying to Mr. Alcock the author said that the influence of supercharge air pressure on the burning of residual fuel oils was investigated during experiments on board the "Auricula" primarily to establish whether engines in which the compression pressures were below normal could be operated on the cheaper fuel oils.

As this particular engine was designed for supercharging, no attempt was made to run a test without supercharged air, but a series of tests in which supercharge air pressures of less than half the normal were carried out and the results were given in Table 9, page 20 of the paper.

It was possible that if the extreme pressures such as those mentioned by Mr. Alcock—atmospheric pressure and 10lb./sq. in. gauge pressure, were tried, a pronounced difference in the combustion efficiency may have been observed. The range of pressures covered by Table 9 were however, considered more representative of the large marine engines in use.

Up to the present the author had no information on the size of the solid particles remaining in the fuel after clarification, and in view of the excellent results achieved, he had not investigated the matter. However, as another contributor had also asked the same question he was endeavouring to obtain the answer, and if the details were available before this reply was required for the press, it would be included.

The fuel pumps used in the experiments were the usual Werkspoor/Bosch type, the latter regulating the quantity of fuel through spill ports. The author presumed that Mr. Alcock would like to know whether the Bosch pump plunger in way of the spilling scroll showed signs of abnormal wear, and he would confirm that after 17 months in service the pumps in the "Auricula" which were being kept under observation showed no greater wear than other plungers which were operating on Diesel oil for a similar period.

When the purifier bowl dirt space became full the fuel being treated would be discharged through the water outlet and would be detected on the sight glass. The colour of the oil was not changed during the centrifugal process.

The author said that he was sure all would welcome Professor Broeze's valuable contribution to the discussion. Like several other speakers, he made only brief reference to French and Italian motor ships operating on heavy fuel, and again nothing was said regarding the characteristics of the fuel used or the results obtained. Now that the author had given such an accurate and complete description of his own efforts, to quote Prof. Broeze, it was hoped that those who were taking an active interest in this problem would follow the lead given, and let us have something in return for what had been given to them.

At one time during the author's experiments it was thought that a circulating system such as the "Pilgrim" would be required, as it was evident that the correct temperature of the fuel just prior to it being injected was most important. This, however, entailed a major alteration which, for reasons given in the paper, it was desirable to avoid. and other means to maintain the temperature of the fuel during manœuvring were tried, and found satisfactory. It was not unlikely, however, that in the experiments now being made with fuel of 3,000 secs. Red. I at 100 deg. F. the "Pilgrim" or some other circulating system may have to be adopted.

Prof. Broeze's remarks upon the results obtained with chromium plated cylinder liners were most interesting, and this may have been one of the answers to excessive piston ring wear. Were it not that piston ring wear in different ships varied so much, even when using Diesel fuel, and this in some ships it was quite reasonable without the rubbing surfaces being treated as described, he would say that this was evidently the answer. He still held the view, however, that piston rings could be made of material that would give more consistent wear-resisting qualities than was the case at present.

The evidence available supported the contention that chromium plating the bore of cylinder liners did reduce liner and piston ring wear quite considerably, even though there were a few instances where the reverse had been the case. What the advocates of this method of reducing wear had to do was to erase from the minds of many shipping technicians the fear that the bonding of the chromium to the cast iron was such that when the skin was worn to an immeasurable thickness, it could flake and damage the cylinder liner.

The author was very gratified at the interest which this paper had aroused, but he would feel that his endeavours to solve this age-old problem had been of no avail unless good use was made of the information he had provided, and the technical advisers of shipping companies, as well as Diesel engine builders, of both marine and stationary types, would carry on as he would do. His immediate objectives were the burning of 1,500 seconds fuel in high speed stationary engines, and 3,000 seconds fuel in two and four cycle marine engines. If these endeavours met with the success he confidently expected, the next step would be to burn "C" grade 7,000 seconds fuel.

There were some, few in number, and mostly belonging to the older school, to which he himself belonged, who felt that now all the troubles associated with the development of the Diesel engine for marine work had been overcome, and such engines compared favourably with any other type as regards reliability, they should leave well alone. This attitude was to a certain extent understandable, because those who adopted it had all the work and worry of bringing the Diesel engine to its present state of perfection, but it was surely not to the credit of the marine engineering profession to know that a power producer which 50 years ago was intended to operate on inferior fuels still required a refined and expensive fuel, not because thermo dynamic considerations demanded it, but because it obviated mechanical difficulties.

Since the paper was written, the price of Diesel fuel had increased 17·7 per cent. and the corresponding increase for 1,500 seconds fuel is 15·3 per cent., so that the saving effected by using the more viscous fuel yas even greater than the amounts given in the paper. The annual saving in a 4,000 i.h.p. installation by using No. 2 boiler fuel would now be £5,285.

Apart from the substantial saving effected by using boiler oil in motorships, another reason why this changeover should take place, and with speed, was the rapidly increasing demand for Diesel fuel on land. If this increasing demand was not off-set by the use of more boiler fuel at sea an increase in the cost of Diesel fuel in relation to boiler fuel was not improbable.

Some may hold the view that an increased demand for boiler oil as fuel for motorships would result in an increase in price in the same way as a greater demand for Diesel fuel on land would increase the price of that grade, but should this be the case the increase in price for boiler fuel would not be proportionate to the increase in price for Diesel fuel, because the cost to produce the latter grade, which was mostly distilled, was much higher.

During these experiments the fuel used had been limited to a viscosity of 1,500 seconds Redwood I at 100 deg. F. This had been the only limitation imposed, since it had been proved that if the fuel was used in the manner described, the normal sulphur content and the Conradson value of such fuels did not adversely affect the running of the engine.

Most fuel oils of this viscosity were blended, that is to say, they comprised a mixture of heavy fuel of between 4,000 seconds and 7,000 seconds Redwood I at 100 deg. F., termed "C" grade fuel, with a lighter fuel, usually of the distilled variety, the proportions being determined by the desired viscosity of the mixture.

In some ships the fuel tank and pumping arrangement was such that mixing of the two grades could be done on board, but it was recommended that to ensure thorough mixing this operation should be carried out before the fuel was taken on board.

Where "C" grade fuel oil and gas oil (or marine Diesel fuel) were both available for bunkering, the depots were in many cases provided with facilities for blending the two grades before they were put aboard. It did not, however, follow automatically that a 1,500 seconds blend could be prepared by any port at short notice, and if the mixing could not be done satisfactorily on board, it may be necessary to accept the normal grade of Diesel oil to meet the immediate need.

Since commissioning, the "Auricula" had covered 98,682 miles at an average speed of 11·45 knots without a single involuntary stop at sea or a moment's delay in port for engine room requirements. In addition to operating at sea the "Auricula" was entering and leaving all ports, no matter how much manœuvring was necessary, on 1,500 seconds fuel. Never had the engine failed to answer promptly, and with certainty, an order from the bridge. Other ships having four-cycle engines were now operating on boiler fuel with equally good results.

It would be recalled that when Nos. 3, 4, 5 and 6 cylinders were opened up after one year's operation, the mean maximum wear of these four cylinder liners was 0·00409in. per thousand hours. Three months later Nos. 1, 2, 7 and 8 of this eight cylinder engine were opened up, and the mean maximum wear of these four cylinder liners was found to be 0·00274in. per thousand hours. From this very large difference in the wear rates of these two sets of cylinders it would seem that the water leakage reported when Nos. 3 and 5 pistons were opened-up (see left-hand column of page 22 of the paper) was responsible for the high mean maximum wear of the first four cylinders to be opened-up, and that 2·7 thousandths of an inch per thousand hours was the correct liner wear rate of this particular engine when operating exclusively on 1,500 seconds fuel.

So many factors affected cylinder liner and piston ring wear that when examining the results obtained in the "Auricula", comparison should be made only with a similar make and size of engine, for the true effect of burning fuels other than Diesel fuel. Several speakers during the discussion stated or implied that the normal wear rate of cylinder liners was 1/1,000in. per thousand hours. After as long and as wide an experience as any, the author could categorically state that this was not the case. There were, of course, exceptional cases. For instance, the author was technically responsible for a 20 year-old motorship which had all original cylinder liners still in use, and the average maximum wear of the 6 liners was only 1·5 mm. This however, was certainly abnormal. It was probable that some confusion arose when speaking of cylinder liner wear owing to both English and metric methods of measurement being commonly used in this country. In terms of the latter system the *normal* liner wear was 0·1 mm. per thousand hours, which was very different to 1/1,000in. per thousand hours.

The author thought it unfair to compare cylinder liner wear rates of high speed engines with those of slow speed marine type engines. The former ran continuously in one direction whereas cold starting air was admitted to the cylinders of marine engines at the end of every voyage. This practice must have had a serious adverse effect upon cylinder liner and piston ring wear, particularly when the refrigeratory effect of the expanding compressed air, as well as the large proportion of moisture contained in such air, was taken into account.

Corrigendum for January Issue of the Transactions

In the obituary of Engineer Rear-Admiral S. R. Dight, the title of the paper for which he was awarded the Naval Architects' Gold Medal should read "Naval Water-tube Boilers, Experiments and Shop Trials".

JUNIOR LECTURES

Modern Power Station Plant.

On Thursday, 22nd January, 1948, Mr. S. B. Jackson (Member) delivered a lecture on "Modern Power Station Plant" at the Wandsworth Technical Institute. The chair was taken by the Principal, Dr. S. C. Robinson. The Council of the Institute was represented by Dr. R. A. Collacott.

Mr. Jackson gave an interesting lecture to about 120 students and dealt firstly with the economic aspects of power generation and the establishment of a central organization, after which, with the help of a number of slides, he took the audience on a tour of a modern power station, dealing in turn with the boilers, turbines, electrical generating plant, control stations and switch gear. The lecturer afterwards replied fully to a number of questions.

On the proposal of Dr. Collacott, a hearty vote of thanks to the lecturer, and Dr. Robinson, the Principal, for affording facilities for the meeting, was carried by acclamation.

GAS TURBINES

A lecture on "Gas Turbines" was delivered at the Municipal College of Technology, Belfast, on Wednesday, January 28th at 7.30 p.m., by Mr. C. C. Pounder (Vice-President).

The Council of the Institute was officially represented by Mr. Denis Rebbeck, M.A., M.Sc., B.Litt. (Member of Council) who was called upon by the Chairman of the meeting, Mr. D. H. Alexander, O.B.E., M.Sc. (Member), Principal of the College, to explain the objects of the Institute in organising these highly appreciated junior lectures.

In the course of his remarks Mr. Pounder traced the analogy between gas turbines and steam turbines, especially as regards the relation between first-cost and thermal efficiency. He impressed upon his audience the fact that the development of any prime mover was a commercial, as well as a technical matter and that, in the ultimate, it was the commercial factors which prevail.

The first part of the lecture was concerned with the principles underlying open cycles, closed and semi-closed cycle, and the effect upon efficiency and cost of recuperators, intercoolers, and so on. Then followed descriptions of the work that was being done on the continent, by various firms, in the development of the gas turbine. Stress was laid upon the size of some of the installations already in service. The special characteristics of marine gas turbines were then dealt with in detail, and for purposes of description, representative gas turbines at present being built by British firms were chosen.

The lecturer then indicated the features of the alloy steels being used for blading, forgings, and castings, and concluded by reference to work being done in U.S.A. especially on gas locomotives.

The lecture was illustrated by lantern slides and wall diagrams.

There was an audience of practically 300, recruited almost entirely from the engineering students of the College.

A vote of thanks to the lecturer was proposed by Mr. A. Stewart —a University student of the College, and seconded by Mr. Wilson, who is employed by Messrs. Harland and Wolff, Ltd., and has had some sea experience during the war, and is at present attending a day apprentice course.

Almost a dozen people took part in the discussion, and Mr. Pounder replied to the various questions raised in great detail.

On behalf of the Council, Mr. Rebbeck thanked the College for the facilities afforded and told of the Council's keen desire to see as many students as possible taking part in the essay competition.

THE COMBUSTION TURBINE

A lecture on "The Combustion Turbine" was delivered by Mr. J. Calderwood (Member of Council) on Friday, 30th January, 1948, to students of the Technical Institute, Falmouth. The chair was taken by Mr. C. J. Tirrell, Principal of the Technical Institute. Mr. D. Dunn (Local Vice-President) represented the Council of the Institute.

The lecturer dealt with the development of the combustion turbine, particularly with its application to marine propulsion, and the lecture was well illustrated with lantern slides, showing the technical cycles and the proposals for turbines under construction and their lay-out for vessels. The audience was very attentive, and by their subsequent questions showed a full appreciation of the clear way in which the subject had been dealt with by the lecturer.

A vote of thanks to Mr. Calderwood was proposed by Mr. G. R. Green, Chairman of the Governors of the Technical Institute. Mr. Dunn proposed a vote of thanks to Mr. Tirrell, the Principal, for the arrangements made for the meeting, which were carried out so efficiently.

THE USE OF ELECTRICITY AT SEA

On Tuesday, 3rd February, 1948, under the auspices of the Institute, Mr. C. P. Harrison (Member) presented a lecture on "The Use of Electricity at Sea" to students of the Engineering Department of the South-West Essex Technical College, Walthamstow. Mr. H. J. Cooper, Head of the Engineering Department, was in the chair.

The lecturer explained the various services that a ship has to provide, and the special difficulties of fitting electrical machinery and apparatus in a ship, as well as the care that has to be taken in design because of the many adverse factors which do not have to be taken into consideration in land apparatus; for example, the pitching and rolling of a ship. He also stressed the great care required in the design of this electrical equipment so that it will continue to function for long periods under various climatic conditions. Numerous slides were shown during the lecture, after which a discussion followed.

SOUTHERN JUNIOR BRANCH I.N.A. AND I.MAR.E.

A lecture entitled "An Introduction to the Vortex Theory of Propellers" was presented at the meeting of the above Branch at Portsmouth on Wednesday, 14th January, 1948, by Mr. K. H. W. Thomas, R.C.N.C., a Student Member of the Branch. Mr. L. J. Rydill, R.C.N.C., also a Junior Member was in the chair.

There was an attendance of 40 members and visitors, and the meeting was followed by an interesting discussion.

ADDITIONS TO THE LIBRARY

Presented by the Publishers

The Elements of Workshop Training—A Textbook for Works Apprentices

(Second Edition). By Edgar J. Larkin, A.M.I.Mech.E., M.I.Loco.E. Sir Isaac Pitman & Sons, Ltd. London. 1947. 256pp., 275 Figs., 4 Diagrams. 15s. net.

The aim of this book is to create interest and impart useful knowledge in the fundamental principles associated with the engineering workshop and to encourage a thirst for knowledge among engineering pupils and apprentices. To this end it is divided into two sections, Part I dealing with Science Applied to the Workshop and Part II Workshop Theory and Practice.

Part I includes chapters on Workshop Mathematics, Mechanics, Elementary Heat, Metallurgy, Hydraulics, Electricity and Chemistry. In such a small book (256 pages) it is obviously impossible for the author to dwell at much length on so many subjects, but he clearly sets out the first principles with which every apprentice should be conversant.

Part II provides a very useful introduction to Machine Drawing, Testing of Materials, Tools, Joinery and Pattern Making, Foundry Work, Smithing, Sheet Metal Work, Machining and Fitting and Assembly, and here, as in Part I, it has been possible to touch upon the first principles of each subject.

Altogether, the book should prove most useful to junior apprentices by affording them an introduction to many aspects of workshop training in a manner which is devoid of complicated detail, and which, compared with the old method of learning almost entirely by experience, should save time in the workshops. It is the reviewer's opinion that the instructional value of the book would have been considerably increased if the author had included, at the end of each chapter, his recommendation as to further reading on the subject that the student might pursue.

Boiler House and Power Station Chemistry

(Second Edition). By Wilfred Francis, M.Sc.Tech., Ph.D., F.R.I.C., F.Inst.F. Edward Arnold & Co. London. 1947. 274pp., 83 Figs., 32 Tables. 21s. net.

This work needs no introduction as it is well-known among boiler house and power station combustion engineers and chemists. This edition improves an already good book. The book has been enlarged to include more material on the constitution of coal, coal cleaning, orthodox methods of analysis capable of being carried out at higher speed and with greater certainty than by standard methods and accelerated methods of proximate and ultimate analysis. The new matter included increases the number of pages by 71 and the number of figures by 21. The reviewer already possesses the first edition and has found it a most useful work.

General chemical aspects of the constitution of pure coal, impurities in coal, combustion characteristics of commercial coals, efficient coal combustion, flue gas treatment, water conditioning, the characteristics and analysis of lubricating and insulating oils, sampling and analysis of coal, ash and grit, washing processes occupy further pages. The details of the various analyses will be of value to marine superintendents wishing to participate in the lessons of shore practice.

The author capably deals with his subject, and the book forms a valuable reference in all the matters with which it deals.

The Journal of Commerce Annual Review of Shipping, Shipbuilding, Marine Engineering and Civil Aviation, 1948

Published by Charles Birchall & Sons, Ltd., 17, James Street, Liverpool, 2. January, 1948. 416pp., profusely illus. 2s. 6d.

CONTENTS

Chairman of the Liverpool Steam Ship Owners' Association.
Through Many Vicissitudes to Ultimate Triumph, by T. E. Hughes.
Short Sea Trades and their Ships, by Frank C. Bowen.
New Era for British Seamen, by Brian Heathcote, Chairman, Seafarers' Committee, Employers' Association of the Port of Liverpool; Capt. W. H. Coombs, C.B.E., President, Officers' (M.N.) Federation; and Thomas Yates, Acting General Secretary, National Union of Seamen.
Merchant Ship Radar in Operation, by Capt. E. M. Robb.
Peculiar Problems of the Dock Industry, by a Special Correspondent.
Cure for Ship Delays in Port, by J. McDonald.
British Port Developments in 1947, by Brysson Cunningham, D.Sc., B.E., F.R.S.E., M.Inst.C.E.
Merchant Ships which set a New Standard, by a Staff Writer.
Difficult Year for British Shipyards, by C. Hope Johnston.
Attributes to Success in Welded Ship Construction, by our Welding Correspondent.
Inventive Progress in Metallurgy, by a Special Correspondent.
Marine Steam Engineering, by a Special Correspondent.
Electricity for Propulsion and Auxiliary Services, by a Special Correspondent.
Progress in Marine Applications of the Oil Engine, by A. C. Hardy, B.Sc., M.Inst.N.A., A.M.I.Mar.E.
Equipment of Passenger Accommodation, by W. A. Gibson Martin, F.R.G.S.
Productions of the Plastics Industry, by a Special Correspondent.
Many Problems encountered by Civil Aviation, by A. James Payne, A.R.Ae.S.
Turn of Tide in Marine Insurance, by D. King-Page.
Accidents Involving Merchant Ships, by G. J. Bonwick.
New Construction in hand or on order in British and Overseas Yards.
Output of British Shipyards and Engine Works in 1947.

"Verbal" Notes and Sketches for Marine Engineer Officers—A Manual of Marine Steam Engineering Practice

(17th Edition. In Two Volumes). By J. W. M. Southern, revised by J. K. Bowden. James Munro & Company, Ltd. Glasgow. 1947. 1,648pp., profusely illus. 70s. net, the set.

Marine engineering students will be pleased to see this book again in publication. The new system of indexing and the placing of descriptions and drawings of the various parts of the machinery in their correct sections should greatly enhance its value as a book of reference for marine engineers while studying for their certificates.

To revise a technical work covering so vast a field of engineering was a Herculean task to undertake. To prevent the book from becoming too bulky and still allow for the introduction of new matter to bring it into line with modern practice it required some drastic pruning, and yet, mentioning only one outstanding item we find a description and drawing of a haystack boiler. Further in view of the introduction of so many high pressure boilers in modern steamships it would have been anticipated that the treatment of the feed water for these boilers would be considered as of paramount importance and would have been given priority in the introduction of new matter, yet in searching through the index and text we find nothing but the old story of salt and scale so ably developed by our ancestors for multitubular boilers.

The beading over of stay tubes as given on page B29 should be deleted, and if a scarf joint had both plates scarfed as shown on page B64 the plate could not be caulked. It is not correct that all parts of a boiler may be repaired by electric welding as stated on page B88, and in the table on page B145 the superheat in the l.p. chest is given as minus 6 deg. Fah. when this obviously could not be a case of supersaturation. It must be very confusing to students to read on page H18 that a radian is the number of degrees in an angle, that angular velocity can be measured in feet, and on page H22 that the efficiency of any heat cycle describes a Rankine cycle.

There is a large amount of excellent material in the book, but it still requires some very careful revision and it would lose nothing in value if some parts which do not serve any useful purpose were deleted.

Register of Ships, 1947-48

The British Corporation Register of Shipping and Aircraft, 14, Blythswood Square, Glasgow, C.2.

The Efficient Use of Steam. Written for the Fuel Efficiency Committee of the Ministry of Fuel and Power by Oliver Lyle. H.M. Stationery Office. London, 1947. 912pp., 438 diagrams, 82 tables, 15s. net., 15s. 9d. post free.

"Steam is industry's most wonderful, flexible and adaptable tool" writes Mr. Oliver Lyle in his book, "The Efficient Use of Steam", which he has written for the Ministry of Fuel and Power.

Mr. Lyle is a member of the Ministry's Fuel Efficiency Committee. In 1944, the Committee produced a handbook on "The Efficient Use of Fuel" and Mr. Lyle's book is a companion volume.

"Steam users" says the author "misuse and ill-treat it because they have never learnt how to use and care for it" and it is to promote its more efficient use that this informative work has been written. Mr. Lyle is no mere theorist, as the Thames-side sugar refinery of the firm of which he is a director, uses less steam per unit of output than, it is believed, any other sugar refinery in the world.

"The new knowledge that the war has uncovered" says the author "is the sad lack in only too many factories of the simple principles governing the economic use of steam. Immense pains are often taken to capture an extra two or three per cent. in the boiler house, yet the factory may be using two or three times as much as is necessary.

The book, which has over 400 diagrams, is intended to be a practical manual for factory steam users; it is not a text book. As far as possible, mathematics have been avoided and no attempt is made to describe the design and construction of the more important pieces of plant, though the behaviour of steam in some of these plants is discussed, often in detail. The first three of the twenty-six chapters deal with the properties of steam for both heating and power and these are followed by fifteen covering the efficient distribution and use of steam. After a chapter on automatic controls, comes one devoted to heat balance with the arguments well illustrated by many industrial examples. The author then deals successively with costing and regression (without advanced mathematics), the saving of power and electricity, the use of economizers, how to set about steam saving, stepping up heat and, finally, a chapter on the ice-water-steam substance itself.

The book contains over eighty tables, beginning with the properties of saturated and superheated steam. These steam tables are based on Callendar's 1939 tables but are calculated to gauge pressures which should prove very convenient to the practical engineer.

Considerable trouble has been taken to make the index complete and there is extensive cross-indexing.

The following publications of the British Standards Institution:—

B.S. 1429: 1948—Annealed Steel Wire for Oil-hardened and Tempered Springs. 10pp. 3 tables. 2s. net, post free, from British Standards Institution, 24-28, Victoria Street, London, S.W.1.

British Standards Yearbook 1947. 324pp. 3s. 6d. post free.

Presented by Lloyd's Register of Shipping

Rules and Regulations for the Construction and Classification of Steel Vessels, 1947-48

Purchased

British Sources of Reference and Information—A Guide to Societies Works of Reference and Libraries

Compiled under the direction of a Committee of Aslib and edited by Theodore Besterman. Published for the British Council by Aslib, 52, Bloomsbury Street, London, W.C.1. 1947. 50pp. 6s. net. (5s. net to Aslib Members).

Scientific Societies in the United States

By Ralph S. Bates. Ph.D. A publication of the Technology Press, Massachusetts Institute of Technology. New York: John Wiley & Sons, Inc. London: Chapman & Hall, Ltd. 1946. 220pp. 21s. net.

Reports of British Intelligence Objectives Sub-Committee on German Industry.

Published by H.M. Stationery Office

No. of report	Title	Price, net
B.I.O.S. 1188	Preliminary Survey of the German Pump Industry—Part III—Centrifugal, Axial Flow, Self-priming, and Reciprocating Pumps, etc.	9s. 0d.
B.I.O.S.	Technical Index of Reports on German Industry (Part 2). Published from 28th July, 1946, up to and including 26th October 1946	1s. 6d.
	Technical Index of Reports on German Industry (Part 3). Published from 27th October, 1946, up to and including 31st December, 1946	1s. 6d.
	Technical Index of Reports on German Industry (Part 4). Published from 31st December, 1946, up to and including 27th March, 1947	2s. 0d.

MEMBERSHIP ELECTIONS

Date of Election, 2nd February 1948

Members
- William Brisbane.
- William Alexander Erskine.
- Michael Mountjoy Hallett, M.Sc.
- Erton Williams Humphreys.
- William Wilson Hutchinson.
- Duncan Stewart Lyall.
- William Grainger Lynch.
- Hugh Mackenzie.
- Sydney Arthur Nash, Lieut.(E). R.N.
- William Leonard Rapson. Lieut.(E), R.N.
- John Russell.
- John Currie Swan.
- Robert William Thomsett.
- Edward Louis Neville Towle.
- John Joseph Hall Wood.
- Sydney William Underhill, Lt.-Com'r(E), R.N.(ret.).
- John Webster.
- Charles Diment Woodley.

Companion
- Horace Major Sullivan.

Associate Members
- George William Atkinson.
- Rajendta Tandon, Lieut.(E), R.I.N.

Associates
- Peter Ernest Begg.
- George Cokayne.
- Frederick William Evans.
- George Edward Butterworth Johnson.
- Richard Henry Jones.
- Anthony Daniel McKendry.
- Clive Bentley Macphail. .
- George Henry May.
- Ralph Dean Warham Millar, Capt.
- Jack Mitton.
- Arnold Nelson.
- Roy Edwin Percy Norman.
- Francis Stubbs Scott.
- Harry Thompson.

Students
- Madhusudan Acharya.
- Derek Wood.

Transfer from Associate to Member
- Norman Wallace Fleming.
- John Bartley.
- Thomas Henry Blood.
- Thomas Donaldson.
- Anatole Fisher.

Transfer from Student to Graduate
- Ronald Robert Rene Rolo, Lieut.(E), R.N.

PERSONAL

H. Coburn (Member) has resigned his appointment with the Vacuum Oil Co., Ltd., and has been appointed as assistant superintendent engineer to Messrs. Philip Bauer, 70a, Basinghall Street, E.C.3.

R. A. Dickinson (Associate Member) has relinquished his appointment with the Ocean Accident & Guarantee Corporation, Ltd., and has been appointed engineer and ship surveyor to the Ministry of Transport at Liverpool.

H. Fenton (Member) has been elected an Associate Member of the Institution of Naval Architects.

G. F. Johnson, B.Sc. (Associate Member) has been appointed principal of the Technical College, Elsham House, Grantham.

J. M. Kay (Member) has been appointed engineer and ship surveyor with the Ministry of Transport (Marine Survey), Aberdeen.

R. J. Llewellyn (Member) of the Port Directorate, Basrah, Iraq, has been awarded the M.B.E. "in recognition of his valuable services".

T. A. V. Meikle (Associate) has been appointed fuel oil technical representative of the Anglo-American Oil Co., Ltd.

D. Rebbeck, M.A., M.Sc., B.Litt. (Member of Council) has been appointed a director of Messrs. A. & J. Inglis, Ltd., Pointhouse Shipyard and Messrs. D. & W. Henderson, Ltd., Meadowside Works, Glasgow. He has also been invited to join the recently formed Northern Ireland Directorate of Scientific Development.

R. Thompson (Member) has been appointed acting chief engineer of the Anglo-Saxon Petroleum Co. (Eastern) Ltd., Singapore.