The

INSTITUTE of MARINE ENGINEERS

Founded 1889. Incorporated by Royal Charter, 1933.

Patron: HIS MAJESTY THE KING.

SESSION 1934.

Vol. XLVI. Part 4.

President: JOHN H. SILLEY, ESQ., O.B.E.

Some Observations on Fuel for Heavy Oil Engines.

READ

By L. J. LE MESURIER (Member) and R. STANSFIELD.

On Tuesday, April 10th, 1934, at 6 p.m.

CHAIRMAN: Mr. J. HAMILTON GIBSON, O.B.E., M.Eng. (Chairman of Council).

THE effect of the recent development of airless injection engines and engines of high speed type on the requisite quality of fuel is discussed. Views are expressed regarding the importance of each characteristic usually found in a Fuel Specification. In addition, the importance of "Ignition quality" is referred to and several laboratory methods of determining this fuel characteristic are described.

Carbon deposits, pitting of exhaust valves, failure of piston rings, crankchamber corrosion and liner wear are discussed chiefly in regard to the possible effects of fuel quality.

A large number of liner wear results taken from main and auxiliary engines in marine service are included, and it is demonstrated that many factors besides the fuel are responsible for the marked differences in wear which commonly occur in practice.

The possible influence of corrosion in the crankchamber and on cylinder liner wear is discussed with reference to recent theories which have been advanced on this subject. Abrasives in the air charge or fuel and distortion of pistons, rings and liners under each change of load or operating temperature are believed to be the most important causes of liner wear.

The conclusion is reached that no single theory of liner wear is capable of accounting for the wide differences and anomalies which are given in data collected over a period of several years under well-controlled conditions. Simple explanations based on laboratory results must be received with caution until their value has been demonstrated under actual practical conditions of service.

It is not always remembered how much the development of both marine Diesel engines and high speed compression-ignition engines has been influenced by changes during recent years in the range and quality of the fuels available.

The early air-injection engines ran with satisfactory results on less refined fuels than the airless-injection engines which are taking their place, while small high speed airless-injection engines are particularly sensitive to fuel quality.

Owing to the rapid expansion of potential and actual fuel supplies the demand for more rigorously selected fuels has so far not led to any serious rise in price. However, it is wise to sound a note of warning that this rigorous selection may not always be possible, and it is our opinion that engine manufacturers would do well not to overlook the possibilities of designs that will run satisfactorily on a wide range of fuels.

This tendency towards the design of fuel sensitive engines has led frequently to the drawing up of unduly restrictive fuel specifications, many of which have been based on unsound or incomplete theories of fuel behaviour. One of the objects of this paper is to show the danger of using single or simplified theories to explain the action of the complex variables which determine the behaviour of internal combustion engines.

Fuel Specifications.

During 1932/33, a joint committee of the Institution of Petroleum Technologists, the Institution of Automobile Engineers and the Diesel Engine Users Association and, simultaneously, a second committee including members from the American Society of Mechanical Engineers and the Society of Automotive Engineers, independently held discussions with the object of placing in order of relative merit the specification items for a compression ignition engine fuel. Though their conclusions were not in exact agreement, it is an interesting commentary on the present trend of ideas that both committees considered ignition quality and viscosity to be the most important characteristics. In view of this conclusion it is proposed to consider these two properties first.

Ignition Quality.

The ignition quality of a fuel for a compression ignition engine determines the ease of starting from cold at slow speeds. It is directly related to combustion shock and there is some evidence to show that it is connected with cases of piston failure on large engines. Thus, though the ignition quality may be of less importance for the marine engine than for the small high speed engine, it cannot be entirely ignored for large engines and a description of the methods of determination used in the Anglo-Persian Oil Company's laboratory may be of interest.

Two different methods of test have been adopted which may be described as (*a*) a *running test* and (*b*) a *starting test*. The first is carried out on single cylinder high speed engines under full load conditions and consists in measuring the delay angle by means of a Farnboro' indicator. The delay angle—the degrees of crank movement between the commencement of fuel injection and the commencement of rapid pressure rise—has been found to give a good indication of the ignition quality of the sample under test. The smaller the angle, the easier is the starting and the less the combustion shock. Since the delay angle varies with engine speed and also with many design factors, it is desirable to convert it into terms which apply as closely as possible to every engine. This is done by using two reference fuels, one of high and one of low ignition quality, and finding the blend of the two which gives the same delay angle as the sample under the same conditions of test. It is our own practice to use a high and a low ignition quality natural petroleum product as reference fuels though we have used, and can convert our reference fuel blends into terms of blends of cetene and α-methyl-naphthalene which have been proposed as standard references.* The latter standards cover a very wide range of ignition quality values and, provided they can both be prepared in a sufficiently pure state to be repeatable and stable in storage, should be admirable for the purpose.

The "cetene number" of a fuel is the percentage by volume of cetene in the cetene/α-methyl naphthalene blend which has the same ignition quality as the fuel. The use of such reference fuels for expressing the ignition quality has so far given results which, for all practical purposes, are independent of the type of compression ignition engine used for the test.

The second method of rating ignition quality, and one which is rather more repeatable as a test method than the first, is a starting test on a single cylinder engine which is motored at a relatively slow speed under steady conditions of jacket and inlet air temperature. The inlet air is progressively throttled until a point is reached at which the fuel does not fire when fuel injection is momentarily permitted to take place. The air pressure in the inlet manifold required to obtain this condition is accurately determined by trial and error and the blend of reference fuels which just commences to misfire at the same degree of throttling is then determined. The results from this method and those found by utilizing the indicator diagrams taken under load have been compared from a variety of engines and rarely show any important difference.

Such engine tests as the above necessitate the use of specially equipped engines which are not available in many laboratories. A simple approximate alternative is the determination of the "aniline point" of the fuel. This consists in finding the lowest temperature for complete miscibility of a mixture of 5 cc. of freshly distilled aniline and 5 cc. of the sample. Below this temperature the mixture gives a cloudy emulsion on shaking which clears suddenly at the aniline point, allowing a very precise determination to be made. Dark coloured fuels require special treatment before the test but present no particular difficulty. The method has been almost as satisfactory as Diesel engine tests for most petroleum fuels, but is unreliable for cer-

* G. D. Boerlage and J. J. Broeze. "Ignition quality of Diesel fuels as expressed in cetene numbers". "S.A.E. Jnl.", 1933, 31, 283.

tain unusual fuels such as some of those from coal, and is uncertain on shale oils which it frequently rates too low. It fails when blends containing ignition dopes are tested and also for some oils not of mineral origin. It is useful as a general guide for distinguishing between a good and a bad ignition quality fuel, as is indicated by Fig. 1 which shows the general relation between cetene number and aniline point for a range of fuels.

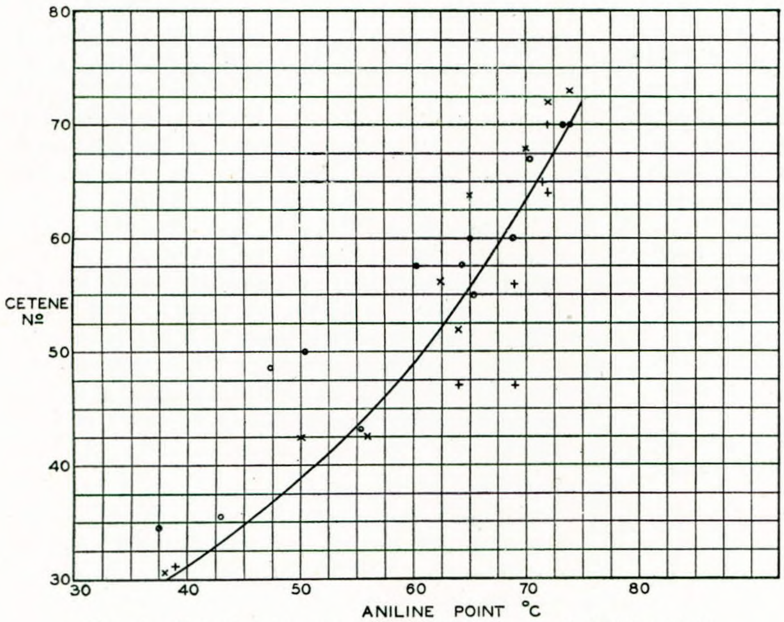


Fig. 1.—Relation between Cetene Number and Aniline Point.

Viscosity.

Apart from the very important *indirect* effect of fuel viscosity in determining the tendency of the fuel to pick up and retain particles of abrasive dirt (an effect which is treated more fully later) viscosity has a pronounced direct influence on engine operation. In the first place the fuel viscosity at engine room temperature determines the pressure drop in the pipe lines between service tanks and fuel pumps. If, owing to excessive fuel viscosity, the suction of the pumps leads to a drop in pressure below atmospheric at any point in the line, air leakage into the line is very likely to occur with consequent cavitation and erratic behaviour or failure of the pumps. Even when lines and connections are absolutely leak free (which is difficult of attainment for lines of considerable length) the dissolved air in the fuel tends to come out of solution under the reduced pressure and thus to lead ultimately to pump failure. This difficulty can obviously be overcome by the use of fuel pipes of sufficiently large bore to handle the most viscous fuels, but frequent instances have come to our notice where pipe lines have been too small.*

* A simple method of calculating the necessary pipe sizes was given in a paper read by the authors before the Diesel Engine Users Association, 30th March, 1933.

The fuel viscosity also has effects on the operation of the fuel pumps and sprayers. Too low a viscosity leads to excessive fuel leakage and may even limit the engine output where an adequate margin of pump plunger stroke is not available over that required for normal fuel requirements without leakage. In addition, too low a viscosity may lead to increased pump plunger and sprayer needle wear, particularly when any fine abrasive matter is present in the fuel. On the other hand, too high a fuel viscosity may lead to sluggish seating of spring loaded pump suction or delivery valves, though this can usually be overcome by fuel heating or, within limits, by increasing the spring loading on the valves.

While the above characteristics of ignition quality and viscosity are undoubtedly important, the other items usually given in a fuel specification are briefly considered below.

Specific Gravity.

It is now generally realised that specific gravity in itself is of little importance when fuels are bought by weight, since the weight consumption of petroleum fuels in well designed engines is practically independent of the gravity. There is a point worth noting, however, in the case of ships' service tanks provided with float indicators marked in weight units. Such indicators are calibrated on a fuel of one particular gravity and the scale graduations are thus really volume units converted to weight for the fuel used when calibrating. The scale necessarily will give misleading results when a fuel of lower or higher gravity is used. Thus, if the tank be calibrated on a fuel of 0·92 specific gravity and this fuel be used in service and subsequently replaced by a 0·86 gravity fuel, there will be an *apparent* increase of nearly 7 per cent. in the weight consumption as measured by the float indicator readings. Instances where this has occurred have come to our notice and the complaint of increased weight consumption has been supported by the fact that a different fuel setting on the injection pump has been necessary. This latter adjustment is, of course, due to the increase in *volume* consumption of the lighter fuel, the consumptions by weight being identical.

Specific gravity is nevertheless a very useful check on the uniformity of supplies from a given source and gives some indication of the type of fuel. In general, the lower the specific gravity for a given distillation range the better is the ignition quality and calorific value of the fuel.

Distillation Range.

At one time distillation range was considered of some importance and one of the pioneer Diesel engine manufacturers, Messrs. Burmeister & Wain, recommended fuel of which the residue left after distillation to 325° C. did not exceed 30 per cent. by volume. Later experience revealed definitely that entirely satisfactory results were obtained with fuels of far higher boiling range. The prevalent opinion to-day is that distillation range in itself has little significance provided that the percentage of volatile material is not sufficient to lower the flash point or viscosity unduly and that the fuel does not contain an excessive proportion of hard asphalt.

It is true, however, that the most suitable fuels for small high speed engines are generally less viscous and give a lower carbon residue than those for large stationary or marine engines, and consequently the boiling range of the former is usually lower. No classification of fuels based on distillation range alone has any reliable significance since different crudes vary considerably as regards the nature and suitability of fractions of similar boiling range.

Hard Asphalt.

Hard asphalt is commonly regarded as an undesirable constituent in fuel though the quantity allowable must be considered according to the type of engine and the crude oil from which the fuel was obtained.

Large engines have no difficulty in burning fuels containing up to 2 per cent. hard asphalt and the clean condition of the combustion chamber surfaces after prolonged running on such fuels shows that the hard asphalt can be completely consumed under suitable conditions.

On the other hand, in small high speed engines where the combustion chamber volume is limited and where the time available for burning the charge is very short, difficulty is experienced with piston rings and exhaust valves and, in general, fuels containing more than about 0·1 per cent. hard asphalt are not recommended for such engines.

These difficulties may well be due, in part, to impurities or abrasive matter associated with hard asphalt, but, in any case, the amount of this constituent does appear to give some approximate indication of fuel quality for small high speed engines.

Carbon Residue.

As regards the Conradson or similar laboratory test for carbon residue, we have not found this to give a reliable indication of carbon formation in an engine.

The conditions of the laboratory test differ radically from those in an engine since in the former the fuel is heated in contact with a very limited supply of air and the residue measured when the volatile material has been driven off. This residue is, in fact, easily burnt in the presence of sufficient air. We have examined the combustion chamber surfaces of engines after using fuel of over 4 per cent. Conradson value, and have found them practically free of carbon after over 7,000 hours in service.

Sulphur Content.

Sulphur content, about which little has been heard for a few years, has again come into some prominence, dew drops and acid drops being the fashionable explanation of cylinder wear, probably as a result of the investigations of the Research Association of the Institution of Automobile Engineers on wear in petrol engines at low cylinder jacket temperatures. We believe there is ample laboratory as well as service evidence to show that the effect of corrosion is generally negligible in comparison with that of the numerous other variables which lead to engine wear. A discussion of this evidence will be given later. It is our present opinion that a sulphur content up to 2 per cent. has no measurable effect *in practice* on cylinder wear in c.i. engines.

Sediment and Ash.

Freedom from mechanical impurities is obviously a desirable quality for any fuel oil and has become almost of first importance since the airless injection engine became the prevalent type. Unfortunately, though most fuel specifications include a laboratory estimation of sediment and ash, the value of such figures, determined on a few ounces of fuel, is extremely doubtful. We have obtained a certain amount of experimental evidence showing that very small quantities of fine abrasive material, too dispersed to be estimated by the analysis of a small sample of the fuel or by miscroscopic examination, may have a very pronounced deleterious effect on the proper functioning and life of an engine. All fuel oils, particularly those of higher viscosity, tend to collect a certain amount of abrasive material during transit from refinery to engine, and it is unfortunate that few users appreciate how difficult it is to remove any but the coarsest particles of this accumulation by normal cleaning methods, or how necessary it is that the removal should be effected as near to the service tanks as possible.

In the above discussion of fuel specifications, carbon formation, piston troubles, corrosion and cylinder wear have been touched upon. It is proposed now to discuss these and other matters in more detail and to give a résumé of the practical and laboratory experience on which our present opinions of the causes of such troubles are based. Some of these opinions run counter to recent theories of fuel behaviour. In such cases it has been our endeavour merely to show how complex are the variables which influence certain aspects of engine performance and how misleading it may be to base theories on a few tests on a limited number of engines.

Carbon Deposits in Engines.

Carbon deposits in compression ignition engines may be classified in two main groups; those which are formed in or around the spray nozzles and those which are formed in the combustion space generally.

Clean fuel, used in a properly designed injection system, should never give trouble with nozzle carbon. We have run high speed engines at speeds from 1,000 to 1,500 r.p.m. on viscous fuel supposed to be suitable only for the largest marine engines and have had no more spray nozzle "trumpet" formation than on the lightest gas oil. At low speeds and light load the viscous fuel led to a small carbon build up (both on the nozzle and in the combustion space generally) but a short period under load burnt it away entirely. With any engine the formation of nozzle carbon and, if formed at no load, its subsequent tendency to burn away under load, are determined by the engine design and by the degree of cooling and the position of the spray nozzles. We suggest that for engines with a high degree of directed air turbulence, the best position of the nozzles is such that the jet orifices are in close proximity to, but out of the direct path of, the high velocity swirl of inflaming fuel and air. This tends to prevent the fringe drops of the fuel spray from being thrown back, partly burnt and coked, against the nozzle end. This deleterious effect of fringe drops has frequently been observed to be more marked with low viscosity than with high viscosity fuels. The former fuels are more efficiently atomized and the small droplets are more readily blown back than are the coarser droplets formed by the more viscous fuels.

Serious nozzle coke formation generally indicates very poor nozzle cooling and it should be taken as an invariable rule that all nozzles should be cooled as efficiently as possible, either by direct water cooling or by means of the fuel itself.

A rare but troublesome form of nozzle carbon formation has been observed inside the nozzle when the cleaning of the fuel has been imperfect. The cases which have come to our notice have been almost entirely confined to engines in which two or more single-orifice sprayers have been fed by a single pump through a distributing system. In such designs the least trace of choking in any one nozzle upsets the fuel distribution, compelling more fuel to pass through the clean than the partly choked sprayer. The latter then begins to overheat, and this leads to cracking of the fuel in the nozzle and finally to complete choking. Multi-hole nozzles are rarely liable to this defect, since the choking of one hole is offset by an increased flow through the remaining orifices, so that overheating does not take place. Incidentally, cases of nozzle choking have come to our notice even when the fuel used was thoroughly cleaned. These were due either to over-heated nozzles causing fuel cracking inside or to the blending of two fuels of different type. The latter usually occurs when a supply of one fuel has been filled into tanks containing a certain amount of a different fuel. Either fuel used alone might have been perfectly satisfactory, but certain instances have arisen when the blending of different fuels led to the throwing out of solution finely divided asphaltic matter, especially after heating in the engine fuel heaters. It is thus advisable to have fuel tanks as nearly empty as possible before filling with fresh fuel from a different source.

The general carbon distribution over the combustion surfaces of compression-ignition engines, other than the hard coke (mainly from the lubricating oil) which tends to form round the circumference of the piston crown and on the cylinder walls above the limit of ring travel, is usually sootlike in character, easily wiped off and quite harmless. In the larger engines of 25 B.H.P. upwards, and of reasonably good design, the amount of deposit appears to be independent of fuel characteristics. As mentioned in the discussion on carbon residue tests, fuels with Conradson values from zero to 4 per cent. have not shown any differences in such engines. In any case where a slow speed compression-ignition engine of 25 B.H.P. or more is sensitive to the carbon residue of the fuel there is room for improvement in design, usually as regards the elimination of stagnant places reached by the fuel spray but not thoroughly swept by the air charge. Smaller engines, particularly the high speed varieties, may give increased deposits at light or no load with a high Conradson fuel, but these usually disappear after a short period of moderate load running.

As regards lubricating oil carbon this usually increases in amount with the engine load, being due to the cracking of the oil at high temperatures. This type of carbon, which is one of the causes of piston ring sticking and which is also liable to choke exhaust ports in two stroke engines, can often be reduced by a careful reduction of the lubricating oil supply until the safe minimum is reached. The use of oil of unnecessarily high viscosity for the engine operating temperature sometimes leads to increased coke formation owing to the thick film of oil on the cylinder walls.

Pitting of Exhaust Valves.

The pitting of exhaust valve seats and seatings is due to the trapping between valve and seating of particles of partially burnt fuel or lubricating oil coke or of mechanical impurities carried into the engine by the fuel or air charge. The design and material of the valves and seatings and their ability to withstand high temperatures without softening are of great importance and have received much attention, with consequent good results, for automobile and aero engines. In large marine Diesel engines considerations of cost have precluded the general use of the more expensive alloy steels.

FIG. 2.—Exhaust valve after using light distillate fuel.

FIG. 3.—Exhaust valve after using Stream-Line treated Diesel fuel.

However, composite valves with special steel faces have proved satisfactory when the general design of the valve has been rigid enough to prevent distortion at operating temperatures.

It seems doubtful whether fuel characteristics have any direct influence on the condition of exhaust valves in a well designed Diesel engine of moderate or large size. However, as mentioned previously, fuel viscosity tends to influence the amount of mechanical impurities picked up by the fuel and carried through to the engine, where it may affect the valve seats.

The use of centrifugal separators for removing such impurities has a marked effect on valve maintenance. When the fuel is properly centrifuged, exhaust valves should generally remain serviceable without regrinding for at least 1,800 hours in large

FIG. 4.—Exhaust valve after using the same fuel as for Fig. 3 but untreated.

engines and 600 hours in smaller engines. Figs. 2, 3 and 4 are taken from photographs of the exhaust valves of an auxiliary engine after running equal times on (*a*) a light distillate fuel carefully streamline filtered before use (Fig. 2), (*b*) a marine Diesel fuel similarly treated (Fig. 3), (*c*) the same marine Diesel fuel drawn direct from storage and not treated in any way before use (Fig. 4). The valve in Fig. 4 shows an increased number of pits, much deeper in the valve seat, than do those in Figs. 2 and 3 which are almost identical in appearance. The seatings in the valve cages gave a similar comparison. An excessive lubricating oil supply, leading to heavy carbon formation which breaks away in fragments, may also aggravate valve pitting.

Failure of Piston Rings.

Apart from piston ring wear, the causes of which will be discussed in conjunction with cylinder liner wear, the breaking of piston rings is occasionally a serious problem.

Ring breakage may be due to various causes, but it usually starts with the top ring, which is subjected to high gas pressure differences between the upper and lower faces. As the cylinder liner wears, the top ring has to follow the liner contour during the compression stroke of the piston and the sudden application of the gas pressure as the top ring is springing outwards subjects the latter to stresses which may cause failure. Further, the top ring has to deal with temperature variations which may cause distortion; this is particularly likely to occur in two-stroke engines where the exhaust ports only cover a portion of the liner circumference. At the moment of uncovering the ports, the hot exhaust products sweep past the face of the ring with a high degree of turbulence and therefore with a high rate of heat transfer. Thus the portions of the ring in line with the ports tend to become hotter than the remainder, almost inevitably giving more or less distortion of the ring.

Such instances of piston ring failure are not in any way attributable to the characteristics of the fuel except in the rare cases where the use of a fuel with a very low ignition quality leads to higher maximum explosion pressures and temperatures. Cases are known, however, where impurities in a dirty fuel have so damaged or partially choked the spray nozzles that local zones of high temperature in the combustion chamber have arisen from the distorted spray. Then local burning of piston crowns and top piston rings has commenced and has rapidly led to serious trouble due to gas erosion past the burnt places.

Crankchamber Corrosion.

It is convenient at this point to leave discussion of combustion space effects and to consider a crankcase phenomenon which has occasionally given rise to trouble.

Cases of corrosion of Diesel crankpins and crosshead pins are from time to time reported and such corrosion has usually been attributed to faults in the lubricating oil or fuel.

Some examples came to our notice a few years ago in which the trouble generally appeared quite suddenly in engines that had been running perfectly before, and manifested itself as corrosion areas on the crank pins, varying in depth from a noticeable surface effect to pitting 1/16th in. depth or more, over the part which received the shock of the combustion pressure.

An examination of the causes of the trouble led to the following conclusions. In the first place, not only was the acidity of the lubricating oil after a period of use independent of the sulphur content or other variations of the fuel, but the corrosion did not necessarily occur in those engines in which the free acidity of the lubricating oil was higher than the average. An examination in the laboratory of metal test pieces, lubricated with used oils containing acid and subjected to shock loading similar in intensity to that on the crankpin surface, showed that the corrosion was mainly a function of the amount of free hydrochloric acid present and of the size of the acid-water droplets dispersed through the oil. The larger the droplets, the more likely they were to be ruptured when the load was applied, thus leading to their dispersion at high velocity across the metal surfaces. If only very fine droplets were present, even though the total acidity were high, no corrosion took place.

An immediate cure for the trouble was the fitting to each lubricating oil drain tank of a hat box which was drained of any settled acid water at regular intervals. In addition, hot distilled water from the steam service was added to the lubricating oil as it entered the centrifuge, and this reduced the acidity and agglomerated and removed most of the acid in emulsion.

In support of the above finding that the corrosion of crankpins, etc., is not determined by the sulphur content of the fuel is the fact that land stationary engines use all kinds of fuels containing up to 2 per cent. sulphur and yet rarely show signs of such corrosion. Further, vehicle engines of the high-speed c.i. type using fuels with 1 per cent. sulphur show no more corrosion than engines running on petrol with not more than 0·05 per cent. sulphur. When there is the possibility of forming free hydrochloric acid, as is always the case in marine use owing to the presence of chlorides in the sea air, even engines of the cross-head type, where the crank chamber is entirely separated from the cylinders, are known at times to show this type of corrosion on crankpins and crosshead pins.

Cylinder Liner Wear.

The mention of acid corrosive effects almost inevitably leads at the present time to the question of cylinder liner wear, since the corrosion theory is the prevalent excuse for wear.

Liner wear is a subject which is of interest to all oil engine users. The shipowner is concerned with the number of years he can run his ships without the expense of liner renewals, while the 'bus company or haulage contractor considers his results on a mileage basis.

The importance of liner wear, however, particularly in marine engines, can be easily exaggerated. To the shipowner the cost of liner renewals, say every 6 to 12 years, forms a very small item in his operating expenses. Much of the work incidental to the replacement of the liners must, in any case, be carried out during the periodic surveys and there is no need for new pistons or, in most cases, for any dismantling of bearings, etc., when liners are renewed.

The vehicle owner is rather more seriously concerned since reconditioning a worn lorry engine

LINER WEAR IN MARINE AUXILIARIES. AIR INJECTION ENGINES

ENGINE REF.	CYLINDER Nº	HOURS RUN	WEAR IN 1/1000" PER 1000 HOURS — AVERAGE
A1	1	7434	1·5
	2	7434	1·1
A2	1	4152	4·6
	2	4152	2·2
A3	1	6089	1·5
	2	6089	2·0
A4	1	4459	1·8
	2	4459	1·8
A5	1	6749	2·5
	2	6749	2·5
A6	1	7899	2·5
	2	7899	1·8
A7	1	15673	2·2
	2	15673	2·5
A8	1	16414	2·5
	2	16414	2·2
A9	1	20520	1·7
	2	20520	1·6
A10	1	19885	2·1
	2	19885	1·5
A11	1	15024	1·7
	2	15024	1·6
A12	1	9027	2·4
	2	9027	1·3
A13	1	9209	1·4
	2	9209	2·1
B1	1	18197	3·4
	2	18197	3·0
B2	1	10555	2·8
	2	10555	5·6
B3	1	16444	2·4
	2	16444	1·9
B4	1	15372	2·1
	2	15372	1·3
T1	1	15958	3·4
	2	15958	3·5
T2	1	17551	2·9
	2	17551	2·9
T3	1	22106	3·7
	2	22106	4·2
T4	1	13200	3·9
	2	13200	4·4
T5	1	15036	3·8
	2	15036	5·0
L1	1	5639	1·4
	2	—	—
L2	1	6582	1·7
	2	5899	0·6

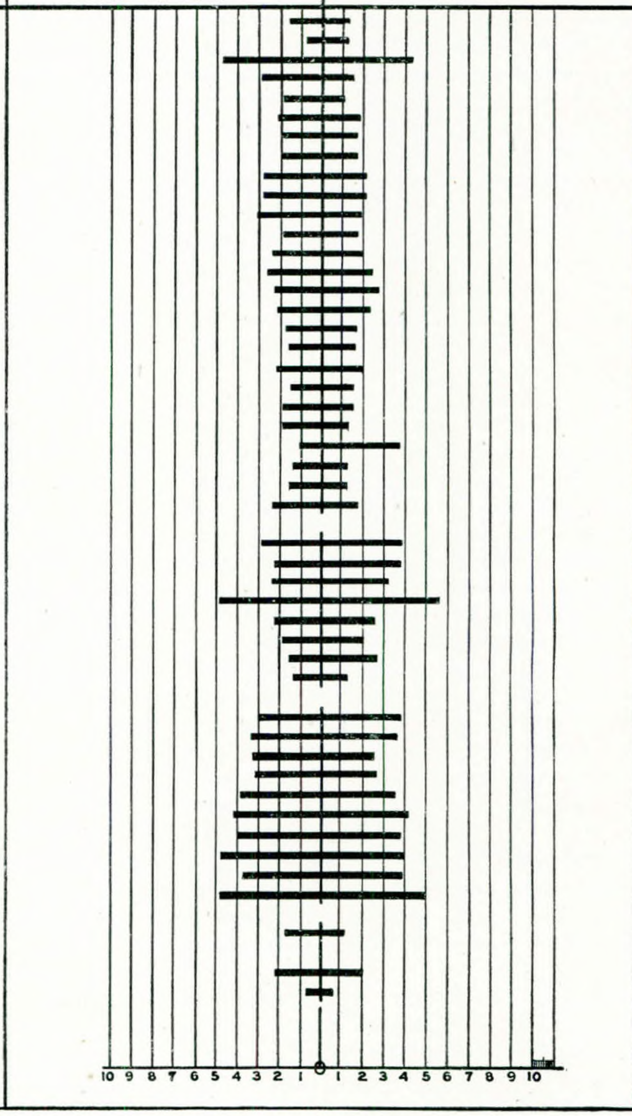


FIG. 5.

involves the complete dismantling of the engine and possibly necessitates regrinding of cylinders and fitting of new pistons. The cost of reconditioning a high speed engine is thus an appreciable fraction of the capital cost of the engine and the actual time between overhauls is also much less than for the average size of marine Diesel engine, either main or auxiliary. Incidentally, Mr. Ricardo, in his proposal to substitute a number of small high-speed engines for each large engine of the type at present used in marine work, appears to have been unduly optimistic as to the effect of such a procedure on maintenance costs.

In general, it is found that liners remain serviceable until the maximum wear amounts to about 1 per cent. of the cylinder diameter in the case of large engines and ½ per cent. for small high-speed engines. Assuming the average rate of wear in both types to be 5 thousandths of an inch per 1,000 hours, the useful life of the liners compares as follows :—

Large engine (say 24in. dia. cylinder) = 48,000 hours.

Small high-speed engine (say, 4½in. dia.) = 4,250 hours.

Reliable data on liner wear are not readily

LINER WEAR IN MARINE AUXILIARIES AIRLESS INJECTION

ENGINE REF	CYLINDER Nº	HOURS RUN	WEAR IN 1/1000" PER 1000 HOURS: FORE & AFT	ATHWART	AVERAGE
AA1	1	10158			1·2
	2	10158			1·8
AA2	1	5400			1·9
	2	5400			1·5
AA3	1	4936			2·8
	2	4936			3·1
AA4	1	4138			2·6
	2	4138			2·6
AA5	1	8199			2·4
	2	8199			2·3
C1	1	11618			2·5
	2	11618			2·2
	3	11618			2·5
	4	11618			2·2
C2	1	11590			2·5
	2	11590			2·2
	3	11590			2·4
	4	11590			2·7

10 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 10

FIG. 6.

obtainable and, in most cases, comparison between published data is impossible as methods of measurement vary as well as conditions of operation, fuel quality, load, etc.

Figs. 5 to 8 show graphically the results obtained from measurements of liners in main and auxiliary engines. All measurements were made by means of micrometer gauges which were carefully checked before each test on a standard gauge set exactly to the cylinder diameter.

The wear in main engine cylinders represents the mean of six measurements taken at the limit of top ring travel and also at 3in. and 6in. below this position in both fore and aft and athwartship directions. It was found as a result of a large number of observations that this method gave the most accurate and reliable indication of the wear. In the case of the auxiliary engines, six measurements were also taken at the top ring travel and 1in. and 2in. below this position, but it was found that, in all cases, the mean of the top four measurements gave a truer indication of wear than the mean of the six measurements. The auxiliary engine results are therefore recorded as the mean of the top four measurements.

The fuel used throughout was constant in quality, being the standard grade of Persian Diesel fuel supplied at the time the results were recorded.

Fig. 9 gives the results obtained with several fuels supplied for marine purposes but excluding Persian fuel. These fuels were picked up in various ports in the Mediterranean, Mexico, California, etc., and were used in three types of engines exactly the same as types referred to in Figs. 7 and 8. The results show clearly the negligible differences in the rate of wear due to changes in the quality of the fuels.

The engine types examined are detailed below :

Auxiliary Engines.

"A"	Air Injection four-stroke.	Two cyls.	300 r.p.m.
"B"	" " " "	" "	400 "
"T"	" " " "	" "	300 "
"L"	" " " "	" "	300 "
"AA"	Airless Inj. " "	" "	300 "
"C"	" " " "	Four "	450 "

All these engines are of the trunk piston type and are rated to develop about 100 B.H.P. The load on auxiliary engines is naturally subject to considerable variation, so that it is impossible to estimate the average mean indicated pressure which varied probably between about 90 and 50lb./sq. in.

Main Engines.

"D" Four-cylinder airless injection two-stroke opposed piston.
Scavenge from below, exhaust controlled by upper piston.

Average output 2,300 B.H.P. at 76 r.p.m. and 85lb./sq. in. m.i.p.

"W" Eight-cylinder air injection four-stroke. Average output 2,350 B.H.P. at 91 r.p.m. and 85lb./sq. in. m.i.p.

"Z" Air injection six-cylinder two-stroke. Opposed scavenge and exhaust ports. Average output 2,300 B.H.P. at 90 r.p.m. and 85lb./sq. in. m.i.p.

"ZZ" Air injection four-cylinder two-stroke. Opposed scavenge and exhaust ports. Average output 1,050 B.H.P. at 95 r.p.m. and 83lb./sq. in. m.i.p.

All these engines are of the crosshead type, and the powers and speeds stated correspond to averages maintained over a number of voyages. On some occasions the powers and mean pressures stated may be exceeded by about 10 per cent.

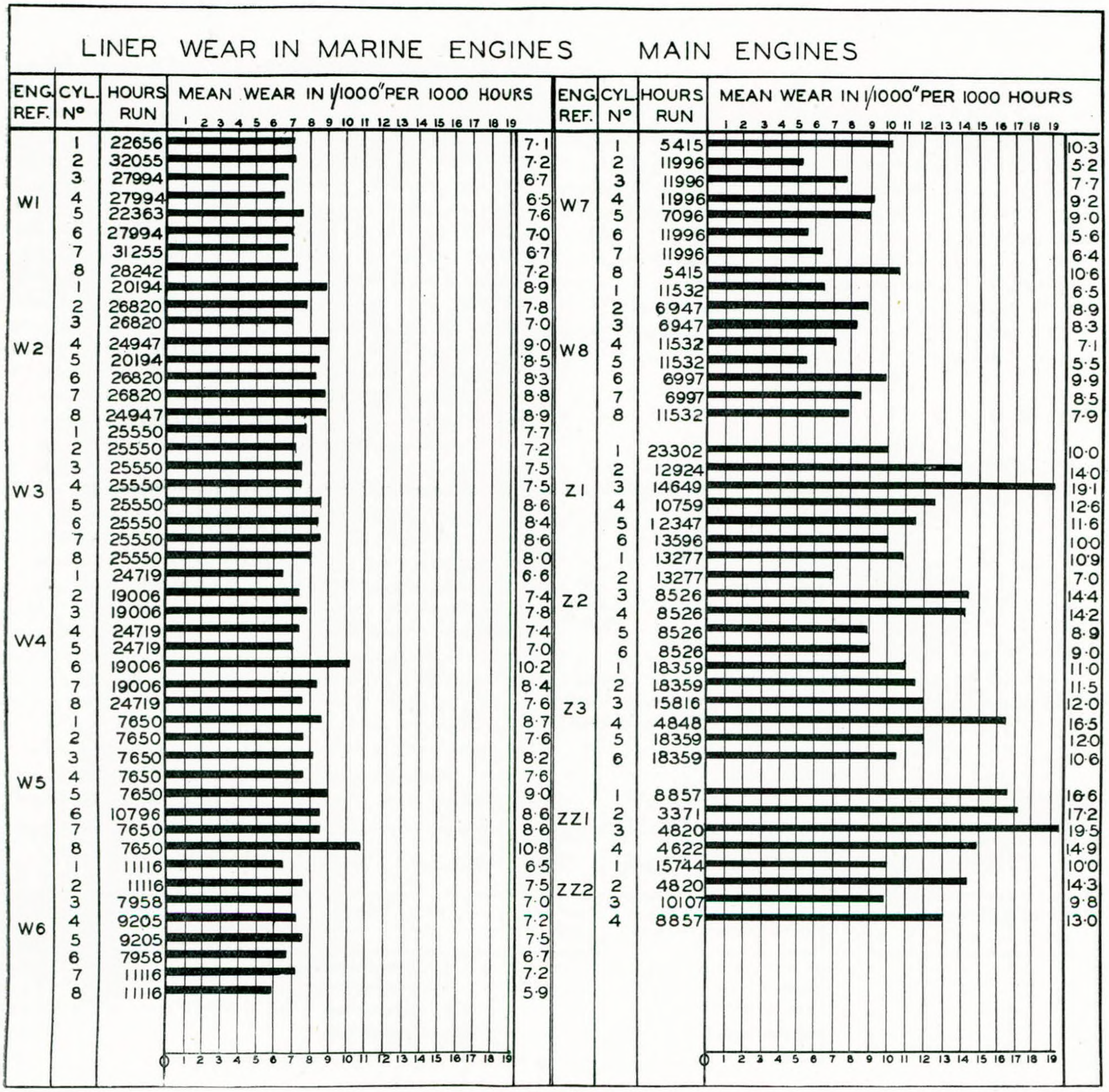
Discussion of Engine Wear Data: Causes of Variable Liner Wear.

One of the outstanding facts which emerges from the study of such a set of strictly comparable data, obtained from engines running on a standard quality of fuel, is the astonishing variation in the rates of cylinder wear. This is marked not only

LINER WEAR IN MARINE ENGINES. MAIN ENGINES

ENGINE REF.	CYLINDER N°	HOURS RUN	MEAN WEAR IN 1/1000" PER 1000 HOURS. UPPER LINER	LOWER LINER
D1	1	11420	1·9	3·5
	2	11420	4·3	2·2
	3	11420	3·8	1·9
	4	10100	7·6	5·4
D2	1	10026	4·9	3·6
	2	10026	4·8	3·9
	3	10026	5·2	3·9
	4	10026	5·5	3·4
D3	1	5776	5·6	4·5
	2	11150	3·6	4·2
	3	11150	6·6	2·5
	4	8976	5·8	4·4
D4	1	16582	8·8	5·2
	2	16582	8·9	4·2
	3	16582	6·6	3·3
	4	16582	6·6	3·9
D5	1	15337	5·7	3·8
	2	13700	4·8	3·9
	3	13360	7·5	5·0
	4	15337	9·9	5·0
D6	1	10536	8·6	4·0
	2	10536	8·4	2·8
	3	6958	4·2	3·2
	4	6958	4·0	4·0
D7	1	17180	8·7	7·9
	2	26185	7·2	6·2
	3	18462	6·6	5·6
	4	17180	5·8	5·0
D8	1	24263	8·9	4·8
	2	24263	10·1	4·7
	3	24263	8·6	5·8
	4	24263	9·8	7·3
D9	1	27044	8·2	4·1
	2	27044	8·6	7·8
	3	13541	8·0	5·1
	4	27044	8·0	3·8
D10	1	21800	9·6	7·0
	2	27206	7·8	9·2
	3	21800	10·0	7·0
	4	21800	9·6	7·0

FIG. 7.



ENG. REF.	CYL. N°	HOURS RUN	MEAN WEAR IN 1/1000" PER 1000 HOURS
W1	1	22656	7·1
	2	32055	7·2
	3	27994	6·7
	4	27994	6·5
	5	22363	7·6
	6	27994	7·0
	7	31255	6·7
	8	28242	7·2
W2	1	20194	8·9
	2	26820	7·8
	3	26820	7·0
	4	24947	9·0
	5	20194	8·5
	6	26820	8·3
	7	26820	8·8
	8	24947	8·9
W3	1	25550	7·7
	2	25550	7·2
	3	25550	7·5
	4	25550	7·5
	5	25550	8·6
	6	25550	8·4
	7	25550	8·6
	8	25550	8·0
W4	1	24719	6·6
	2	19006	7·4
	3	19006	7·8
	4	24719	7·4
	5	24719	7·0
	6	19006	10·2
	7	19006	8·4
	8	24719	7·6
W5	1	7650	8·7
	2	7650	7·6
	3	7650	8·2
	4	7650	7·6
	5	7650	9·0
	6	10796	8·6
	7	7650	8·6
	8	7650	10·8
W6	1	11116	6·5
	2	11116	7·5
	3	7958	7·0
	4	9205	7·2
	5	9205	7·5
	6	7958	6·7
	7	11116	7·2
	8	11116	5·9

ENG. REF.	CYL. N°	HOURS RUN	MEAN WEAR IN 1/1000" PER 1000 HOURS
W7	1	5415	10·3
	2	11996	5·2
	3	11996	7·7
	4	11996	9·2
	5	7096	9·0
	6	11996	5·6
	7	11996	6·4
	8	5415	10·6
W8	1	11532	6·5
	2	6947	8·9
	3	6947	8·3
	4	11532	7·1
	5	11532	5·5
	6	6997	9·9
	7	6997	8·5
	8	11532	7·9
Z1	1	23302	10·0
	2	12924	14·0
	3	14649	19·1
	4	10759	12·6
	5	12347	11·6
	6	13596	10·0
Z2	1	13277	10·9
	2	13277	7·0
	3	8526	14·4
	4	8526	14·2
	5	8526	8·9
	6	8526	9·0
Z3	1	18359	11·0
	2	18359	11·5
	3	15816	12·0
	4	4848	16·5
	5	18359	12·0
	6	18359	10·6
ZZ1	1	8857	16·6
	2	3371	17·2
	3	4820	19·5
	4	4622	14·9
ZZ2	1	15744	10·0
	2	4820	14·3
	3	10107	9·8
	4	8857	13·0

FIG. 8.

as between the different engines but even between different cylinders of the same engine. This indicates that many of the causes of cylinder wear must be independent of the quality of the fuel. The negligible effect of changing the fuel shown by the results given in Fig. 9, supports this contention.

That a variety of other factors do operate is, of course, well known, and the complexity of their action makes wear data exceedingly difficult to interpret. It is proposed in the remainder of this paper to discuss the causes of such variations in wear data and to give a number of observations on the subject made in the course of experimental work and from practical experience.

Sticking of Piston Rings.

The binding or breaking of a top piston ring during the period over which wear measurements are taken tends to transfer the maximum wear from the vicinity of the upper limit of the top ring travel to the vicinity of the second ring travel limit. This, in turn, may stick or bind during the fairly prolonged periods between marine engine overhauls so that the maximum wear belt is again shifted. The nett effect of this is, of course, to reduce the maximum wear below that which would have been recorded, had no rings stuck. Almost without exception, however, auxiliary engines have shown the greatest wear at the limit of top ring travel whereas the wear in the main engines has been fairly evenly distributed down the top six inches of the stroke. Thus, in the case of the above records for *auxiliary* engines, it is fair to assume that, since ring sticking has not been marked, the wear in excess of that measured in the least worn cylinder of each engine must be attributed to factors other than those directly due to the fuel quality. In Table I below are shown the minimum recorded wear figures for various auxiliary engines taken from Figs. 5 and 6. In addition, the maximum wear in the same engines is given for comparison. The difference between the minimum and maximum values on any one engine (Figs. 5 and 6) is wear not directly attributable to fuel quality.

TABLE I.

Maximum and Minimum Cylinder Wear in Auxiliary Engines.

Type.		Minimum wear. F. & A.	Minimum wear. Athwart.	Maximum wear. F. & A.	Maximum wear. Athwart.
A.	...	0·8	1·1	4·7	4·3
B.	...	1·3	1·2	4·9	5·6
T.	...	3·1	2·5	4·8	5·0
L.	...	0·8	0·6	2·1	2·0
A.A.	...	1·2	1·2	3·2	3·0
C.	...	2·3	1·8	3·0	2·5

Cylinder and Ring Distortion.

Undoubtedly cylinder distortion under service conditions plays a big part in determining these large wear variations. It will be observed from Figs. 5 and 6 that the wear of the auxiliary engine cylinders is rarely symmetrical, but that it may be greatest either fore and aft or athwartships. It is not dependent on the line of thrust, even in trunk piston engines. The geometrical arrangement of the liner flange support and the cylinder head joint may be such that there is a bending moment between those points leading to distortion which alters with every change of load and engine temperature. Similarly, uneven casting stresses in the various cylinders, and slight variations in material when different engines of the same type are considered, may both lead to different degrees of distortion. This is bound to have a pronounced effect on the comparative rates of wear, since the local pressure between the ring faces and the cylinder walls will be affected by every change of load and temperature. It seems as if almost every design of engine distorts slightly under load and wears to an equilibrium shape at that load and running temperature. If the running distortion between the lower and upper parts of the liner differs appreciably owing to uneven cooling, then the rings have little chance of bedding effectively over the whole of their travel and the general wear is thereby increased. Laboratory data which we have obtained on the effect of distortion on the rate of cylinder wear is given later in the section dealing with tests to examine the possibility of corrosive wear. It is sufficient to state here that tests on a single cylinder high-speed engine showed that a running-in period, the duration of which depended on the load, was necessary after every change of load and temperature before repeatable rates of wear could be obtained. Once the running-in period was completed, the subsequent rate of wear under the steady conditions was practically independent of fuel type,

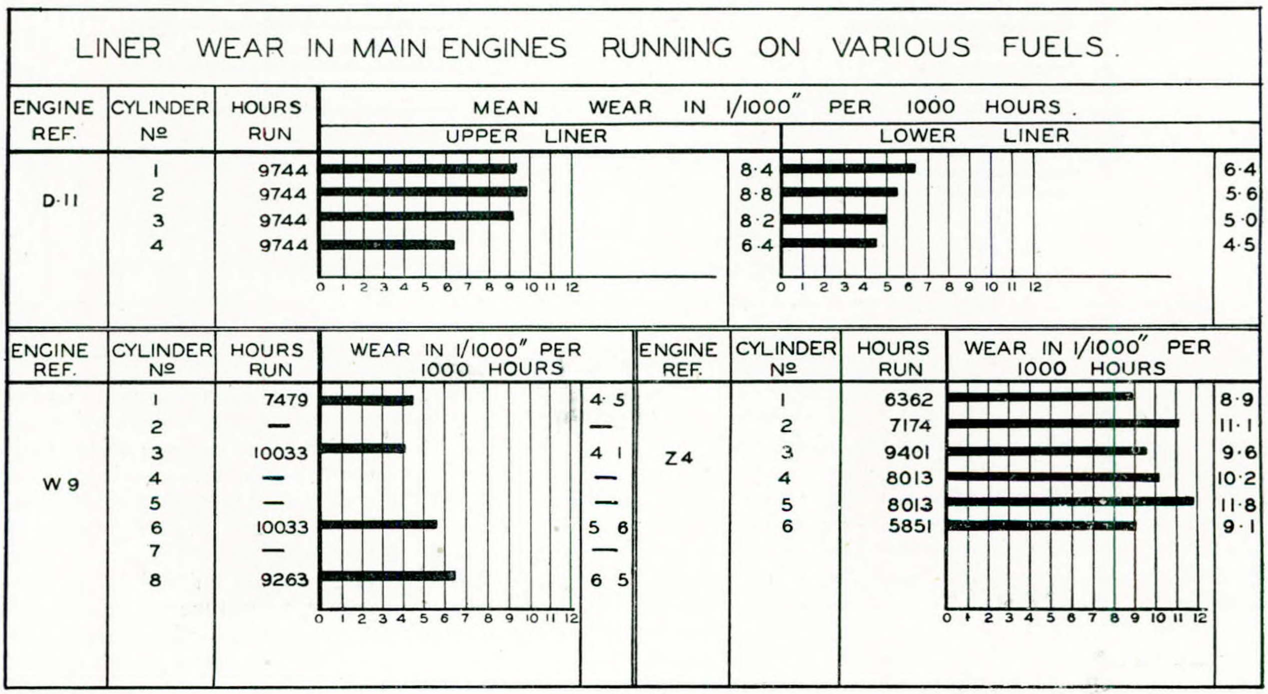


Fig. 9.

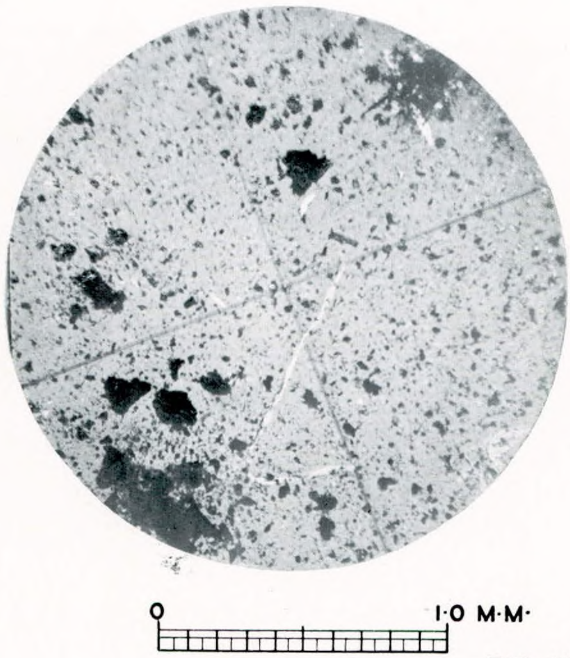


FIG. 10

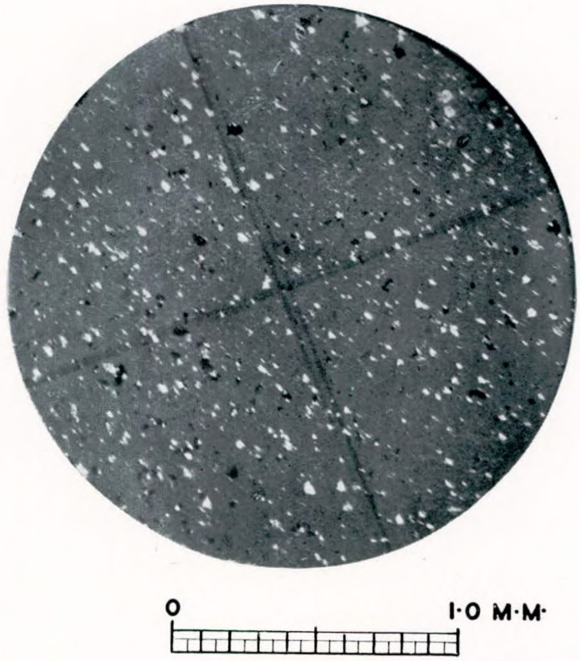


FIG. 11

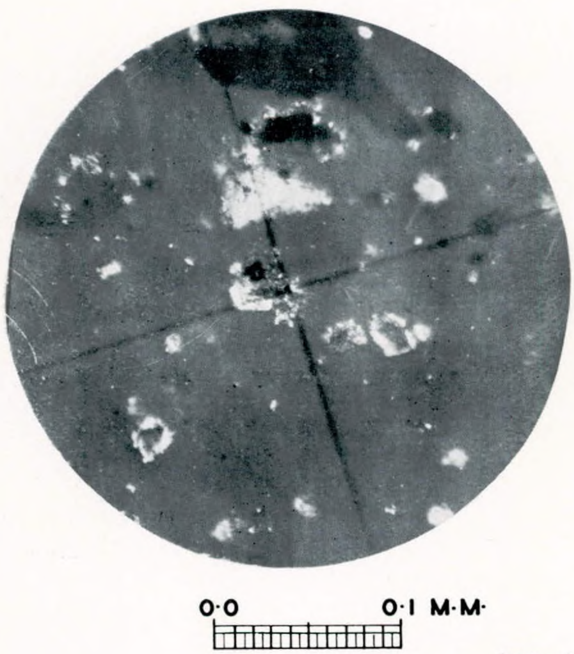


FIG. 12

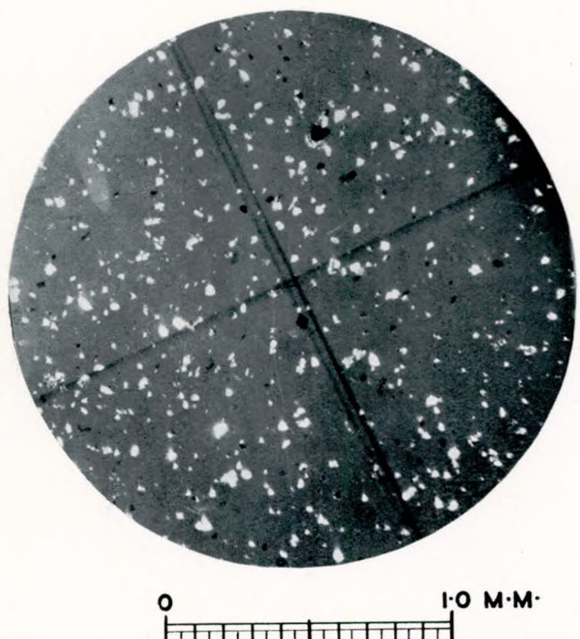


FIG. 13

FIG. 10.—Sample of deposit after removal of oil and water.

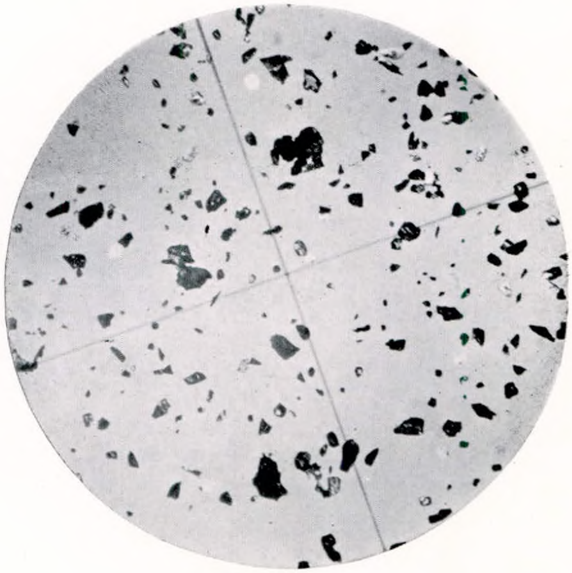
FIG. 11.—Sample after ignition to remove organic matter.

FIG. 12.—As in Fig. 11 but with higher magnification.

FIG. 13.—Sample after removal of iron oxide, leaving mineral matter.

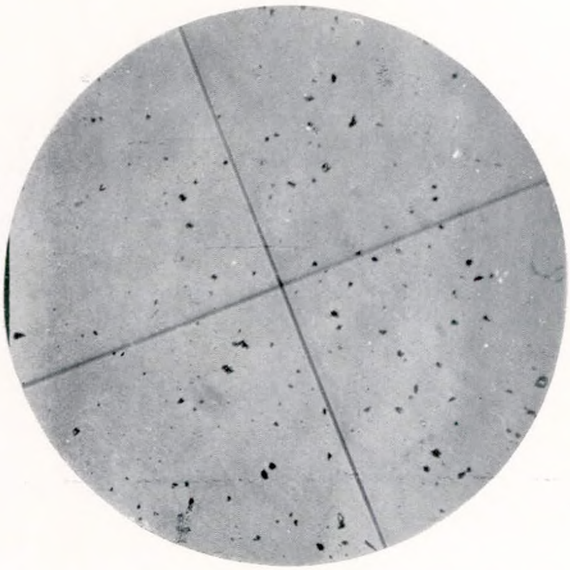
0·0 0·1 M·M·

FIG. 14



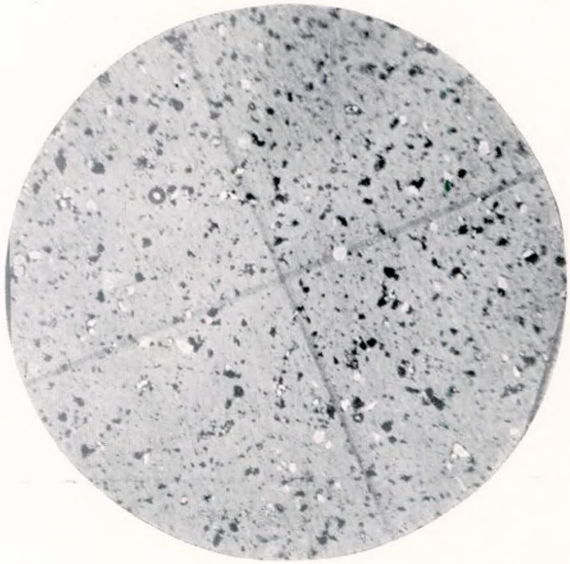
0 1·0 M·M·

FIG. 15



0 1·0 M·M·

FIG. 16



0 1·0 M·M·

FIG. 17

FIG. 14.—As in Fig. 13 but with higher magnification.
FIG. 15.—Coarse particles in Carborundum Paste.

FIG. 16.—Fine particles in Carborundum Paste.
FIG. 17.—Particles in Jewellers' Rouge.

provided all the fuels used were carefully cleaned. The effects of fuel quality on cylinder distortion appear likely to be indirect. If, owing to the presence of dirt in the fuel, partial choking of spray nozzles occurs, this will deform the spray distribution and thus lead to local overheating and possibly burning of the piston crown and upper rings. It is also possible, particularly in small high-speed engines, that the use of a fuel of low ignition quality may give rise to similar effects.

Effect of Abrasive Material in Fuel or Air Charge.

Reference to dirt in fuels brings us again to a point which we have repeatedly stressed—the necessity for really thorough removal of adventitious abrasive dirt from the fuels for airless-injection engines.

Some explanation may be needed to account for the presence of abrasive material, especially in distillate fuels. Since many crude oils contain sand and other gritty matter, if any residual oil from such crudes be blended in a Diesel oil it is certain that the latter will contain solid material in suspension. Other crudes are extremely clean and in these, and straight distillate fuels, the impurities usually consist of atmospheric dust blown into storage tank vents and, to a much greater extent, of iron oxide and bottom settlings picked up in tanks from previous supplies. The same amount of dirt enters petrol tanks but settles easily, though this does not prevent carburettor petrol-pump bowls or even float chambers from gathering sediment, some of which finds its way into the engine. This petrol suspended dust may, however, be too fine to span the oil film between piston rings and cylinder walls and, if so, will be harmless.

In the case of more viscous fuels of the marine Diesel type any quantity from 1 to 50 gms. of sediment may be found in a single 40 gallon barrel, the amount depending on the origin of the fuel and the care taken in settling and draining storage tanks. Some of this sediment is large enough to be kept back by the usual service tank gauze strainers and some of it is non-abrasive organic matter the only deleterious effect of which may be on the functioning of fuel pumps and spray valves.

Of the finer abrasive particles some can be taken out by special fine mesh strainers, these being the particles which tend to damage fuel pumps and spray valves, but there is a residue of abrasive material, some of which can be removed by careful centrifuging, while the finest can only be taken out by filtration such as that possible in the streamline filter. It has been our experience that it is the size of particle which can only be removed by thorough centrifuging or, for the finest particles, by streamline filtration, that gives rise to that part of the abrasive wear in an engine cylinder which can be attributed to the fuel.

In some early experiments on a 25 B.H.P. horizontal four-cycle cold starting airless injection engine we found that, under standard conditions, there was an approximate relationship between the rate of cylinder liner wear and the amount of silica found in the fuel sediment. The relationship was not linear, the effect of equal increments in the content of abrasive being much more marked when the total abrasive content was low. The result was that, with the more viscous fuels, several successive centrifuge treatments were required before the progressive reduction in the amount of dirt in the fuel produced any measurable effect on the rate of cylinder wear. Once this point was reached, further cleaning had a marked effect on the wear.

Later experiments, both on single cylinder high-speed engines and on two engines of the auxiliary type (one a four-cycle and the other a two-cycle engine) have given support to our previous conclusions. The small high-speed engines gave about 25 per cent. less wear when run on a twice centrifuged distillate fuel than on the same fuel taken direct from barrels and, by laboratory tests, apparently in a clean condition.

The results from the larger engines are in substantial agreement, though small differences have appeared between the two types. In both, the rate of cylinder wear is decreased considerably by careful centrifuging of the fuel. In the four stroke engine the wear on a marine Diesel fuel after either four centrifuge treatments or Streamline filtering was the same as on Persian Light Diesoleum, this representing a decrease in wear of between 10 to 50 per cent. on that given by the marine Diesel taken straight from storage tank without treatment and without any particular precautions as to settling. It should be mentioned that these two fuels differ appreciably as regards viscosity, sulphur and hard asphalt content.

On the two-stroke engine, streamline filtration of the marine Diesel fuel was necessary before the wear was reduced to that on the twice centrifuged light diesoleum. This fact suports the view that abrasive wear on cylinder liners occurs when the particles of abrasive span and rupture the oil film between cylinder walls and piston rings. In the four-stroke engine the idle exhaust and suction strokes tend to renew a reasonable oil film at the top of ring travel, but the two-stroke engine does not have this facility, so that finer particles of abrasive can span the film and cause wear. In both types, abrasive wear is most likely to occur near the upper limit of travel of the top piston ring since, in this region, temperatures and pressures are the highest and the oil film thinnest.

Analytical and microscopic examination of the sediments contained in marine Diesel fuels when taken from users' storage tanks reveal a very heterogeneous collection of material. Included in the sediments are iron rust and scale from tanks and pipe lines, water soluble salts such as sodium and magnesium chlorides and calcium sulphate, a quantity of waste and other organic material and mineral matter, mainly silica or silicates. The relative abrasive effects of these constituents are not well known, but it is certain that both the iron rust and silica are abrasives and even the soluble salts have some lapping action under suitable conditions. The appearance of the various constituents resembles that of similar material extracted from the air charge with which we propose to deal in detail.

The general effects of abrasive matter on liner wear will presumably be the same whether such abrasive enters the engine via the fuel or air charge. In both cases the relative effect of a given quantity of abrasive will vary with the type and size of engine and the material of which the liners are made.

It is surprising how much adventitious matter can enter with the air charge even in a marine engine. Fig. 10 is a photo-micrograph of a sample of the deposit, after removal of oil and of water soluble salts, which was collected from the wires of a 1½in. mesh inlet air grid to the scavenge inlet trunk of a marine two-stroke engine. Fig. 11 shows the material of Fig. 10 after ignition to remove organic matter. It consists mainly of iron rust and crystalline mineral matter and is shown in a higher degree of magnification in Fig. 12. Figs. 13 and 14 show this mineral matter, in two degrees of magnification, after removal of the iron oxide by acid treatment. It was sufficiently abrasive to scratch glass. For comparison with these photographs are given Figs. 15 to 17, which represent, respectively, the larger and the finer particles in fine carborundum paste and the particles of iron oxide in jeweller's rouge.

As stated previously, the sediment removable from fuels is of the same general nature and is quite unlike the insignificant amounts of solid matter which can be detected in clean crude oils such as that from the Persian field.

Corrosive Wear.

In view of the complexity of the problem of cylinder wear which is revealed by a study of wear in a number of engines such as has been outlined above, it seems surprising that any simplified theory of wear could have gained a considerable measure of support, particularly from men eminent in the engineering industry.

Nevertheless a theory of corrosive wear is very popular at present and is frequently quoted as a comprehensive explanation of cylinder wear both in petrol and compression-ignition engines.

This view becomes prevalent and disappears in cycles with somewhat monotonous regularity. About six or seven years ago, the sulphur content of a fuel was thought by some to exert an important effect on liner wear. Observations from practice over several years satisfied most engineers concerned with the running of large engines that sulphur had no measurable effect. The recent work of the Research Association of the Institution of Automobile Engineers under the direction of the late Mr. W. N. Duff has led to a revival of interest in the question.

It is to be regretted that prominence has been given to some of the results of this research, separately from the context, in a manner almost certainly remote from the intentions of its authors.

The effect of the Research Association's work in renewing the idea of corrosive wear arose chiefly from the fact that certain of the experimental results on short runs in petrol engines at varying jacket temperatures indicated that cylinder wear was most marked at low temperatures, particularly when lubrication was starved. It was suggested that this low temperature effect was due to the corrosive action of aqueous acid solutions, condensed on the cool metal surfaces from the combustion products of the fuel. Such effects could be expected to be most marked on surfaces not protected entirely by carbon or by an oil film, thus explaining the location of maximum wear at the upper travel limit of the top ring.

Actually the results only show a disproportionate rate of cylinder wear during excessively long warming up periods with abnormally starved lubrication. Even in vehicle engines it is difficult to believe that these conditions exist for sufficient time to account for an appreciable fraction of the total wear in service. The time required for the oil pressure to be fully established after starting an automobile engine is not more than 15 seconds. Actually the oil film left on the walls from the previous shutting down is probably a sufficient protection during the short time required to re-establish circulation. In the case of marine Diesel engines, for which the starting up periods form a very much smaller fraction of the total running hours than is the case for automobile petrol or Diesel engines, the possible effects of such corrosive action are bound to be even less.

As stated previously, our experiments with both c.i. and petrol engines have led us to the conclusion that, in any investigation of engine wear that necessitates a variation in load and temperature conditions, effects may be attributed to corrosion or other factors which are really due to cylinder distortion.

In some tests on a single cylinder high-speed c.i. engine, we found that (even under full load conditions which greatly accelerate running-in effects) after a change in jacket temperature from 80° C. to 20° C. three successive running-in periods of 20 hours duration were required before repeatble wear measurements could be obtained on a given fuel. The rate of wear during the first run after the change in jacket temperature was nearly three times as great as that obtained when the running-in was complete. It is obvious that this ratio would have been much greater if the test periods had been shorter. Obviously, also, any wear measurements made after short runs without allowance for distortion effects consequent on change of load or temperature would lead to the drawing of very erroneous conclusions.

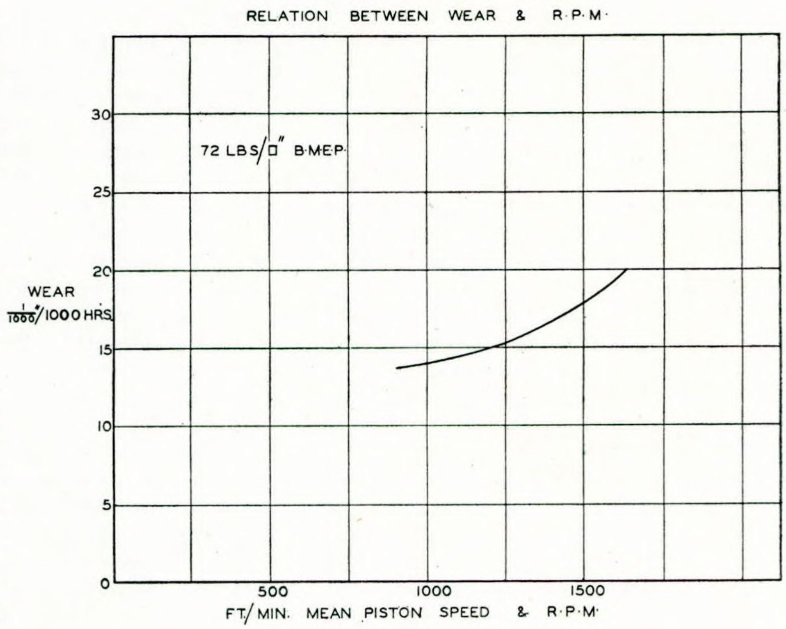


Fig. 19.

Our tests on single cylinder petrol engines made with adequate precautions to eliminate running-in effects after each change of load and temperature, confirm that the wear increases as the jacket temperature is reduced, but the ratio with normal lubrication is only of the order of two to one between jacket temperatures of 20° C. and 100° C. At light load—the usual condition during the warming up period—the wear ratio for the two jacket temperatures was scarcely changed, but the total wear at light load at either temperature compared with that at full load at the same temperature was very much reduced. The reduction was, in fact, so great that even with a cold jacket the wear at light load was much less than that at full load with hot jacket.

It is our opinion, therefore, that any corrosive action which occurs during the normal light-load warming up period of an internal combustion engine can have no practical effect on the general rate of wear under operating conditions.

Effect of Lubricating Oil.

While the wear of engines which depend for cylinder lubrication on oil thrown from the big ends and main bearings may be affected by the viscosity of the oil, especially during starting from very cold conditions with too viscous a lubricant, there is no evidence that viscosity of the lubricant has any appreciable effect on wear of engines of the marine type in which the cylinder lubricant is fed in a controlled quantity directly to the walls from the moment of starting. During the long period over which the various marine engines referred to in Figs. 5 to 9 were being examined, several grades of lubricating oil were tried in some of the types, without showing any measurable differences in rate of wear. In the "D" type engines the grades chiefly used were well-known oils, having Redwood I viscosities at 140° F. of 130", 175", 193" and 210"; in the "W" type, 160" and 580" oils were used, and in the "Z" type the viscosities were 360" and 473". In some cases a given grade of oil was used for several years before a change was made to a different grade, and a few grades other than those mentioned were also tried over periods of about twelve months each but without disclosing any effect on the average rate of wear.

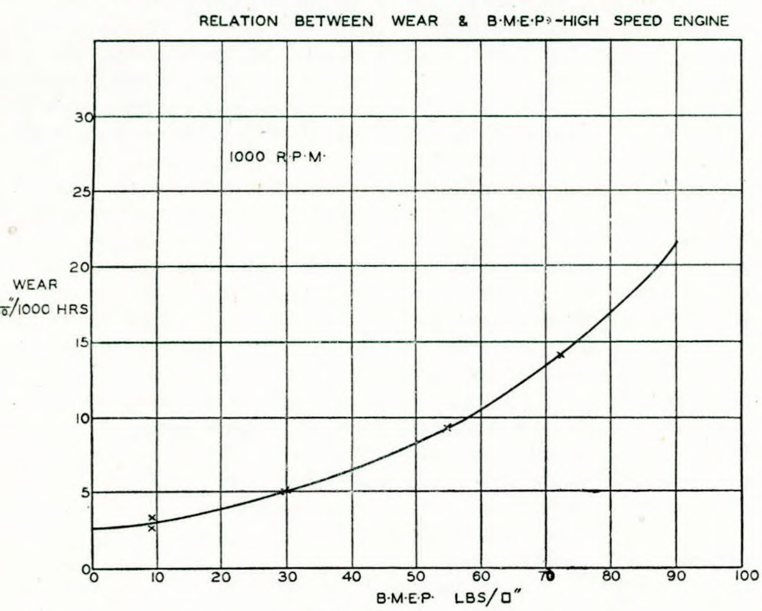


Fig. 18.

Effect of Speed and Load.

Figs. 18 and 19 show the changes in the rates of cylinder wear of a high speed c.i. engine at normal operating temperatures in so far as wear is affected by B.M.E.P. and R.P.M. respectively. Tests on a second high speed engine at 70lb./sq. in. B.M.E.P. and at no load, at 1,000 r.p.m. and 80° C. jacket in each case, gave a wear ratio of 6 : 1, which agrees well with the ratio of about 5·6 : 1 shown for the first engine in Fig. 18. Similarly a single cylinder petrol engine, running at 1,500 r.p m. and 100° C. jacket temperature, gave a wear ratio of 6·7 : 1 between full load and no load after distortion effects had been eliminated by careful running-in before each test.

In all the above examples the cylinder liners were cast integral with the jacket castings. Tests on the engine referred to in Fig. 18, after fitting a "centrarded" liner, with hardened and tempered rings, showed that the alteration in materials reduced the full load wear by about 50 per cent. Since this test was made after only 20 hours total running-in time, it is probable that an appreciable further reduction will take place on subsequent runs.

For road transport engines, the constantly changing load and speed conditions, distortion effects due to variations in jacket temperatures, and the effects of varying quantities of road dust taken in with the inlet air, all tend to make the results of wear measurements very difficult to interpret. It is obvious that an immense amount of carefully controlled experimental work has yet to be done before definite conclusions can be drawn as to the average relative importance of each of the wear factors to which we have referred. At present, our opinion is that combustion-product corrosion has only a negligible effect under practical conditions. Cylinder distortion is probably important in some engines, though there is a general tendency to reduce distortion effects in new designs by more careful attention to proper metal thicknesses and uniform temperatures of the upper and lower portions of cylinder liners. Abrasion is probably the most serious factor and can be attributed in part to the fuel storage conditions and in part to the inlet air.

No single theory of wear appears capable of accounting for the wide differences and curious anomalies which appear in such wear data as have been given in Figs. 5 to 9. We trust that these data will be borne in mind as each new and convincing laboratory explanation is advanced.

The authors are indebted to the Directors of the Anglo-Persian Oil Co. for permission to publish this paper, which contains the results of investigations chiefly carried out in the A.P.O.C. Research Laboratory at Sunbury-on-Thames.

DISCUSSION.

Mr. A. E. L. Chorlton, M.P., C.B.E. (Member) congratulated the authors particularly upon their courage in opposing the almost universally-accepted idea that corrosion, about which so much had been heard recently, was the chief factor in liner wear. The authors would have the support of practical people, because the theory of corrosion had been overdone when considered with actual experience. Everyone knew how much depended upon the operator's knowledge of the engine and the general working condition of all the parts.

In the speaker's early days the same difficulties —more exaggerated—had been encountered and little knowledge had been then available to deal with them. They had been attacked from many points and the experience thereby gained led him largely to agree with what the authors had submitted to the meeting that evening.

Even when the gas engine was in use—before the oil engine came to the front—he had realized that cleanliness was one of the main factors in obtaining a good running engine without wear. The importance of cleanliness, i.e., of the air and fuel, was shown by the authors' experimental work and confirmed the speaker's past experience.

He wanted to stress the point of distortion. He thought that this played a greater part than even the authors were disposed to accept. If an engine was put together and fitted properly, why was it that even when running-in fairly slowly trouble was experienced, that lubrication was insufficient or ineffective, and that wear took place? Distortion appeared naturally to be one of the main explanations. He had tried on one occasion to finish the cylinders at the working temperature.

The authors had not dealt with varieties of rings which had been devised specially for the purpose of meeting the changing cylinder conditions and to prevent gas passing the ring. (At this point Mr. Chorlton showed some slides of older engines which he discussed).

Continuing, he said that in the early days they had worked at high temperatures consistently, whilst as regards the Continental engines which would be discharging at only 120° F. he did not know that anything particular was found out thereby except that it could be done successfully. The engines of the Airship "R.101" were steam cooled and therefore boiling all the time.

The nineteen oil engines running in Canada on the National Railway, which were of the high-speed type, had run over 5,000,000 miles (one car alone had covered 450,000 miles). There had been very few liners, etc., changed in the six years and this gave much better conditions of wear than the authors gave.

With harder materials, the authors stated, the wear was reduced. This, of course, was to be expected, and as all the factors were improved, such as hardening the liners and rings, increased cleanliness by the use of first-class filters, etc., for the fuel and lubricating oil, the life would be correspondingly increased.

He would conclude by saying that it was timely for those who were accustomed to the relatively slow marine engine to consider whether it would not be ousted by engines of higher speed. He did not suggest that bus engines would be used on board ship, but engines with 15in. cylinders running at 1,000 r.p.m. seemed quite probable.

Mr. C. G. Williams (Manager, Research Department, The Institution of Automobile Engineers) said that the authors, on pages 142 and 143, referred to the investigation on cylinder wear of petrol engines carried out by the Research Department of the Institution of Automobile Engineers. In this investigation it was found that below a certain cylinder wall temperature there was a rapid increase in wear, and this increase was attributed to the deposition on the cylinder walls of moisture containing various acids, with consequent corrosion. The authors now came forward with the suggestion that the I.A.E. were deceived; what had been thought was due to corrosion was really due to distortion. It was unnecessary to repeat all the evidence for considering corrosion to be responsible for wear at low temperatures, but one of the experiments was particularly relevant. If cylinder distortion was responsible for the increase in wear at low temperatures then this increase should be the same whatever the fuel. This was not the case. Actually, the increase varied according to the corrosive products formed, and hydrogen—a fuel incapable of forming corrosive products—showed no increase, though distortion was presumably the same as on petrol.

Again, the increase in wear occurred abruptly at a cylinder wall temperature just below the dew-point, just when one would expect condensation of moisture to begin. This temperature was the same for different engine designs, surely another fact showing that distortion was not responsible.

He would like to make it clear, however, that the Institution had never suggested that corrosion was "a comprehensive explanation of cylinder wear"; all that had been claimed was that corrosion was a factor of considerable importance, a view which he saw no reason to modify after perusing this paper. He might add that unpublished work which the I.A.E. had carried out during the last year all went to confirm that corrosion was very largely the cause of wear at low temperatures.

Dealing with the authors' criticisms in greater detail, they stated on page 142 that the I.A.E. results "only show a disproportionate rate of cylinder wear during excessively long warming-up periods with abnormally starved lubrication". He entirely disagreed with this description of the Institution's experiments. It was quite true that in some of the tests the oil supply to the cylinder walls was withheld for the first five minutes after starting from cold. The authors apparently considered this period excessive because the oil pressure on an automobile engine was fully established in less than fifteen seconds after starting. He was afraid, however, that the reading of the pressure gauge had little or nothing to do with the time taken for the oil to reach the cylinder walls, particularly the top of the bore. Tests carried out some time ago in the United States on a number of engines showed that the average time taken for the oil to reach the cylinder walls at an engine speed of 1,500 r.p.m. was five minutes after starting and that, during cold weather, this period was exceeded. These results had been recently confirmed in this country, the time taken for fresh oil to reach the top of the cylinder bore exceeding five minutes. With such figures in mind it could certainly be claimed that the five minute delay in the Institution's tests was quite normal.

The authors described the warming-up period in the Institution's tests as excessively long. Actually, the cylinder walls had almost reached their maximum operating temperature ten minutes after starting from cold, a period which he was sure was exceeded on many automobile engines.

The authors found it difficult to believe that the conditions of starved lubrication and delayed warming-up existed for sufficient time to account for an appreciable fraction of the total wear in service. It might be difficult to believe, but it was nevertheless a melancholy fact. As a result of the Institution's tests, and from an examination of data supplied by a large number of manufacturers and operators, his own opinion was that on the average automobile engine and under average running conditions corrosion probably accounted for about 50 per cent. of the total wear. Depending largely on operating conditions, the actual percentage would vary widely and might be considerably less than this when an engine was operated continuously, and much higher when an engine was operated very intermittently. For example, the cylinder wear on a certain vehicle was about 0.001in. per 3,000 miles for fairly long-distance service, while the same vehicle showed a cylinder wear of 0.001in. in only 300 miles, i.e., ten times as great, when used for city delivery purposes involving a large number of stops per day. He could cite many other examples, supplied by manufacturers, showing how the cylinder wear on vehicles varied according to the frequency and duration of warming-up periods.

All the Institution's tests had been carried out on petrol engines, but it was interesting to note that Boerlage had observed similar accelerated wear on oil engines when starting from cold.

At the bottom of page 142 the authors implied that the Institution had attributed to corrosion what was really due to cylinder distortion. After referring to the necessity for running-in periods to allow for distortion effects, the authors described a test of their own in which three successive running-in periods were necessary before repeatable wear measurements could be obtained, the implication being that no such precautions were taken in the I.A.E. tests, and that the Institution's conclusions were based on "snap" readings. Reference to the published report of the Institution's work, however, would show that their standard procedure was to take three or more successive readings until results were repeatable. The I.A.E. had carried out a few hundred such tests by now, but had not been led to believe that distortion was responsible to any great extent for increased wear at low temperatures, though he did not wish to imply that distortion was a factor of no importance.

He did not profess to explain the variations in cylinder wear shown in Figs. 5 to 8, but before it was assumed that distortion was entirely responsible he would like to inquire whether it was quite certain that, on all these engines, fuel of equal purity was used, that the load factor was the same, and that the lubrication and jacket water temperatures were the same for all the cylinders. Finally, was combustion equally efficient in all the various cylinders? To quote Boerlage : "wear is caused mainly by defective combustion, which results in sticky or acid products".

Eng. Rear-Admiral J. Hope Harrison (Member) submitted that there was no evidence to show that different fuels where improperly consumed varied considerably in causing wear. There was general agreement that abrasive matter in fuel caused wear, but the authors' contention that this was due to the abrasive matter being caught between the ring and liner had not been proved. There was positive evidence that dust played an unimportant part in causing wear. Was not wear caused rather by the overheating of the fuel at the nozzle due to the presence of abrasive matter in the fuel? On page 133 the authors stated that in a certain design the least trace of choking caused the nozzle to begin to overheat and this led to cracking of the fuel in the nozzle and finally to complete choking. What they wanted to know was what properties were required in a fuel in order to keep wear down to a minimum when this occurred. When different fuels were cracked in the above manner certain products were liberated. The speaker contended that wear was largely caused by the action of these products on the freshly-scraped poorly-lubricated portion of the liner. The results might be (*a*) a considerable increase in temperature causing distortion, and (*b*) corrosive action, by some of the products of cracking, causing growth, either of which would account for excessive wear at the point when it was usually found.

It appeared to him that if the conditions in an engine when it was running could be reproduced (with the one exception that no oil was burnt), and at the same time introduce an abrasive artificially, wear would not take place locally as it did at present but more uniformly down the liner. Hence they must look for something in the fuel which caused the material of which the liner was made to distort or grow at the point where excessive wear was found; this would also tend to increase wear because of the impossibility of lubricating rubbing parts at high temperatures by the methods now employed. The authors combined knowledge and experience of both engineering and chemistry, and it might be the chemist would help most if he could tell what the most undesirable products were when fuel oil was cracked and whether there were some fuels which were less liable to produce these than others. If pernicious products were produced from all fuels when cracked in this manner, then the metallurgist must be called in. The authors had quite rightly stressed the fact that the cleaner the fuel the better the results. The examination of large quantities of fuel as delivered from the oil suppliers had shown that, as delivered to the consumer by the oil companies, fuel was almost invariably reasonably clean. But before it reached the engine, in some manner, it often became contaminated and careful filtration was again necessary in many cases. But on the other hand there was evidence that clean fuel if burnt improperly would cause wear—not to the same extent perhaps, but *would* definitely cause wear.

They thus arrived at the result that while abrasives in fuel caused wear they caused it largely by increasing the difficulty of correctly consuming it in an engine, and not by becoming wedged between the piston-ring and liner. The graphs shown in Figs. 5, 6, 7, 8 and 9, added to their knowledge and if carefully studied and analysed afforded valuable information. If one took a weighted average, wear in Fig. 5 was about 0.00186in. per 1,000 hours while in Fig. 6 it was 0.0021in., which compared favourably with a large number of cases the speaker had collected. Wear shown in Figs. 8 and 9 was excessive and he felt that this might be explained if full details were available.

He had an example of irregular wear of a liner which was only discovered after the liner was reground, showing the necessity for taking measurements of wear at numerous points round the liner where the top ring ended its travel, at the combustion end, and not at the conventional four points. The authors referred to a similar case on page 135, and attributed it to impurities in the fuel damaging or choking the nozzle. The speaker served on the Committee mentioned by the authors on page 130, but could not agree that all the members were satisfied that ignition quality and viscosity were the most important characteristics of a fuel. For small high-speed engines a fuel that would remain liquid at low temperatures and not deposit wax was desirable. The authors' simple alternative for obtaining the ignition quality of a fuel would be useful to users. Large slow-speed engines had had satisfactory results when using fuels containing considerably more hard asphalt than two per cent. To the user, the Conradson test told little or nothing.

He could not agree with the authors that the sulphur content of a fuel was negligible. There might be no evidence that sulphur caused liner wear, but the presence of sulphur in fuel, in any quantity, was undesirable for other reasons.

It was pleasing to hear the authors' opinion of laboratory tests for wear. He feared that certain results recently published were obtained without the investigators realizing the fact stated on page 140 that for each change of load a running-in period was necessary before reliable data could be obtained. To the user, the authors' remarks about cleaning fuels were extremely helpful.

He would like to see the graph in Fig. 19 taken further down the scale.

On page 136 it was stated that a comparison of large and small engines showed the life of the liner to be 48,000 and 4,250 hours. He suggested that as the former were usually run at 100 r.p.m. and the latter about 1,200 r.p.m. the wear per stroke was the same for each.

Was not the permissible liner wear before renewal given by the authors rather high? Wear and B.M.E.P. given in Fig. 18 was misleading. Supercharged engines where B.M.E.P. was high had shown only normal wear. When wear increased rapidly with B.M.E.P. he suggested that it was not due to high pressure but to the engine being run at a load for which it was not designed. The contention (page 144) that no single theory of liner wear accounted for everything was very true.

Mr. A. Wolf (Visitor) said that he agreed entirely with most of the points raised by the authors, in spite of the fact that some of their conclusions were contrary to widely held current views.

The authors had referred to the use of the stream-line filter for removal of abrasives. He gathered that this had been in the laboratory only and would like to ask whether, in their view, it could be used satisfactorily on a large scale without the dimensions of the plant becoming too large. Were there any other means (apart from centrifuging) of which the authors were aware for the removal of the finest abrasive particles, and were there likely to be difficulties with the stream-line filter on account of water in the fuel becoming absorbed by the paper of the filter packs? It might be best, perhaps, to combine the use of the centrifuge with the filter so that the moisture was largely removed in the centrifuge.

The authors had recorded that liner wear was independent of the viscosity of the cylinder oil within limits of 130″ to 580″ Redwood I at 140° F. While this at first sight appeared to be contrary to what one would expect it seemed to him that, although changes in viscosity would affect oil film thickness in the lower parts of the liner, there was not a true film at the upper end where the wear was important, and under these conditions viscosity gave no indication of lubrication efficiency.

Compounding might be beneficial in some respects if there were not attendant disadvantages in Diesel engines, and an alternative might be the addition of colloidal graphite to the lubricant in the proportion of, say, 0.1 to 0.2 per cent. Caution would, however, have to be observed when the same oil was employed for cylinders and bearings, as the graphite, although less liable to lead to stable emulsions with water than compounded oils, still did reduce the demulsibility factor.

On page 141 the authors stated that when the abrasive content of a fuel had been reduced by repeated centrifuging to a comparatively low figure a much greater reduction in liner wear per unit reduction of abrasive was observed than in the earlier stages of centrifugal treatment. No explanation had been suggested, but in the course of conversation the authors had given an explanation which seemed worth putting on record. The abrasive matter in a given fuel varied considerably in size, and in accordance with Stokes' Law the larger particles were much more readily removed by centrifuging than the finer. Consequently, on repeated treatments the average size of particles removed became smaller and smaller until a stage was reached where the range of sizes was such as to pass readily between the top piston ring and the liner in the parts of the cycle where there was only a low pressure on the rings; these particles, however, were still sufficiently coarse to bridge the oil film when the rings were under pressure. These coarser abrasives in this range produced the most wear, but further treatment eliminated the larger of the dangerous particles and wear then became noticeably less. The finest particles were too small to bridge the oil film and lead to wear, but the limiting dimensions depended largely on the engine design, thus treatment suitable for some engine types was inadequate for others.

In connection with the remarks in the paper on the entry of abrasives into the engine with the air charge, he would like to ask the authors what were their views on the efficiency of the various types of air cleaners on the market.

He was inclined to agree that whatever might be the effect of high sulphur content of the fuel on cylinder wear of engines running at low jacket temperatures and with restricted feed of lubricant to the cylinder, the sulphur content of the fuel had no measurable effect on wear of compression-ignition engines which ran for practically the whole of their working life at normal jacket temperatures.

It might appear startling that two per cent. of sulphur in the fuel had no effect, if one calculated the amount of sulphur acids formed by the combustion of such a fuel in a large engine. Fortunately for the engineer, sulphur dioxide (the predominant sulphur compound in the combustion products) did not attack steel or iron except in the presence of moisture, and moisture did not occur at the wearing places in an engine running under normal conditions. Moisture which could collect during starting and warming up was probably rendered harmless by the oil film, especially if the warming up load were light so that the oil film was not so readily squeezed out.

While sulphur in the fuel had no effect on liner wear in large engines, it did in certain cases have a most pronounced effect on crankchamber corrosion. Fortunately, once the cause was recognised the remedy was simple and effective. Crankcase corrosion often followed the development of leakage from the circulating water system, and generally the oil in use, rather than the true cause, was blamed. In other cases rapid increase of piston blow was the beginning of trouble. Instances had been recorded where no less than 7 per cent. of ferrous and ferric sulphate formed by the action of sulphur compounds from the fuel was found in the oil in the crankcase.

The statement by the authors that corrosion in the crankcase was mainly a function of the amount of free hydrochloric acid present and of the size of the droplets was remarkably interesting and new to the speaker. It cleared up a difficulty which had puzzled lubricating technologists for some years. The chlorides might, of course, be derived from sea water leakage as well as from salts carried in the sea air. The effect of drop size explained why more crankcase corrosion might sometimes be experienced with a high grade lubricant of good demulsibilty than with a poor grade oil, as the latter might have a tendency to emulsify with the water and thus form non-coalescing droplets which remained separate. These would be too small to cause corrosion. At the same time it must be remembered that a reasonable degree of demulsibility was necessary to allow the acid droplets to be centrifuged out efficiently.

Mr. Wolf endorsed the statement that even engines of the crosshead type with the crankcase separate from the cylinder were known at times to show bearing corrosion. This could occur even with double-acting engines where the piston rod had to pass through both the cylinder gland and the crankcase gland. It was necessary to remember that the oil film on the rod was capable of absorbing combustion products while it was in the cylinder and of carrying these down through both glands into the crankcase. Probably only dry SO_2 gas was transferred, but this could become dissolved in any water in the crankcase oil with subsequent harmful effects.

He knew of one instance where the piston rod leakage oil was being collected and added to the crankcase. Crankchamber and centrifuge bowl corrosion were evident, but were removed when the addition of contaminated oil was stopped.

Mr. H. S. Humphreys (Member of Council) said that a point which occurred to him in connection with the diagrams of cylinder liner wear was that less variation in wear was evidenced in the case of the Doxford engines than in the others. It was significant that, except in the case of the Doxford engines, all the types which were compared were fitted with cylinder covers. He suggested that when the covers were tightened after overhaul it was quite possible that the cover studs might be set up to a considerable variation in tension, depending upon the mood of the man who hardened-up the cover nuts. When the engines were running there would be a continual and important variation of stress on the liner flange which would be transmitted to the liner surface and might possibly lead to an increase in liner wear. This also appeared to him to be borne out by the fact that the rate of liner wear shown on the diagrams was greatest in the two-stroke type of engine where there was the greatest offset between the liner and cover joints. The renewal or annealing of the copper joints each time the covers were lifted would lessen the tendency for the man to overstress the cover studs when tightening up.

It was also observed that the liner wear in the way of the upper piston of the Doxford type engine was 25 per cent. to 50 per cent. higher than in way of the lower piston. Where the piston was made to float this was not the case, so that side movement of the piston might largely affect liner wear.

It might be of interest to state that this increased liner wear in way of the upper piston applied not only to the Doxford engine, which had the exhaust ports at the top and scavenge ports at the bottom of the liner, but it was also found to be the case in Cammell Laird-Fullagar opposed-piston engines which had the scavenge ports at the top of the liners and exhaust ports at the bottom. He understood that the same applied to the Junkers high-speed engines.

A point which might be overlooked was that in the opposed-piston engine the power developed in the lower part of the cylinder was higher than in the upper, due to the obliquity of the connecting rod, and this of course was more pronounced in the latest differential stroke type, where the upper piston had a shorter stroke than the lower.

It was reasonable to suppose from these facts that the difference in wear was due to side movement of the piston—certainly it could not be attributed to the fuel.

Regarding the authors' remarks on lubricating oil, a case had come recently to his notice of considerable increase of liner wear after changing the grade of lubricating oil. Whilst he agreed with the authors that one should not jump to hasty conclusions, could they say whether, so far as corrosion of liners was concerned, one cylinder oil might have a greater affinity for acid than another? Although perhaps hardly comparable, would it not be practicable to run on a compounded oil for cylinder lubrication as was done with compressors? The fatty matter in the compounded oil might act as an adherent for the oil to the metal surfaces and increase the wetting power.

Mr. J. Calderwood, M.Sc. (Member of Council) proposed a hearty vote of thanks to the authors. This was seconded by **Eng. Lt.-Comdr. H. J. Nicholson, S.R., R.N.** (Member) and accorded with enthusiasm. Mr. Le Mesurier, on behalf of Mr. Stanfield and himself, briefly responded.

By Correspondence.

Mr. H. J. Young (Member) wrote that he was in accord with the authors' belief that the effect of corrosion was generally negligible in comparison with that of the numerous other variables which led to engine wear. On the other hand, it required to be recognised that there were instances where conditions had favoured one or other of the variables—be it corrosion, rusting, distortion or anything else—with the result that that one had had a distinct and peculiar bearing upon the case or cases in point, just as experiments had been carried out upon liner wear which had been, so to speak, partial to corrosion or its effects. This was not suggesting that the experiments themselves had been unfair—far from it—but that the very nature of the experiments and the very translation of their results had dealt with the particular rather than with the general variable.

It was very encouraging to see that the authors bravely referred to corrosion as the "fashionable explanation" and the "prevalent excuse" for liner wear. It was to be hoped that their frank method of dealing with the "corrosion boom" might arrest it and prevent further harm being done. The harm referred to was that corrosion had been more or less exploited, no doubt to the horror of those workers whose sole purpose was research and whose findings had been turned into headlines.

The authors mentioned crankchamber corrosion and said that it had been attributed to faults in the lubricating oil or the fuel oil. This again was largely a matter of "fashion". He (Mr. Young) found nothing of the kind. The trouble was contamination of the lubricant by matter from the combustion zone, but not necessarily produced there. For instance, he found that the intercooler tubes of copper had lost about a pound in weight each, that the piston crowns were copper plated, that copper sulphate was present in large amount in all the deposits on the crown and, finally, that copper was to be detected in the lubricating oil. The contamination was of such order that none of the several laboratories analysing the oil found anything the matter with it, but his (Mr. Young's) D.O.C. test showed it easily. This test was one where the warm oil was run over warm steel and bearing metal, and the corrosive attack, if any, examined under a microscope. The same type of corrosion could be imitated by adding minute amounts of sulphuric acid or acid sulphates to new mineral lubricating oil, but not by adding hydrochloric acid or chlorides or sea water. Also it was found that oils taken from lorries, buses and cars sometimes gave the same effect and this in cases where the vehicles had been functioning in inland cities.

Likewise, it was to be remembered that they were using petrol whereas the ships were burning oil. That high-sulphur fuel caused the trouble was against the weight of the evidence. Generally speaking, motor ships functioned equally well with either high or low sulphur fuel, and it was within the writer's experience to know that very many ships had functioned well with no little sea water in their lubricant.

Starting with his experience of ordinary steam engines some twenty or more years ago, he had seen definite proof of the etching of piston rings and cylinder bores, this etching being rather greater in the case of superheated steam jobs and being common to all internal combustion units. The writer, six years ago, communicated with Mr. Henry Ford on the subject and submitted his evidence to the Dearborn Research Laboratories of that firm. The subject was not new, but it had come up in a new form in the automobile world, which was new to the subject and very agitated to-day concerning liner wear.

Looking closely into such data as they thought were facts, it was not by any means clear that corrosion was a main factor—far less the main factor—in liner wear. For example, austenitic cast iron was resistant to corrosion, but liners made of that type of iron had not been outstandingly wear-resisting. As another example, taxi-cabs functioning in big cities like London suffered terribly from the wear of liners. These taxi-cabs idled, cooled off on ranks, crawled, hurried, and were driven or were on duty twenty-four hours daily. In other words, they fitted the corrosion theory perfectly and could be cited as an ideal example . Yet all-pearlitic cast iron of the "Vacrit" type had produced a definite improvement, and the significant point of this was that cast iron of the "Vacrit" type was not non-corrosive. It should be mentioned that these fleets of taxi-cabs might number as many as 500 or more each and that the wear of the liners was not tested on one or two cabs but upon dozens. Also, the engineers in charge kept records of the pistons, rings and liners because it involved financial considerations of no mean order.

Those people using all manner of peculiar irons for cylinders were, in the writer's opinion, likely to be brought back to a study of all-pearlitic iron as the right method of attacking the problem. The progress of cast iron had been seriously retarded by the attention given to test bars or, at any rate, to something not of the same form, mass and section as the castings concerned and, therefore, not of the same structure. Speaking carefully from such evidence and such experience as he had to date, he believed that liner material should be of such structure as would not easily disintegrate, would hold itself, its sulphide and phosphide and its graphite voids together and not let any of them loose when abrasion occurred; finally, it should be a little malleable and, therefore, capable of quickly forming a working skin and as quickly of reforming it over any wounds caused by rusting, corrosion, abrasion and so on. This theory of good-wearing liner material had thus far proved good in practice, and it had the added advantage, so far as results went, of not requiring hardened piston rings.

The authors drew attention to distortion as a main factor. It might be within their experience to know that pistons had been known to seize up with no explanation available from the measured clearances. The point, however, was that the clearances could not be measured when seizure occurred, but the fact of the seizure was ample proof that the clearances did not exist at that moment.

It was, perhaps, a pity that the authors needed to devote so much attention to proving that high sulphur fuel did not necessarily mean increased liner wear or even liner wear at all, but, as with corrosion, it had been misinterpreted until it became a bogey. It was to be hoped that now they had published many convincing facts and figures, it might be possible for them to do further work upon abrasives, carbon deposits, distortion and other valuable points about which the paper gave just enough information to make them wish for more from the same source.

Mr. S. E. Laxton (Shell-Mex and B.P. Ltd.) wrote that he would comment on the authors' observations in connection with crankchamber corrosion from the standpoint of one who had, for a number of years, been actively engaged in the study of lubricating phenomena.

The authors stated that corrosion on bearing surfaces subjected to shock loads in an engine was mainly a function of the amount of free hydrochloric acid and of the size of the acid-water droplets dispersed through the oil. Further, the larger the droplet the greater the likelihood of its rupture and subsequent dispersal at high velocity under the shock load. This would seem to indicate that in the opinion of the authors "corrosion" was caused by a combination of acid corrosion and the erosion consequent upon high velocity dispersal in confined spaces. Leaving the question of acid corrosion which possibly could be dealt with to some extent by washing in the usual centrifugal separator, it would seem that erosion could be reduced by arranging for greater dispersion of acid-water droplets throughout the lubricating oil. If this were the case, it would seem that an oil having a high resistance to emulsification such as Pennsylvanian oil, for example, would be less suitable as a crankchamber oil than an oil having a lower resistance to emulsification.

Mr. K. O. Keller (Member) wrote that the authors had done a great service to the engineering community by collecting data on cylinder liner wear as tabulated, particularly in Figs. 7 and 8. The picture offered by these two figures revealed the astounding variation in liner wear, and made one wonder on what line of thought engine designers should concentrate for improvements.

It was quite evident that fuel oil could not always be used as an excuse for liner wear, and the remedy must be sought in other directions. Even the quality of material of liners and/or piston rings did not offer an explanation, as liner wear differed between cylinders of the same engine which were generally of identical material.

These figures, however, did reveal that there was a greater uniformity of liner wear in a cylinder without ports than with ports, and this would suggest that in a liner with ports the rings were never at rest radially and circumferentially, i.e., the rings were virtually rotating and thus kept on wearing off the high spots, it being remembered that liners never remained uniformly round when expanded under variation of temperatures.

A further possible explanation might be found in reactions, i.e., torque deflection or vibration from the crankshafts being transmitted to the pistons, whereby the pistons were unduly pressed against one portion or other of the cylinder surface, thus adding to the wearing qualities and possibly assisting movement of the piston rings, as already referred to.

A further cause of liner wear was sometimes observed where excessive lubrication had been applied as a remedy. In a uniformly cooled cylinder and piston the lubrication ought to be reduced to the very minimum and thus reduce formation of carbon, as this carbon with certain grades of lubricating oil was of an abrasive nature.

It would have been interesting to know whether there was any considerable variation in the fuel consumption of the three types of engines, as there could be no doubt that the more complete the combustion was the less fuel it was necessary to inject and, therefore, fewer particles of carbon would reach the cylinder walls.

Mr. H. Mackegg (Associate), referring to the comments made by the authors with regard to the pitting of exhaust valves and cylinder liner wear, wrote that some results which had been obtained at a well-known land Diesel engine installation might be of interest. In this station six engines had been operating for the past seven years, during which time all the fuel oil used had been purified in two De Laval centrifugal oil purifiers. The total fuel oil consumed during these seven years was 9,725 tons, and the total running period of the engines was 111,500 engine hours. The exhaust valves were able to run not less than 1,000 hours before they had to be taken down for re-grinding, and so far it had not been necessary to replace a cylinder liner on account of liner wear.

Mr. A. Beale (The Stream-Line Filter Co., Ltd.) wrote that the Stream-Line filter was now available in a form and with accessories which made it definitely applicable to practical use in connection with the class of fuel used for marine compression-ignition engines.

Referring to the discussion on liner wear and Mr. William's information regarding a 'bus engine which gave wear figures of one-thousandth of an inch per 1,000 miles on long distance work and one-thousandth of an inch per 300 miles on short journeys, it might be of interest to contrast some carefully-checked figures which had recently come to the writer's notice. A certain provincial 'bus company using petrol engines, with the lubricating oil frequently cleaned by filtration, reported average figures as under:—

For liners of hardness approximately 1,000 Brinell, 17,500 miles per 0.001in. wear.

For liners of hardness approximately 500 Brinell, 7,700 miles per 0.001in. wear.

The fleet average of the cylinder bores at the time of reporting was 62,000 miles. These seemed to be decidedly good figures for engines engaged in arduous service.

THE AUTHORS' REPLY TO THE DISCUSSION.

Mr. Le Mesurier, on behalf of Mr. Stansfield and himself, stated that Mr. Chorlton appeared to agree generally with their conclusions. His slides of the piston rings with which he had experimented in his early gas engines were extremely interesting. The possible effect of piston rings had not been overlooked, but time had necessitated their omitting it. They had rung the changes on practically every type of piston ring, and could not say that vast differences as regards wear had been found. They had noticed, however, that where liners were worn improved results were obtained by using rings of the double-seal type which kept a better gas joint.

They quite agreed that lubrication at the top of the cylinder liner was relatively inefficient because it was impossible to scrape a substantial layer of oil from the bottom of the liner up to the top, where the main wear occurred, although they were experimenting with a special type of top ring arranged to act solely as an oil carrier, not exposed to pressure differences but helping to maintain a good film for the second ring, which was the pressure seal.

Mr. Chorlton had also referred to liner wear on locomotive engines. The conditions as to average load, average speed, etc., were not comparable with marine engines, and there were insufficient data to compare the results from a large number of engines which had run a total mileage of 5,000,000 with only a few liners changed and the results from individual marine engines as published in the paper.

He had also referred to the use of hard materials in small engines of the fast-running type. They had no doubt that by this means these engines would be able to run longer for a given consumption of cylinder liners than they required at present.

It was interesting to note the agreement with their ideas of the importance of the part played by distortion and also of the necessity for cleanliness.

Mr. Williams was quite naturally critical of the remarks they had made on the very interesting work carried out by his Institution. They hoped, however, that their remarks had not been misunderstood for they had clearly stated that "It is to be regretted that prominence has been given to some of the results of this research, separately from the context, in a manner almost certainly remote from the intentions of the authors". They did not think their ideas were as far apart as Mr. Williams might have led those present to believe, and would suggest that the I.A.E. would be among the first to deprecate the sweeping statements which had appeared in the semi-technical press recently claiming corrosion as the *sole* important cause of cylinder wear. They did not contend that corrosion played no part in the wear of the engines under certain circumstances, but they did not think it had any *practical* effect in the great majority of cases. Where it was an important factor it was a relatively simple matter to reduce it materially. Mr. Williams countered this contention by quoting results from petrol engines of the same type running over distances of 300 and 3,000 miles giving the same total wear but operating under different duties. But how did this evidence indicate that corrosion was the major cause of the difference? The conditions of intermittent duty and variable temperature were not only those which would introduce corrosion in an extreme case but also such that distortion would be the greatest, and it might easily be that the abrasive factor also was greater in the town than in country service with modern road conditions. Further, the relative effects of fairly steady loading on the one hand, and a rapid succession of full throttle accelerations on the other would aggravate the differences, so that it could be equally well affirmed that the heavy wear was due to a combination of circumstances favouring distortion, abrasion and high average mean pressures.

Mr. Williams had also referred to the remarks on the short time necessary for the lubricant to reach the cylinder walls and suggested that it had been assumed that this was taken as the time required for the pressure gauge to reach its maximum reading. This was not the case. The paragraph in which the rate of rise of oil-gauge pressure was mentioned was, perhaps, not sufficiently amplified, but it was only intended to convey that the lubrication would be established not very long after the maximum pressure was reached. They had actually run an engine from a condition in which the cylinder walls and piston were quite dry, and, by careful observations, had found that after a matter of 35 seconds a coating of lubricant had reached the top of the cylinder.

The same speaker had mentioned that his experiments were checked by three readings, but it was advisable to state the length of time over which each reading was taken. They had found that it was possible to obtain proportionate wear between seven and twenty hour runs, but that a fifty hour run might give a lower relative figure, thus it would be perfectly possible to run an engine under cold conditions for three periods of, say, five hours each and to get repeatable results, but after fifty hours, when distortion had been eliminated, totally different values would be obtained. In recent tests on large engines runs of 500 hours were being made to ensure reasonable averages.

With regard to Mr. Williams' comments on Figs. 5 to 8, it was simply intended to convey that distortion was one of the factors, and there were, they would emphasise, many factors in liner wear which required investigation before the whole story could be told. They would say, however, that in the case of the results published the fuel was as nearly of equal purity and consistency throughout as it was possible to obtain it. Also the load factors over such long times as were examined would average out about the same. Finally, they could find no practical effect of corrosion. They could produce laboratory results which would show corrosion differences, but in practice these differences became completely wiped out.

Mr. Williams also mentioned the elimination of low temperature wear in a petrol engine when hydrogen was used as a fuel. As had already been stated, they did not contend that corrosion could never occur, and in the tests to which reference had been made the cylinder temperature was obviously so low that the limit had been passed below which it began. They would mention, however, that above this critical temperature, which they still thought was rapidly passed in almost every type of service, the wear on petrol and on hydrogen was not appreciably different. Mr. Williams had himself during conversation since the reading of the paper made an interesting suggestion based on experimental work, and this was that the carbonic acid formed in far greater quantities than any other corrosive during very cold running conditions below the dew point might be a factor. If this were the case it became very clear that, since carbonic acid solution was an essential product from any hydrocarbon fuel used in any engine which ran with the cylinder walls below the dew point, the only remedy for cold corrosion in those instances where it occurred was to use different materials. Changes in the fuels used could only be expected to have a minor relative effect.

Admiral Harrison had stated that there was positive evidence that dust played an unimportant part in causing wear. This was a rather surprising statement and the authors could not agree that it was generally true. It might be that in certain cases where the dust particles were all large in size they did not work down between the wearing surfaces, but there was abundant proof that the finer abrasives entering an engine were often responsible for heavy wear. It was well known in the case of vehicle engines, for example, that an air filter which only removed part of the atmospheric dust (the part containing the large particles) was of practically no use, but that a really efficient air filter could reduce wear appreciably.

There was little to be gained by trying to select the fuel to prevent cracking in an overheated nozzle. While there were differences in cracking temperatures, all fuels could be cracked and the range between them was small in this respect.

Selection of fuel in an attempt to gain a few degrees margin in the maximum desirable nozzle temperature would probably lead to the use of a type which was poor in almost every other respect, and more harm than good would be done by this method of attack. The only safe method was to keep the nozzles thoroughly cooled so that the temperature was well below the danger zone and this was easy for a designer to do if he made it one of the principles of design of airless-injection engines' nozzles.

Admiral Harrison's remarks about the distribution of wear in a liner could be very well explained by their theory that abrasives were playing an important part. At the top of the liner the conditions, as Mr. Wolf had stated, were probably such that true film lubrication was not effected. Consequently fine abrasives might make contact between the liner and the piston ring. Further down there was a better and thicker film which might also contain abrasives but the film dimensions and operating pressures there were such that the solid particles did not span the film. Admiral Harrison quite rightly mentioned that at the top of the liner the piston ring was at rest and over the region of wear the rings were moving very slowly, but it was just at this point where the velocity was lowest that it was most difficult to establish a good oil film. At the centre of the stroke where the velocity was high a good film was readily made and maintained and it was, therefore, not to be expected that wear would be uniform throughout the stroke.

The speaker was glad that the Diesel Engine Users' Association recognised the importance of the consumer taking every precaution to maintain fuel in a clean condition. With regard to the effects of different types of fuel the short delay high ignition-quality fuels burnt in a well distributed manner in the cylinder since they ignited not too far from the spray valve, thus the droplets which might carry abrasive had burnt away before they reached the cylinder wall. This meant that there was nothing left but a particle of abrasive from any originally dirty particle of fuel and the energy left in this was unlikely to carry it to the cylinder wall. In the case of a long delay poor ignition quality fuel the combustion started further from the spray valve, with consequent higher local temperature zones, and a tendency for the late burning droplets to carry with them any abrasive on to the cylinder walls before the mass of fuel was burnt and the energy of emission from the sprayer lost. It seemed likely, therefore, that both higher temperature stresses and also more wear might accompany long delay than short delay fuels.

With regard to irregular wear, this had been noticed in several cases but, for practical purposes, it was unnecessary to keep track of it. Records might be useful as an indication of the nature and extent of distortion effects, but sticking of piston rings and the positions of ring joints could also cause such irregularities, which then developed and altered in an erratic manner.

Admiral Harrison had said that while there might be no evidence that sulphur caused liner wear the presence of sulphur in fuel, in any quantity, was undesirable for other reasons. The authors would like to know just what these reasons were as they had no knowledge of them. Many things had been attributed at different times to sulphur but investigation had, they believed, always shown that something else was responsible.

With reference to the graph of Fig. 19, unfortunately the engine from which it was obtained would not run at all steadily at lower speed, but there was an indication that the curve might rise as the speed was further decreased. It was hoped that additional work might be carried out on this subject at a later date since the lower speed range represented the starting and low speed acceleration conditions of vehicle engines.

The permissible wear of liners of the large engines had been found to be limited chiefly by ability to start, and one per cent. of the bore was not an unreasonable figure.

Mr. Wolf had mentioned the possible effects of sulphur and stated an interesting figure in connection with the weight of SO_2 produced in a marine engine in twenty-four hours when using ten tons of fuel per day. To their mind that was rather conclusive evidence that, when such quantities of SO_2 were produced in an engine using fuel with a sulphur content of 2 per cent., that corrosion was negligible since no increase of wear was experienced over fuels with much lower sulphur contents. They were sure that there must be many engineers who, from practical experience, had come to the same conclusion.

Mr. Wolf had also asked if the streamline filter was an economic proposition. At the present time there was not a streamline filter on the market available for the purpose in question, although they had been using one in their laboratory tests nearly large enough for a marine engine. One of the difficulties had been to deal with fuels containing—as any fuel might—a small amount of water which tended to choke the filtering elements. This difficulty seemed to be superable and the results were very promising. They felt that further development of the filter was well worth while and did not know of any other type on the market which would deal with the very fine abrasives they thought it so important to remove.

Mr. Humphreys had mentioned an interesting point in connection with the Doxford engine. It was quite true that in that engine there were no cylinder covers to cause a differential initial stress on the liner surface such as might be caused by the tightening of the cylinder head studs. It was possible in fact that some of the variations in liner wear shown in the diagrams might be due to the man who tightened up the studs after each examination. They had recently seen a high-speed Diesel engine, in the cylinder of which very definite evidence of distortion showed close to certain of the studs. The wear on the Doxford engine was like that of all opposed-piston engines—invariably greater on the upper liners except when the upper piston was made to float. The only floating piston they knew of was showing about the same, or rather less, wear on the upper than on the lower liner. It all pointed to the probability that the actual mechanical conditions under which the engine was running were responsible for this difference in wear. It was very obvious that such factors as fuel or lubricating oil could be entirely eliminated as an explanation of the differences in the upper and lower liner wears. In a Doxford engine even with exactly the same stroke for the upper and lower pistons, perhaps 25 per cent. more power was developed by the lower piston. That need not be expected seriously to alter the wear conditions in a constant-pressure cycle, though it might expand the band of wear over a wider area.

They could not answer Mr. Humphreys' query whether certain lubricating oils had a greater affinity for acid than others. They had no experimental or practical evidence that lubricating oils appreciably affected wear in such engines. With regard to the question of compounded oils for cylinder lubrication, their own impression was that the use of these was dangerous in case any of it got into the crankcase and accentuated any corrosive action or emulsion formation.

Mr. Stansfield, in further reply to Mr. Williams, said that perhaps each of them had "a little something the other hadn't got" and he thought a subsequent discussion of experimental detail would be well worth while.

He would like to deal specially with question regarding the time required to establish the lubricating oil film in a petrol engine. He had recently made a test on a well known car engine using a summer grade oil under rather cold atmospheric conditions for such a grade. The engine was motored round, with the pistons and cylinders initially dried, until oil worked its way on to the piston crowns. The time taken varied from five to ten minutes, depending on the cylinder under observation. It was noticed, however, that the engine turned very harshly during only the first half minute or so of the test, and it was a well-known fact that the oil film on a cylinder wall of any engine just after opening out was very thin indeed—so thin that it seemed surprising that any lubrication could occur at all. Coupling these facts together it occurred to him that the first visible signs of oil on the pistons might not be connected at all with establishment of normal lubrication, but might only be evidence that the spaces behind the piston rings had filled with oil and that some of this had worked up through the ring gaps. The test was therefore repeated and a Strobophonometer was applied to record the engine vibrations. With a running speed of 300 r.p.m. the oil pressure rose to maximum in fifteen seconds after starting and vibration was heavy due to the dry pistons. Vibration was still as great after twenty-five seconds, but it then began to fall rapidly and after thirty-five seconds had reached a steady value. The test was repeated again and stopped after twenty-five seconds. The cylinder walls were then flushed with a colourless oil solvent and no discolouration took place, indicating that no oil film had formed. A further repeat was made and this time the test was stopped after thirty-five seconds. The washings of the walls were then discoloured yellow from the oil film which had formed. It seemed to him that once a few drops of oil were flung round the lower part of the cylinder the rings rapidly spread them and carried up a film of thickness equal to that present under normal running conditions, and that oil consumption and pumping depended more on conditions around and behind the rings and had very little to do with the film thickness on the pressure surfaces at the point of maximum wear. It was on data of this description that they had based their view that the working film of lubricant did not take very long to form.

It was also of interest to record that the same engine was subjected to a road test of 16,000 miles at an average speed of 33 m.p.h. in runs of about 100 miles between each start. The cooling water temperature was thermostatically controlled and the results showed a wear about eight times greater than that on variable throttle bench runs under the same jacket temperature, mean speed and load conditions.

The Authors, in reply to the written contributions to the discussion, stated that Mr. Young had very fairly pointed out that different causes might produce wear in different circumstances and had agreed with their distaste of research results being turned into headlines. His remarks on the application of the D.O.C. test were interesting, but cases had been examined where crankchamber corrosion had taken place and the D.O.C. test had failed. Perhaps, however, the test had been wrongly made or the sampling bad, but there had always been hydrochloric acid in the oil in such instances.

With regard to cylinder materials, it was very difficult to distinguish between the effects of corrosion resisting properties, increased hardness accompanying the change of materials, and, a point of some importance, the improved balance which might have been obtained between the hardness of the cylinder and that of the piston rings. It was certain that improved knowledge of the materials to be used for the rubbing surfaces both as regards their general properties and their best relative properties would go far to solve the wear problem.

Mr. Laxton had interpreted the authors' views on the action of acid droplets in causing crankcase corrosion correctly, but they had insufficient data of a reliable nature to be able to give any considered opinion regarding the effect of differences in demulsification value. It seemed possible, however, that the foreign matter collected by any lubricant during the first few hours of use might so reduce its initial demulsification value as to make all oils other than compounded ones substantially the same in this respect.

Mr. Keller asked on what line of thought engine designers should concentrate for improvements. Mr. Keller himself seemed to have worked on one of the very successful lines since he had achieved good results by using cylinders in which the temperature variations were kept in as uniform zones as possible. Aero engine builders had worked with very carefully machined air-cooled cylinders which had either to be almost free from distortion under very severe conditions and gave excellent wear figures or which were condemned as failures—there was no half-way house in this class of engine. It was either almost distortionless in so far as any section became non-circular, or it was an impossible design.

Mr. Le Mesurier had seen many engines of the two-stroke type in which the piston rings had not been pegged but which had worn into grooves coinciding with the ports. There was definite evidence against rotation in these cases which he thought were fairly common. The pronounced temperature differences from one side of the cylinder to the other and from one part of the ring to another seemed to him to be sufficient to account for serious wear troubles in some instances.

The effect of excessive carbon from the lubricant as a wear factor had not been properly examined, although he had seen isolated cases where aluminium pistons had been badly scored with the carbon from the lubricant burnt at the top of the cylinder walls.

Unfortunately it was not possible to give accurate fuel consumptions of the various engine types examined since it was necessary, in marine engines, to judge the power simply by taking the total fuel consumptions and assuming a certain test-bed specific fuel consumption for each.

With reference to Mr. Mackegg's remarks, they had frequently run exhaust valves up to 1,800 hours on centrifuged fuel, after which the valves could easily be reconditioned by re-grinding. This statement referred to valves from an engine with cylinders 740mm. diameter.

Mr. Beale's figures showing the possible effect on wear of cleaning the lubricating oil of bus engines, and also the effect of cylinder hardness, were an interesting commentary on the need for caution in ascribing to any one cause the high wear of engines running on intermittent duty, and indicated how much work still had to be done before it was safe for designers to be content with anything less than the elimination of every suspected cause of wear as far as this could be achieved within commercial limitations of cost.

INSTITUTE NOTES.

VISIT TO BATTERSEA POWER STATION.

By the courtesy of Dr. S. L. Pearce, C.B.E., Engineer-in-Chief of the London Power Company, Ltd., a party of forty members of The Institute visited the Battersea Power Station on the afternoon of Tuesday, April 10th, 1934. A complete tour and inspection of the station was made under the guidance of four members of the operating staff, who spared no efforts to render the visit most interesting and instructive.

On the conclusion of the tour the visitors were entertained to tea in the staff restaurant, when Mr. J. Carnaghan (Vice-President) expressed the thanks of the Council and the members of the party for the privilege so kindly afforded by the Engineer-in-Chief and particularly to the members of the station staff for the courtesy and attention accorded to the visitors.

An excellent description of the station appeared in "Engineering and Boiler House Review" of April and May, 1933, and we are indebted to Engineer Rear-Admiral W. M. Whayman, C.B., C.B.E. (Vice-President) and Messrs. Babcock and Wilcox, Ltd., for kindly supplying reprints of this article to the members of the party. Further copies are available and may be obtained through the Secretary at The Institute.

ELECTION OF MEMBERS.

List of those elected at Council Meeting held on Monday, May 7th, 1934.

Members.

James Stirling Allan, The Bungalow, Cardonaghy, Cullybackey, Co. Antrim, Ireland.

Albert Edward Batten, 108, Pettits Lane, Romford, Essex.

Edmund Brown, The Nook, Bar Terrace, Falmouth.

Norris Burrow, Hesslewood, 17, Carton Grove, Shipley, Yorks.

Ronald Blackwood Collin, 6, Agden Road, Sharrow, Sheffield.

Hector Idris James, 30, Harbour Road, Barry, S. Wales.

Arthur Wellesley Jeffery, 385, Mosspark Boulevard, Mosspark, Glasgow, S.W.2.

Ronald Lacey, 45, Shirley Road, Cardiff.

Richard Lamb, 29, Beechwood Avenue, Monkseaton.

Thomas Hartley Lees, 73, Ferndale Road, Liverpool, 15.

John Lewis Luckenbach, 24, Old Slip, New York City, U.S.A.

John F. Macdonald, 12, Newton Grove, Bedford Park, W.4.

Odazir Aristides Moreau, Compania Anonima Venezolana de Navegacion, Maracaibo, Venezuela.

John Joseph Murray, Burma Marine Service, New Law Courts, Rangoon, Burma.

Sidney Clifford Page, 22, Penylan Terrace, Cardiff.

George Crooks Roxburgh, 21, Howards Lane, Putney, S.W.15.

William Basil Slater, 156, Ferry Road, Leith, Edinburgh, 6.

Walter Augustus Stewart, Lieut. (E.), R.N., c/o Lloyd's Bank, Devonport.

Cyril Wallis, Chinese Maritime Customs, Shanghai, China.

Associate Members.

Walter Frank Bailey, 42, Crescent Road, Rhyl.

Oliver Black, 212, Duncairn Gardens, Belfast.

Lewis Leslie Broad, 15, Wesley Place, Peverell, Plymouth.

Albert William Cole, 29, Achill Road, Upper Drumcondra, Dublin.

Robert Joseph Karr, 33, Ponsonby Avenue, Belfast.

Associate.

William Percival Halcrow, Rotherdean, Hamble, Hants.

Transferred from Associate Member to Member.

Norman Wilson, 6, Wilson Street, West Hartlepool.

ADDITIONS TO THE LIBRARY.

Purchased.

Report on the Examinations of Candidates for Certificates of Competency in the Mercantile Marine and the Sea-Fishing Service for the year ending December 31st, 1933. H.M. Stationery Office, 2d. net.

Statutory Rules and Orders, 1934, No. 279 (Factory and Workshop. Dangerous and Unhealthy Industries). The Docks Regulations, 1934. H.M. Stationery Office, 4d. net.

Lloyd's Register of Yachts, 1934. 42s. net.

Guide to the Refrigeration Exhibition. (Science Museum, April-August, 1934). H.M. Stationery Office. 6d.

Presented by the Publishers.

Nickel Bulletin on "Expansion Control by the use of Nickel Alloys".

"History of Steam Navigation in the Middle East", by T. G. McNie (Member). In manuscript form.

Ohio State University Bulletin, No. 1. Vol. III. "Surface Clays and Shales of Ohio".

"Steam Plant Corrosion", by J. S. Merry. Paper read before the Engineer Surveyors' Association.

The following British Standard Specifications:

No. 228-1934.—Steel Roller Chains and Chain Wheels (revised April, 1934).

No. 327-1934.—(Part I) Derrick Cranes—Power Driven (revised April, 1934).

No. 545-1934.—Machine Cut Gears. B. Bevel (with Helical, Curved and Straight Teeth).

No. 4A-1934.—Dimensions and Properties of British Standard Equal Angles, Unequal Angles and T Bars for Structural Purposes. (Partly superseding No. 6-1924).

CD. 3097.—Addendum to B.S. No. 4-1932. (Reference Numbers).

Proceedings of The Institution of Civil Engineers, 1932-33, Part I, Vol. 235, containing the following papers:—

"The Willington Bridge, Calcutta", by Mair.

"The Present Position of the Pressure-Charged Heavy-Oil Engine", by Moore.

"The Causes and Prevention of Bed Erosion, with special reference to the Protection of Structures Controlling Rivers and Canals", by Butcher and Atkinson.

"The River Hooghly Tunnel", by Norrie.

"A Comparison of the Results of Observations on Surge Tank Installations, and on their Scale Models; with an Investigation of the Dead-Beat Surge Tank, and of Surge Tanks of Non-Uniform Cross Section", by Gibson and Cowen.

"The Laws of Siphon Flow", by Davies.

"Power-House Foundations and Circulating-Water Tunnels at the Ford Motor Company's Works, Dagenham", by Allin and Nachsen.

Transactions of the Institution of Mechanical Engineers, Vol. 125, 1933, containing the following papers:—

"The Aluminium Industry in Scotland", by Boex.

"Kinematic Design in Engineering", by Pollard (Thomas Hawksley Lecture).

"Heat Liberation and Transmission in Large Steam-Generating Plants", by Robey and Harlow.

"High-Speed Diesel Engines for Marine Service", by Ricardo (Thomas Lowe Gray Lecture).

"Heat Transfer between Metal Pipes and a Stream of Air", by Griffiths and Awbery.

"Calculation of the Specific Surface of a Powder", by Heywood.

"The Geared Marine Oil Engine", by Bradbury.

"Factors Affecting the Grip in Force, Shrink, and Expansion Fits", by Russell.

"Diesel Traction", by Lomonossoff.

"Sugar Factories and Sugar Machinery", by Kilpatrick.

"Oil Storage and Transport Equipment, with special reference to the Application of Welding", by Adlington.

"Some Technical Aspects of High-Pressure Boiler Design", by Davis and Timmins.

"Experimental Work in connection with the Feed System of H.M.S. 'York'", by Pendred.

"Power Factor Correction", by A. E. Clayton, D.Sc. Sir Isaac Pitman & Sons, 126 pp. 2s. 6d. net.

This book is one of the well-known Primer series. In each book a particular branch of technology is dealt with. In the present work, the fundamental principles of the correction of power factor of electrical circuits is covered, the causes affecting the power factor of supply system, improvement of power factor, static and rotary condensers, phase advancers and a comparison of power factor correction methods being also included.

The work is the second edition, the first having been published in 1923. The additions are not very extensive.

Written primarily for students, it is elementary and successfully fulfils its purpose.

"Automobile Electrical Equipment", by A. P. Young and L. Griffiths. Iliffe & Sons, Ltd., 336 pp., 308 illustrations. 15s. net, by post 15s. 6d.

This volume is a successor to "Magnetos", by A. P. Young. It embraces electric lighting, starting and ignition as applied to the motor car and is an exceedingly comprehensive work.

Chapter I deals with the fundamental principles of electricity, such as the laws governing the flow of current through a conductor, magnetism and electro-magnetic induction. It also gives a description of the materials used in the construction of electrical equipment.

Chapter II describes the complete electrical equipment of modern motor vehicles, both car and cycle. The subjects of generation, storage and distribution, ignition, lighting, starting, and accessories are also dealt with. The last subject—accessories—is treated in most detail and descriptions of electric horns, speedometers, petrol pumps, signalling devices and windscreen wipers are given.

Chapter III on the dynamo and generator explains, without the use of complicated mathematics, the generation of electricity, and this leads up to a description of the methods of generation used in modern dynamos and generators for motor vehicles; a comparison is also made of the two systems now in use—the constant current and constant voltage systems. The latter half of the chapter describes with the aid of illustrations, modern generators of many makes.

In a similar manner Chapter IV deals with the starting motor, both for motor vehicle and aircraft engine starting.

Chapter V on the battery makes clear the purpose of the storage battery on an automobile. A description of the lead-acid and steel-alkaline batteries and the principles of their operation are given, whilst charging is also briefly referred to.

The next chapter contains a very good account of the problems of providing efficient illumination of the road ahead of an automobile without causing headlight dazzle. The cause of dazzle and the attempts to minimize it in modern anti-dazzle devices are described.

The last and most elaborate chapter in the book is devoted to ignition and is divided into the following nine sections :—

(1) Giving a description of various ignition systems and a comparison of the two principal systems now used, namely, battery-coil and high-tension magneto.

(2) Containing a very instructive account of the process of firing a charge in a cylinder of a petrol engine, and the factors affecting this process are fully discussed. The nature of the spark discharge from a magneto is carefully analysed; and the best form of spark for efficient ignition described.

(3) Dealing with battery-coil ignition in detail. The principles of operation are explained and several equipments of different manufacture described. The coil, contact breaker, distributor head, condenser unit and the automatic timing unit are also treated.

(4) Explaining very fully the theory of the working of the high-tension magneto, both of the rotating armature and inductor types as well as the progress of design and development of the magneto up to the present-day product of the manufacturer.

(5) Describing the design and construction of representative types of magnetos now being produced for use on motor cars, commercial vehicles and motor cycles. Both rotating-armature and inductor type magnetos are described in considerable detail.

(6) Dealing similarly with aeroplane magnetos, as well as hand-starting magnetos for aeroplanes.

(7) On the subject of magneto installation and timing, describes methods of driving the magneto and also deals with different forms of couplings. Timing the magneto and automatic timing controls of several makes are also included.

(8) In addition to describing the magnetising of a magneto explains the timing of the apparatus, i.e., the determining of the position of the rotating armature or magnet in relation to the "make" and "break" contacts. Some space is also devoted to the setting of the distributor and the care of the magneto in service.

(9) Dealing thoroughly with the design and construction of the sparking plug, which is a vitally important unit in any high-tension ignition system. Plugs of several makes are described and illustrated, and the book concludes with comments on plug testing devices.

The work should prove very valuable to all interested in engines and their electrical equipment, and has the added advantage of not being too technical.

"Principles of Direct Current Electrical Engineering", by the late James R. Barr, A.M.I.E.E. and D. J. Bolton, M.Sc., M.I.E.E. Sir Isaac Pitman & Sons, Ltd., 486 pp. 21s. net.

Professor Barr's "Direct Current Electrical Engineering" needs no introduction to students of that subject, having been recognised for two decades as one of the leading standard works for second year students.

The second edition by the late J. R. Barr, A.M.I.E.E., now coupled with the name of D. J. Bolton, M.Sc., M.I.E.E., lecturer in Electrical Engineering at The Polytechnic, Regent Street, London, as joint author, is now before us and has been thoroughly revised and brought into line with current practice, while still retaining that clarity of style and expression which made the first edition so popular.

The present edition makes use of the symbols and nomenclature which have received international sanction, so that its modernisation is complete. From the point of view of the marine engineer and electrician who requires a text book covering all the phases of direct current installations, not unduly loaded with formulæ, it can be recommended with complete confidence. In this respect it is a considerable improvement on the earlier edition, the latter having devoted considerable space to the principles and design of dynamos. This has now been condensed to one chapter dealing with the principles and performance of the dynamo followed by a similar chapter on the motor. Subsequent chapters deal on general lines with both machines and cover construction, design, rating and testing. The scope of the book may be gathered from the fact that it covers in simple style which can be digested by marine engineers and electricians the following subjects :—

Fundamental principles, storage batteries, lighting, cables, dynamos, motors, switchgear and control gear, fuses and circuit breakers.

BOARD OF TRADE EXAMINATIONS.

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

Name.	Grade.	Port of Examination.
For week ended 12th April, 1934 :—		
Laird, Charles A.	2.C.	Newcastle
Stewart, William T. ...	2.C.	"
Bartley, Francis J.	2.C.M.	"
Dobson, George W. ...	2.C.M.	"
Ross, Thomas W.	2.C.M.	"
Turnbull, Frederick... ...	2.C.M.	"
Phillips, Rees L.	2.C.	Cardiff
Quayle, Arthur J.	2.C.	"
Cochrane, John P.	2.C.	Liverpool
Herdman, Robert D. ...	2.C.	"
Kelly, Francis A.	2.C.	"
Diamond, Reginald	2.C.M.	"
Allen, John E. L.	2.C.	London
Third, Charles	2.C.	"
Farmer, Frederick G. R. ...	2.C.M.	"
Allan, Robert	2.C.	Glasgow
Anderson, John P.	2.C.	"
Matthewson, James	2.C.	"
McArthur, Charles	2.C.	"
McDougall, Duncan... ...	2.C.	"
Strachan, Alexander M. ...	2.C.	"
Taylor, William A. H. ...	2.C.	"
Nicoll, David...	2.C.M.	"
Skinner, Richard W. ...	2.C.M.	"
Dahl, John L.	1.C.	Liverpool
Jones, Thomas E.	1.C.	"
Kaighen, Joseph R.	1.C.	"
Lear, Balfour	1.C.	"
Little, Frederick	1.C.	"
Williamson, John	1.C.	"
Collin, Ronald B.	1.C.M.E.	"
Lees, Thomas H.	1.C.M.E.	"
For week ended 19th April, 1934 :—		
Erskine, William A. ...	1.C.	Glasgow
Henderson, Andrew ...	1.C.	"
Kirk, James	1.C.	"
Rodger, James E.	1.C.	"
Archibald, Alexander W. ...	1.C.M.	"
Ackland, William H. ...	1.C.	Cardiff
Tucker, Ronald L.	1.C.	"
Cain, William A.	1.C.	Liverpool
Cara, Howard	1.C.	"
Sutton, Sydney A.	1.C.	"

Name.	Grade.	Port of Examination.
Braunton, Harold	1.C.	Newcastle
Davison, Ralph	1.C.	"
Shotton, George B.	1.C.	"
Taylor, Henderson K. ...	1.C.	"
Thomson, James R.	1.C.	"
Doidge, Francis H.	1.C.	London
Honess, Herbert L.	1.C.	"
Kelly, John	1.C.	"
Kiellor, David	1.C.	"
Shannon, Arthur A. ...	1.C.	"
Slater, Eric R.	1.C.	"
Reid, John G.	1.C.M.	"
McCallum, William ...	1.C.M.E.	"
Dickens, Charles W. ...	1.C.M.E.	"
Bishop, Frederick W. ...	1.C.S.E.	Newcastle
Thomas, Albert J.	1.C.M.E.	Glasgow
Drape, John	1.C.M.E.	Newcastle
Rodger, Robert	1.C.M.E.	Liverpool
For week ended 26th April, 1934:—		
Greenmon, Albert V. ...	2.C.M.	Newcastle
Scaife, Allen A.	2.C.M.	"
Shaw, Thomas	2.C.M.	"
Wolfe, Arnold	2.C.M.	"
Aldous, George J.	2.C.M.	London
Black, Oliver	2.C.	Liverpool
Karr, Robert J.	2.C.	"
Stevenson, George B. ...	2.C.	"
Stevenson, Robert	2.C.	"
Currie, Alexander L. ...	2.C.	Glasgow
Farquhar, John MacK. ...	2.C.	"
Gosnell, Thomas	2.C.	"
Kerr, Henry F.	2.C.	"
McIntosh, Douglas B. ...	2.C.	"
Steele, William H.	2.C.	"
Murie, Sydney	2.C.M.	"
Stirling, Robert	2.C.M.	"
Abbey, Edwin S. B.	2.C.M.	Newcastle
For week ended 3rd May, 1934:—		
Crow, George N.	1.C.	Liverpool
Hillhouse, John	1.C.	"
Kilvert, Francis E.	1.C.	"
Mannington, Charles H. ...	1.C.	"
Patterson, William H. ...	1.C.	"
Yeoman, Charles	1.C.	"

Name.	Grade.	Port of Examination.
Headrick, Duncan G. ...	1.C.	Glasgow
Coskry, John M.	2.C.	"
Brown, John	1.C.	Newcastle
Carr, Webster	1.C.	"
Newlands, Victor R. ...	1.C.	"
Southern, Reginald	1.C.M.	"
Willis, John T.	1.C.M.	"
Robertson, James	1.C.M.E.	"
Dale, Frank R.	1.C.M.E.	"
Jackson, Ernest G.	1.C.M.E.	"
Jones, William J.	1.C.M.E.	Liverpool
Hughes, Samuel	1C.M.E.	"
MacLeod, Alexander ...	1.C.M.E.	Glasgow
Murray, Alexander	1.C.M.E.	London
MacRae, Donald	1.C.M.E.	"
Champness, Gerald T. ...	1.C.M.E.	"
Little, Frederick	1.C.M.E.	Liverpool
Grainger, Henry W. ...	1.C.M.E.	"
Allan, Walter A.	1.C.M.E.	"

JUNIOR SECTION.

Marine Vibration.

Mr. J. Calderwood, M.Sc. (Member of Council) delivered a lecture under the above title at a meeting of the Junior Section which was held at The Institute on Thursday, April 12th. The Chair was occupied by Mr. H. R. Tyrrell (Associate). After referring briefly to the various combinations of circumstances which gave rise to vibration in a ship's structure, the Author proceeded to deal particularly with vibration of the propelling machinery, illustrating his points by means of actual diagrams taken from ships in service.

The discussion which followed was contributed to mainly by several senior members present, the questions and the Author's answers adding greatly to the information conveyed by the lecture.

A hearty vote of thanks was accorded to Mr. Calderwood at the close of the meeting, on the proposal of Mr. S. N. Kent (Past-Chairman of Council).

ABSTRACTS.

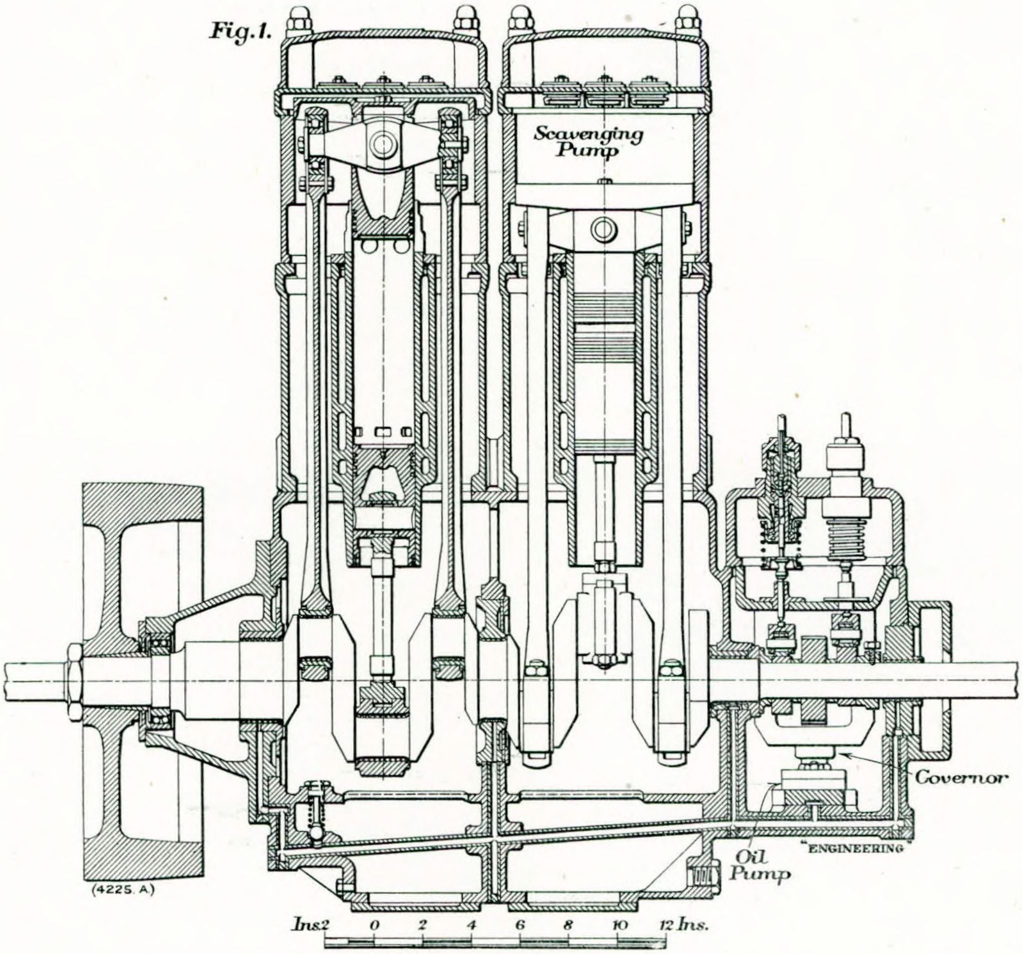
The Council are indebted to the respective Journals for permission to reprint the following abstracts and for the loan of the various blocks.

The British Junkers High-speed Engine.

"Engineering", 12th January, 1934.

The opposed-piston type of engine manufactured by Messrs. Junkers-Motorenbau G.m.b.H., of Dessau, is well known for its reliability and economy. The high-speed models have been particularly successful, the six-cylinder L5 model, for example, having to its credit several world records when fitted to aircraft. This engine forms one of a range designed for driving generators, for marine and for general-purpose work. Their manufacture has been taken up in this country by Messrs. Peter Brotherhood, Limited, of Peterborough. The range includes units having 1, 2 or 3 cylinders, developing 10 h.p. to 12 h.p. per cylinder at 1,200 r.p.m. to 1,500 r.p.m. As the majority of our readers will be aware, Messrs. Brotherhood can supply high-speed engines for higher powers up to 440 brake horse-power from their range of Brotherhood-Ricardo models.

The two-cylinder model is illustrated in the drawings, Fig. 1 and in Fig. 3. Fig. 4 shows a typical fuel-consumption curve. It may be recalled that the engines operate on the two-stroke cycle, and that the upper pistons are connected to the crankshaft by means of side rods, as shown in Figs. 1 and 3. The scavenge pump is located at the top of the cylinders, the pump piston being mounted on a crosshead to which the upper of the two power pistons is connected. The arrangement can be clearly seen in Fig. 3. The air from the pump is delivered into the cylinder through tangential scavenge ports, which impart a rotary swirl to the charge. The ports, which can be seen in the upper



part of the left-hand cylinder in Fig. 1, are controlled by the top piston, while the exhaust ports, shown at the bottom of the same cylinder, are controlled by the lower piston. The scavenging arrangement described, besides being on the uniflow principle, ensures a supply of cool air uncontaminated by oil. The air in the engine casing merely pulsates at every stroke, the casing acting as an equalising receiver. The cylinder bore is 65mm. ($2\frac{9}{16}$in.), and the combined stroke of the two pistons is 210mm. ($8\frac{1}{4}$in.). The piston velocity is low, being 827ft. to 1,033ft. per minute. The fuel pump, centrifugal governor, lubricating-oil pump, and the filters for both the fuel oil and lubricating oil, are incorporated in a distribution gear housing, mounted on the end of the engine casing as shown in Fig. 1. The control lever and speed-adjusting gear are also mounted on this housing. The fuel pumps, which are of special Junkers type, are operated through rocker arms from cams on the crankshaft. The governor, which can be seen below the crankshaft in Fig. 1, is driven by a skew gear mounted between the cams, and regulates the supply to the engine by varying the amount of fuel by-passed to the pump suction on each stroke. The fuel nozzle is of the valveless open type, and injects the fuel into the cylinder in the form of a fan-shaped spray.

As regards the construction, the cylinders are independent castings bolted to the crankcase, the scavenge cylinders being mounted above the power cylinders, as already stated. The power cylinders are water-jacketed, and large doors are provided in the crankcase to give access to the working parts. The pistons are made of special cast-iron. The connecting rod for the lower piston is fitted with a roller bearing at the small end, and a white-metal lined bearing at the big end. The two rods for the upper piston are fitted with self-aligning roller bearings at the top ends and white-metal lined bearings at the bottom. As will be clear from Fig. 1, the two-cylinder engine is of the three-bearing type, while the three-cylinder engine is of the four-bearing type. The crankshaft is machined from a solid nickel-steel forging in all the engines. When fitted, the circulating and bilge pumps are bolted to the end cover and driven from the crankshaft. The lubricating-oil pump is of the gear type and is mounted below the governor, as shown in Fig. 1. It draws its supply from the sump and delivers the oil under pressure to the main bearings,

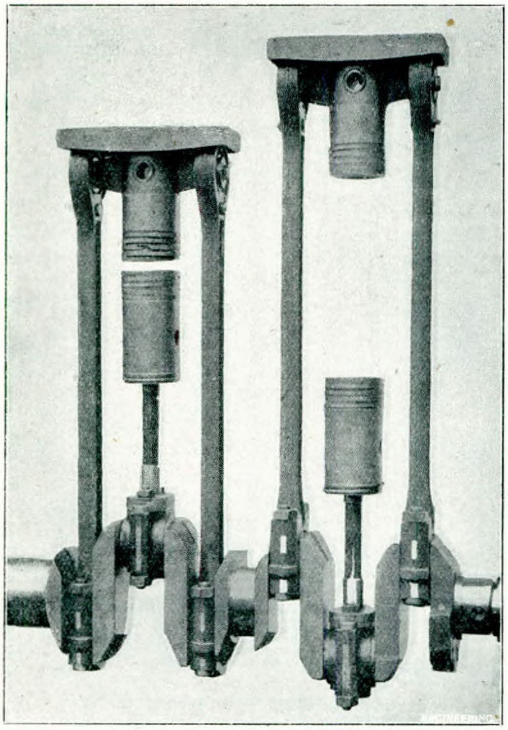
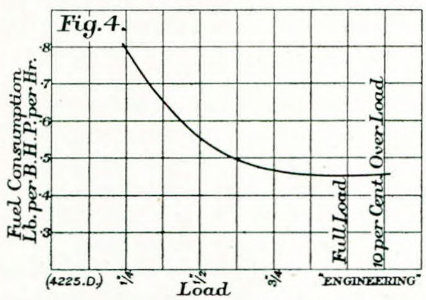


FIG. 3.

from which it passes through holes drilled in the crankshaft to the various big-end bearings.

It will be appreciated that the engines, being of the opposed- piston type, are excellently balanced, and therefore run very smoothly, with a marked absence of vibration. Owing to the adoption of the two-stroke cycle, a very light flywheel is sufficient to give even running. The engines will start by hand immediately from cold on the normal fuel oil, and the upkeep charges are low in the absence of valves and their concomitant valve gear. Con-



trol is by a single lever, which is directly connected to the fuel pumps for priming the injection system prior to starting, and for stopping the engine. An air filter is fitted to the intake, which can be kept in effective condition by dipping the plates which it contains into lubricating oil at intervals of about a month. Either thermo-syphon or pump cooling can be arranged according to requirements. As shown in Fig. 4, the fuel consumption at full load is approximately 0·45lb. per brake horse-power hour.

The Parsons Hollow Turbine Blading.

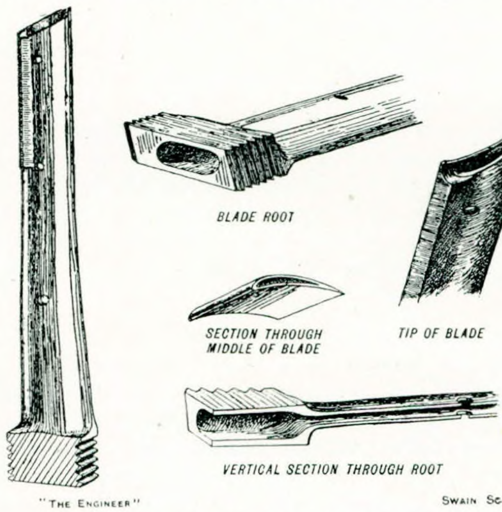
"The Engineer", 12th January, 1934.

By devising a method of manufacturing turbine blades hollow from end to end, C. A. Parsons & Co., Ltd., have once more been responsible for a notable advance in the construction of steam turbines. The effect of this new development is to bring about a substantial reduction in the weight of the blading, and therefore to permit of higher blade speeds and consequently of greater outputs, without increasing the stresses. It has long been recognised that the power which can be efficiently generated by a turbine running at a given number of revolutions per minute is limited by the area available for the flow of steam through the last rows of blades. This area, in turn, is limited by two considerations: firstly, that the necessity for avoiding excessive differences of blade pitch forbids the blade length exceeding about one-third of the wheel diameter; and secondly, that prudence with regard to centrifugal forces limits the permissible velocity of the blade tips. The velocities in common use make it essential to taper the blade profiles, so that the cross section at the tip is appreciably smaller than that at the root, although regard for the proportions of the steam passages obviously limits the amount of tapering that can be adopted.

An examination of modern practice in connection with the low-pressure blading of steam turbines convinced Messrs. Parsons that no further advance was possible along ordinary lines of construction. The ratio of blade length to wheel diameter had been pushed to the extreme even with twisted blades, and blade tip speeds did not permit of any further increase consistently with safety. The one thing wanted was lighter blading. Experimental work with the various light alloys held out no hopes of progress in this direction, for none of them had the requisite strength and other qualities. High-chromium steel was the best blading material that the metallurgists had yet produced, and there seemed no prospect of finding any other material equally good.

For many years it had been Messrs. Parsons' practice to manufacture their stainless steel blading by a hot rolling process, each blade being rolled integrally with its root and spacing piece, so as to conserve the continuity of the grain of the metal from end to end. The blades so formed were ideal as regarded strength and durability, and therefore the problem resolved itself into rendering them lighter in the only possible way, namely, by hollowing out the interior. Presuming that this could be done, it was obvious that a parallel hole throughout the whole length of the blade was not the best solution. To secure the maximum advantage the hole must not only be of the same shape as the blade, but it must also taper along its length so that the cross-sectional area of the metal becomes progressively less from the root to the tip of the blade, in order to obtain uniform strength.

After much experimental work, during which many difficulties were encountered, the manufacture of hollow blades, rolled from solid billets of stainless steel, is now being carried out on a commercial basis at the Heaton Works. The first of these blades were fitted, with the approval of Messrs. Merz & McLellan, and the consent of their clients, to the rotor of one of the 50,000 kW. Parsons turbines now running in the Dunston power station of the North-Eastern Electric Supply Company, Ltd., and similar blades are being used in the 30,000-kW. turbine for the Southwick Station of the Brighton Corporation. An illustration of one of the hollow blades, provided with the standard Parsons erosion-resisting shield, is given in the accompanying engraving. The blade in question is 17in. long overall and weighs 1½lb. A solid blade of the same dimensions would weigh 2lb. Furthermore, the centre of gravity of the hollow blade is much nearer to the root than that of the solid blade. For equal centrifugal stresses, therefore, the hollow blade could be run at a speed 15 per cent. greater than that of the solid blade. Up to the present, owing to the limitations already referred to, the maximum power that could be developed with both efficiency and safety in a 3,000 r.p.m. single-exhaust turbine working with ordinary steam conditions and high vacuum has been about 15,000 kW. With the new hollow blading this power can be raised to about 20,000 kW., and 40,000 kW. or more can be developed in a double-exhaust turbine running at the same speed.



Parsons Hollow Turbine Blading.

Although the practical significance of such results will be most fully appreciated by the designers and users of steam turbines, the solution of so difficult a problem as the production of hollow turbine blades will interest engineers in every branch of the profession. The blades are rolled individually from billets of high-chromium steel, the root being integral with the blade and the hollow formation is produced without recourse to any subsequent welding, brazing or soldering process. Moreover, the hole through the interior of the blade is of exactly the same profile as the blade itself, and tapers slightly in its length so that the walls are thinned at the top and increase gradually in thickness towards the root. By varying the wall thickness in this way the theoretical requirements for uniform strength are fulfilled without adversely affecting the external form of the blade. The manufacturing process is fully patented and has passed the experimental stage.

Coal v. Oil for the Navy.*

By Engineer Vice-Admiral Sir Reginald W. Skelton.

"The Engineer", 23rd March, 1934.

Introduction.

Coal *versus* oil fuel for the Navy—the subject on which I am privileged to address you this afternoon, has, as a matter of fact, ceased to exist for some years as a controversial question for the responsible authorities, at any rate since the Great War.

It can also be said that all thinking naval executive and engineer officers and naval architests are agreed that the fuel of to-day must be liquid; but since this country does not, unfortunately, possess within these islands any known appreciable source of natural oil, but does possess large quantities of the best steam-raising coal, it is quite natural that those people who earn their livelihood from coal should be bitterly disappointed that their fuel cannot now be made use of in the British Navy, and that, misled by the less responsible publicists and supported by even less reputable facts and data, they should from time to time question Naval policy and plead for sympathy.

You will gather from these opening remarks that I am myself in no doubt whatever as to which is the proper fuel to be used to-day.

I have seen it argued that the present generation of naval officers is not responsible for the use of oil fuel; that is quite true, but the aim of that statement was to show that some distinguished naval officer—or politician—(names were actually mentioned) drawn into the spider's web of some oil magnate, had combined with Machiavellian cunning to force this unwanted foreign product on the British Navy.

It is hardly worth while discussing such suggestions; the truth is, of course, that you cannot stop the march of progress, and the fact is that no single individual or even a small coterie of individuals has been responsible for the introduction of oil fuel for the Navy.

Its technical development and use has, under successive Engineers-in-Chief of the Fleet, and one might say the whole naval engineering *personnel* at

* Royal United Service Institution, Wednesday, March 14th, 1934, at 3 p.m.

sea, proceeded from day to day; the technique being assured, the approval for its adoption has, in all the circumstances to be considered, been made, not by one man, but successively by a host of men in the governing positions.

These developments are evolutionary; they can be delayed, they can be hastened; but if good and right, their preponderating advantages must lead inevitably to their increasing use.

About 1908, destroyer programmes with oil fuel alone having progressed perhaps somewhat quickly, some doubt was felt about the certainty of supply, and it was decided that the "Beagle" class of twenty T.B.D.'s, then being designed, should use coal. The disadvantages of coal, already well known in the technical departments, soon became apparent to all, and in the very next programme coal was finally abandoned for the "Acorn" class, oil restored, and this continued ever since. Coal lasted in the destroyers one programme only, after oil had once been tried—one year's batch—and the following comparison shows the reason.

"Acorn", as compared with "Beagle", had a superior armament—20 per cent. less displacement, cost 16 per cent. less, and was $1\frac{1}{2}$ knots faster and could hold her speed until fuel ran out.

Since that date the developments in T.B.D.'s with oil fuel have far outstripped those mentioned as a comparison between "Beagle" and "Acorn".

It seems the Admiralty were all the time from 1903 onwards tending towards 100 per cent. use of oil fuel in the Navy, and yet it is 1931 before a petition is engineered for a return to coal. Was King Coal asleep?

But after all it must not be supposed that the experiments and improvements in the burning of oil fuel made at Haslar and in the Fleet were confined to oil alone. Mechanical stokers had been tried, and all the advancements in the handling and burning of coal by the mercantile marine and in shore power stations have always been, and are being, watched to see if any of them could be applied with benefit in H.M. ships.

Technical.

The calorific value of oil fuel is about 1·3 to 1·4 times that of coal. As measured in British thermal units, oil is about 19,000, while best Welsh steam coal is about 14,500.

But while oil is fairly uniform in quality, whatever its geographical origin, while it does not deteriorate with storage, nor does it contain ash, coal is not uniform, not even Welsh, while the variations in coal from the various sources of origin over the world are enormous. Coal does deteriorate slightly with storage; it becomes dusty with handling, and contains an objectionable amount of ash, though these disadvantages can be mitigated by modern methods of washing and handling.

The space required for stowing 1 ton of Welsh coal is 40 to 43 cubic feet, whereas 1 ton of oil fuel averages about 38 cubic feet; moreover, oil bunkers can be safely filled to 95 per cent. full stowage, whereas in coal bunkers there is an appreciable loss from broken stowage, sufficient space having to be allowed under the beams at the crown of the bunker to provide for ventilation and to permit egress of coal trimmers.

Pulverised Fuel and Mixtures.

I will make a short digression here to mention pulverised fuel and mixtures of pulverised fuel and oil. Pulverised fuel cannot be carried in bulk; it is dangerous; but even if it could, it would have to be kept "fluffed", i.e., prevented from packing, and in that condition requires much more space—55 to 60 cubic feet per ton. Alternatively, if the coal is pulverised as it is required for use, on the "hand-to-mouth" system, then much additional machinery, absorbing space and weight, must be installed to do the work.

Mixtures of pulverised fuel and oil, erroneously called "colloidal fuel", have been tried for many years, and while increased weights of this fuel per cubic foot of space over oil alone can be stowed, no mixtures so far tried have proved really stable or suitable for stowage in and use from warship tanks.

Stowage.

Oil can be stowed in any compartment, large or small, within reason, in ships, no matter what shape or where situated; contiguity to the boilers is not necessary, and the fullest use of every such space throughout the ship to each and all of the boilers can be made without impairment of supply.

Transport of Boilers.

In coal-burning ships the only readily accessible stowage is above the floor plates and abreast the boiler-rooms, and in ships requiring much endurance a large proportion of the coal must be stowed in bunkers which are not easily accessible or which cannot be worked without increasing the labour necessary to keep up and maintain supply. In the war, for example, many ships carried large quantities of coal in reserve bunkers which it was found impossible to use, and for operational purposes had no value whatever, and under no circumstances could such coal be transported to satisfy any other rate for steaming but a low rate.

To supply coal from bunkers to boiler-rooms a number of water-tight doors must be fitted in the bulkheads, scuttles and armoured doors in the protective decks, making for weakness and expense in construction and vulnerability under working conditions at sea. With oil fuel these doors, scuttles, etc., are not required, and the water-tight subdivision is therefore more efficient, the protection is thereby improved, and the strength of the structure increased. Moreover, the bulkheads, decks, etc., forming the boundaries of the fuel tanks remain fully efficient, being always under test, a condition which cannot be assured with the boundaries of coal bunkers. In the latest warships, in which the weight of fuel carried reaches 30 per cent. of the displacement, this advantage is most valuable.

General Effect on Design of Ships.

It is almost impossible to design a warship providing for anything approaching an equal supply of coal to each group of boilers, and still more difficult to ensure this state of affairs at the commencement of an action. I may mention my own ship, H.M.S. "Agincourt", as a particularly glaring example, although in fairness it must be said that the ship was not Admiralty designed. She had three boiler-rooms, A, B, C. A had 450 tons of coal abreast it, B had about 800 tons, and C, including reserve bunkers, about 2,000 tons (my figures are, at this distance of time, approximate). If it had not been possible to carry 600 tons of oil fuel in the double bottoms, and if we had not converted the boilers to take Admiralty oil fuel fittings during the first six months of the war, while remaining at sea, that ship could never have remained in the line, after a few days out of harbour at high speed, with battleships of contemporary Admiralty design; and the anxiety of the chief engineer and the captain of such a ship, as to whether the fuel could be brought to the furnaces to satisfy all conditions of steaming, is not such as one who has experienced it will easily forget.

It might be argued by the technical protagonists of coal (if there are any such people—I have yet to discover them) that modern coal-handling machinery could be devised to bring coal from any part of the ship to the fires, without requiring trimmers; perhaps it could, but how to do so without putting impossible encumbrances on the naval architect, impairing the water-tight subdivision of the ship, and introducing heavy and complicated machinery to go wrong at any moment in action, is quite beyond my own vision.

Protection.

It has been claimed that coal bunkers provide protection against enemy action, which oil bunkers do not, and the case of a torpedo hitting H.M.S. "Marlborough" at Jutland is quoted as the classical example. As a matter of fact, that torpedo expended most of its energy on a Diesel engine electric generator (much to the gratification of the engineer commander, who got a new and better one), and the saving of the ship by coal bunkers is simply not the truth. But in any case the claim as to coal bunkers is largely fictitious.

It is necessary, for reasons I have already shown, to trim down coal from the upper bunkers as soon as possible after leaving harbour to ensure an adequate supply in the immediate vicinity of the boiler-rooms for action, and the supposed protection afforded by the coal will probably be lost by the time contact with the enemy has been established. It might even be the case that at the critical moment a bunker door might be open and jammed with coal.

Fuelling Ship.

Another advantage, arising from the same fact, is in fuelling ships. Fittings required for refuelling are merely pipes, filters, and valves, and involve much less disturbance to the hull structure than those required for coaling. The rates of refuelling can be considered as two to three times the rate of coaling, and that with practically no effort on the part of the *personnel.* Ships can also be stored and ammunition embarked at the same time. As soon as these operations are performed the ship is ready for sea, without having to be cleaned and without a fatigued *personnel.*

General Effects on Design of Machinery.

In the design of the machinery no actual advantage accrues to the main propelling steam turbines from the use of oil fuel, but when we come to the boilers and boiler-rooms the advantages are most marked. The human element sets a limit to the size of fire-grate which can be adopted, since, if the length of the grate is increased beyond about 7ft. 6in., the fires cannot be efficiently served and cleaned. The length of oil-fired boilers is only limited by the consideration of ensuring that the particles of oil and air necessary for its combustion can reach the extreme end of the combustion chamber. Modern oil-fired boilers can be made up to a length of 20ft. and more, if necessary. For high-powered ships, therefore, the use of coal involves a large number of small boilers, whereas with oil the same output can be obtained from a small number of large units, an arrangement which results in a considerable saving in the weight and space required for the machinery. It also permits of a more favourable water-tight sub-division of the hull with consequent improvement in immunity from under-water attack, both to hull and machinery.

Coal-fired boilers necessitate the installation of machinery and gear for getting rid of ashes; they require relatively more fan engine power, and the general effect on machinery design is to add greatly to the weight and space required.

Manning.

The engine-room complement of a large ship is decided chiefly by the number of men required to steam the ship continuously at high power, working in three watches, and it follows that this complement for a large coal-fired ship is from three to four times that of an oil-fired ship power for power; for example, H.M.S. "Tiger", 108,000 s.h.p., coal and oil, E.R. complement 600; H.M.S. "Hood", 144,000 s.h.p., oil only, E.R. complement 300. In a modern 8in. gun cruiser an increase of at least 250 men on existing complement would be required.

Supposing for the moment that it were

possible to convert the Navy as it exists to-day to an all-coal one, an addition of the order of 15,000 men would be required.

Operational.

Oil fuel ships can steam continuously at maximum power, say, 90 per cent. to 100 per cent., until all the fuel on board, wherever stowed, is expended, without any noticeably increased effort on the part of the *personnel.* There is little fouling of the combustion spaces in the boilers, no fires to be cleaned, no ashes to be drawn and pushed overboard, and there are no calls made for deck assistance.

As between the two fuels, and with the latest improvements, combustion with oil almost attains that theoretically possible and is under perfect control all the time. With coal the limitations are most serious; one has only to read the Admiralty regulations in the "Steam Manual" of the all-coal-fired-ship days to realise this. A full-power trial then consisted of eight hours at 100 per cent. F.P. with sixteen hours at 60 per cent. Sixty per cent. was the maximum power obtainable until the coal was finished, and, speaking from considerable experience, it can be said that even this low percentage of power depended very largely on the organisation, the skill, and endurance of the engineering *personnel,* and with, in many cases, frequent calls for deck assistance to bring the coal in distant bunkers to the vicinity of the various stokeholds.

Is this enormous handicap and all that follows from it in the qualities of the ship to be lightly accepted? I know of no naval engineer officer who has experienced service under both conditions who would think twice about the matter.

Supply.

I come now to an important question which, I believe, really forms the basis of all arguments and of all agitation against oil, and that is the question of supply.

It is contended that while our supplies of oil could all be cut off at source, the supplies of home-produced fuel are always available. Putting aside for the moment those cranks who will not listen at all to any of the reasoned arguments on the coal *versus* oil question, it is quite natural that many naval officers, retired, and others deeply concerned for the Navy and the safety of this Empire, must say to themselves: can we keep going under all the possible circumstances of war and the requirements for the adequate defence of the Empire?

The whole question of oil *versus* coal in the matter of supply is most involved, because modern transport of almost all kinds and all the three services, Navy, Army, and Air Force, depend on adequate supplies of liquid fuel.

It is beyond the purpose of this lecture to introduce the matter of the possibility of home-produced liquid fuels. It would be a most serious impeachment of our controlling authorities—and that includes others besides the Board of Admiralty —if they had not been the very first to realise the importance of this question and to make a proper provision. It may well be that risks have been taken, and yet those risks have received careful and proper discussion and have been found in all the circumstances to be justifiable.

It is quite obvious that none of us here knows quite enough to discuss the matter properly. I certainly do not pretend to myself; nor, I imagine, would it be altogether in the public interest to give all the facts in connection with arrangements for supply of oil in war. But this at least can be said: we are not dependent entirely on supplies from any one country or from any one part of the world, and it is as ridiculous to say that our supply of oil is liable to be cut off at its source at any time without a shot being fired to defend it, as to say the same of any other raw materials, such as food.

Reserves of oil can be and, I have no doubt, are being built up as the responsible authorities may judge necessary. In some respects it is easier to build up reserves of oil at distant fuelling bases than it is to build up reserves of coal, a fuel much more liable to deterioration and much more of which for the same performance would be required; over 40 per cent. more tonnage is required to carry the same useful quantity of coal than for oil; in point of fact the position is far worse than that, because oil can be carried in the double bottoms and tanks other than bunkers, and in those of ships other than pure colliers or oilers.

Another point that is often forgotten is that there can be no certainty or, I hope, probability that future wars will be fought entirely in home waters, and quite apart from the difficulties of transport mentioned above, there can be little doubt that in most parts of the world it is now easier to get oil fuel than good Welsh coal.

The one disadvantage of having to transport oil in large quantities to these islands is fully recognised, and without exception everybody concerned would much prefer to use a home-produced fuel, were it possible to do so.

Briefly and to summarise, the advantages obtained from the use of oil are:—

Increased endurance for a given weight of fuel approximately up to the ratio of 2 to 1.

Longer periods at sea without having to return to harbour.

Increased power and speed for a given weight of machinery.

Alternatively equal power can be obtained on a reduced weight and space of machinery, permitting the difference in weight and space to be devoted to other military requirements, viz., armour protection, armament, etc.

Increased flexibility.

Reduced complement.

Short time required in harbour to replenish with fuel and stores, and ability to go to sea at once without a fatigued *personnel.*

Full power can be maintained as long as fuel lasts instead of only 60 per cent.

Absence of smoke and ability to control smoke for tactical purposes.

Transfer of fuel for correction of heel and trim in event of damage.

Transport to distant fuelling stations more easy and less of it required in store.

No deterioration in storage.

In conclusion it can be stated that on a limited displacement it would be impossible to design a coal-burning ship having the same military characteristics as a ship burning oil.

Water-piston Gas Engines.

Prof. Dr.-Ing. G. Stauber, Berlin, has formulated rules of design for rotary water-piston machines, which have given satisfactory results in practice.

"Internal Combustion Engineering", January, 1934.

Anything which contributes to the simplicity and directness of conversion of heat into mechanical energy, while reducing the incidental thermal and mechanical losses, will obviously help to cheapen energy and promote the development of internal combustion engines. In these respects, the gas turbine is very attractive, internal combustion being directly applied to the rotation of the turbine wheel and driving shaft. There are, however, in this machine thermo-dynamic and constructional difficulties which appear to be overcome by the use of a rotary water-piston engine. The possibilities and advantages of a water column as a piston are evident in the well-known Humphrey pump, but there are important basic conditions to be observed before water, which is virtually incompressible, but has neither rigidity nor tensile strength, can be applied successfully as the primary mechanical transmission or piston element in a prime mover. What these conditions are, and how they may be fulfilled, form the subject of an address delivered by Prof. Dr.-Ing. G. Stauber to the Electrotechnical Association, Munich, some months ago. Without going into the mathematical considerations presented in the original paper, it may be said that the problem resolves itself into the establishment of conditions which will enable a water column to move rapidly to and fro without breaking into foam or spray. As the water has no tensile strength, this means that the column must always be subject to a positive force in the desired direction of motion; and as the water is under no mechanical constraint in the direction in which it acts as piston, this force must be provided by a net balance of acceleration (either gravitational or centrifugal), in the desired direction of motion. From every standpoint, the use of a rotary piston construction is indicated; it affords (1) direct utilisation of torque; (2) the simplest possible valve gear; (3) automatic cooling, sealing and lubrication of the motor wheel and its slides by water; and (4) centrifugal acceleration, which keeps the water pistons in correct form and position. The use of water pistons, says Prof. Stauber, alone makes rotary piston machines applicable to high working temperatures and high outputs.

Stability of Water Column.

The basic requirement of a water-piston engine is revealed by the unsatisfactory performance of certain double-acting horizontal compressors in which the horizontal movement of a steel piston, in a pipe connecting two vertical cylinders, was used to move water up and down in those cylinders. At low speeds, the water thus displaced acted as a piston compressing air in the upper part of the vertical cylinders, but at higher speeds the action failed, the upward acceleration of the water columns exceeding the downward acceleration due to gravity and resulting in foaming at the moment when the water-piston should be commencing its downward travel. For the same reason, says the author, the Vogt double-acting horizontal two-stroke gas engine of the same general construction, with water-pistons between its combustion chambers and the mechanical piston on the piston rod, gave unsatisfactory results.

One method suggested for overcoming these difficulties consists in the use of a "pendulum ring" machine of the type shown in Fig. 1, from *Zeitschrift des Vereines deutscher Ingenieure.* This consists essentially of a water turbine in which

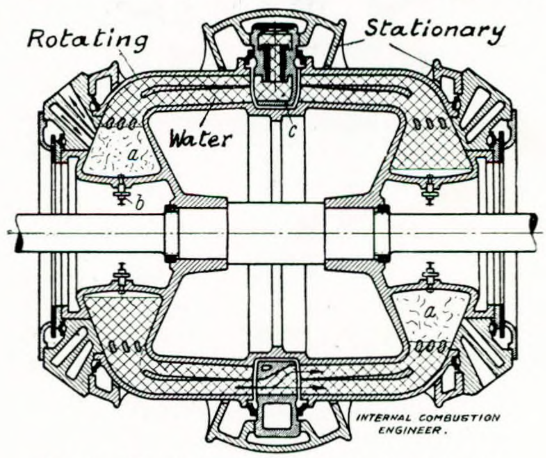


Fig. 1.—The "Pendulum Ring" Gas Turbine.

the water flow is produced by gas pressure. There are combustion chambers (a) with ignition plugs, (b) the water oscillates to and fro between the rotating cellular wheels through the passages of a fixed guide ring. In this type of machine, the determining condition is that the inward acceleration of the water surfaces must not exceed the outward centrifugal acceleration. Either too low speed of revolution or too high combustion pressure may lead to foaming or spraying, and the impossibility of axial scavenging necessitates a reversal of flow which further increases the liability to splashing.

Rotary-Piston Advantages.

The author recommends a rotary piston machine of the sliding vane type, this fulfilling the following desiderata: (1) Gas spaces inside (i.e., at the shaft end of the stroke) and fully sealed by water at the time of maximum gas pressure and temperature; (2) radial partitions between the cells, permitting better control of water level than is possible where curved partitions are used; (3) axial scavenging of combustion spaces; (4) ports for exhaust, scavenging and charging situated in the outer half of the stroke, permitting overflow of surplus water; and (5) freedom from splashing dependent only on the constructional dimensions of the rotary piston mechanism and regardless of the gas pressure, the quantity of water and the revolutions per minute. The last-mentioned characteristic, steady water surface under all conditions, subject to correct mechanical design, is clearly of fundamental importance as regards the future of rotary water-piston machines, whether as prime movers or as compressors.

There are already various wet and dry rotary piston machines with internal and external driving of the pistons, but, for the purposes now under consideration, the author advises the use of the sliding vane type with a roller ring taking most of the thrust of the rotor and thus reducing the wear on the casing.

Construction and Performance.

In the rotary piston gas engine shown in Fig. 2 (*ibid.*), *a, b* represent the centre lines of the rotor and casing respectively; *c*, the scavenging air inlet, opposite to the gas outlet *k*; *d*, the gas inlet; *e*, make-and-break ignition plugs; *f*, striking magnets attracting the contact rods in the plugs and ensuring a powerful ignition arc, even if the plugs are wet; *g*, slide vanes; *h*, a roller ring carrying the rotor thrust; and *i*, the external water seal. The ordinary two-stroke cycle is used, but bled or extracted working gases are used to provide scavenging air by ejector action, thus eliminating the use of an exhaust boiler and steam turbine. In the neighbourhood of the outer dead-centre of each rotating water-piston there occurs, in continual sequence, bleeding of gases, ejection of residue after expansion, exhaust, scavenging and charging. The control of the events in each chamber occurs automatically as the latter passes the ports in the casing. After passing the exhaust and scavenging ports, the compartments are charged with pre-compressed gas. The seals are so arranged and constructed that water lubrication is sufficient. The replenishment of the water-pistons by cold water from the casing occurs automatically in the neighbourhood of the scavenging zone, while water warmed by heat withdrawn from the rotor flows out through the exhaust port.

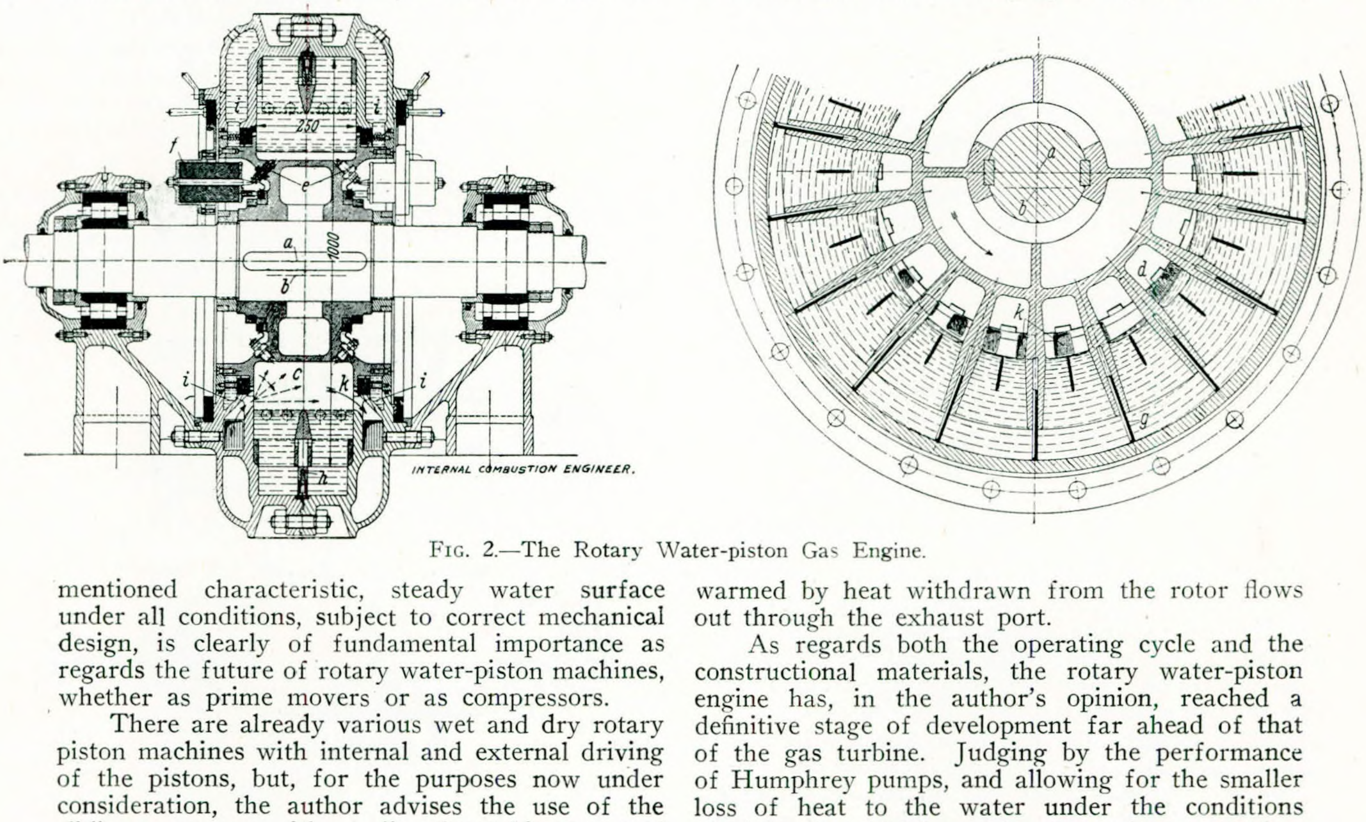


FIG. 2.—The Rotary Water-piston Gas Engine.

As regards both the operating cycle and the constructional materials, the rotary water-piston engine has, in the author's opinion, reached a definitive stage of development far ahead of that of the gas turbine. Judging by the performance of Humphrey pumps, and allowing for the smaller loss of heat to the water under the conditions obtaining in a high-speed rotary piston machine, the author estimates that the indicated efficiency of a rotary water-piston gas engine of the type described should be about 32 per cent. Most of the internal friction consists of liquid friction on the wet walls of the casing and there should be no difficulty in realising a mechanical efficiency of 80 per cent. at about 500 r.p.m., the thermodynamic brake efficiency of the machine being then about

26 per cent. As regards the limits of size and output, the author suggests a maximum peripheral velocity of about 820ft. per sec., corresponding to an output of about 3,000 h.p. at 125 r.p.m. with a rotor of about 13ft. diameter and $3\frac{1}{4}$ft. width. Two such machines, one on each side of an electric generator, would provide a 6,000 h.p. unit. Larger sets could probably be built if required, but not up to the capacity of steam turbines. These figures, which might otherwise be regarded only as hypothetical, gain in significance from the author's statement that practical tests during a period of two years have demonstrated the operating capabilities of the rotary piston engine and have given results which will be published by the builders in due course. It is reasonable to suppose that these results are consistent with the figures mentioned above.

Combined Marine Steam Engine.

"The Engineer", 23rd March, 1934.

On Saturday, March 17th, official sea trials took place off the river Tyne of the cargo steamer "Adderstone", which has been re-engined by White's Marine Engineering Company, Ltd., Hebburn-on-Tyne, and equipped with an arrangement of the "White" patented combined steam engine and turbine, taking steam at 200lb. pressure and 620 deg. Fah. superheat from oil-fired cylindrical boilers. The speed trials were carried out in squally weather with some fog. The ship, which has a length of 400ft., with a beam of 52ft., has a deadweight-carrying capacity of about 7,700 tons, on a draught of 25ft. 4in. During the trials the machinery was run at all speeds from zero up to 300 r.p.m. for the reciprocating engines, with a turbine speed of 3,000 r.p.m. We are informed that it operated silently, efficiently, and without vibration under all trial conditions. With a total horsepower of 1,800 to 1,860, and a propeller speed of about 75 r.p.m., a mean speed of 11·56 knots was recorded. The steam consumption of the main engine was 7·8lb. per I.H.P. hour, and the fuel consumption worked out to 0·7lb. of oil per I.H.P. hour for all purposes, which is equivalent to a coal consumption of 1lb. per I.H.P. hour for all purposes.

Operation and Design Defects Diagnosed by Welding Repairers.

"The Oil Engine", March, 1934.

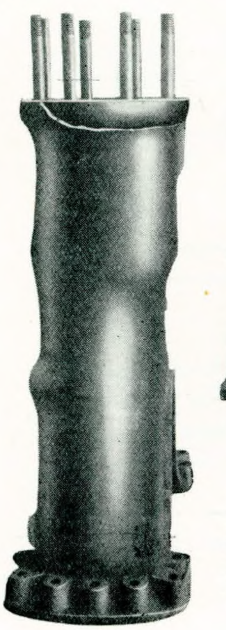
Usually a repairer is able to give useful hints to the designer and to the operator, for he encounters not only those failings which are due to weakness and normal wear and tear, but to the mishaps which result from mismanagement and carelessness.

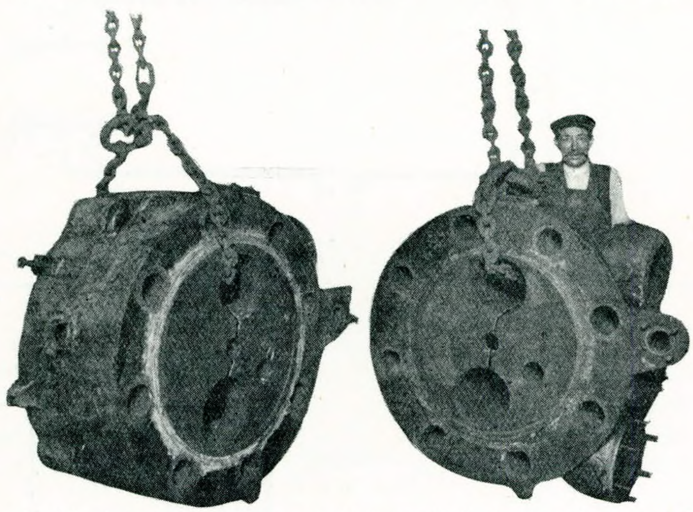
During the course of a discussion recently, the writer was informed that as a result of a diagnosis of defects calling for welding repairs and based upon a very large number of cases, the conclusion was reached that the majority of serious faults which develop in modern oil engines is due not to bad workmanship or poor design, but to operation blunders.

The most frequent oil engine welding repair is to cracked cylinder heads. They come both in winter and summer, and in almost every case the cause is directly traceable to improper handling of the cooling system.

Violent Changes of Temperature.

In many cases transport vehicle engines are over-cooled. This leads to carelessness in watching the water level, the gradual diminishing of which is not noticed until the shortage is indicated by boiling. It is then that damage can easily be done. The driver seizes the first opportunity to replenish the radiator, and fills it with cold water before the engine has cooled. The result may be a diminutive crack across a specially overheated section of the head or an extensive series of cracks which may even damage the cylinder bores.





(Left) An engine frame casting cracked due to the use of excessive force when tightening down the cylinder head nuts. (Above) Two cylinder heads, each weighing some two tons with bad cracks between the valve seatings. Welding satisfactorily repaired these three defective components.

Until comparatively recently it was no uncommon thing when a part of the water jacket of an engine was cut away to find that circulation was being impaired by the presence of foundry coring, but this is now an unusual occurrence. When an obstruction is found—and it is always sought when a heat crack or fracture bears signs of being attributable to this cause—it is much more often due to an operator's carelessness than to inadequate filtration.

It frequently happens that oil engines suffer damage due to the formation of fur and scale in the water jackets, but when such troubles arise they are always easy to remedy. Again, it is in the areas subjected to the highest temperatures where cracks occur.

A common cause of failure, particularly with small compression-ignition engines, is the use of excessive force in assembling and dismantling. It appears that mechanics, realising that high internal loading has to be resisted, are liable to employ greatly excessive leverage on holding-down nuts, with the result that castings may be cracked.

In the case of small multi-cylinder high-speed engines in which the common cylinder head is of some length, valve port and jacket cracks can be caused much more easily than is generally supposed by unequal tightening of the large number of holding-down nuts that is provided. Particular care should be taken first not to use undue force, and secondly to follow a carefully considered order of tightening.

Large oil engines which have cylinder heads provided with threaded holes for eye bolts to facilitate lifting, often make their way to a welding specialist as a result of great force being exerted with the hoist before all the holding-down nuts and other fittings have been removed. It is clear that when the designer provides a ready means for the application of considerable force, he should also be at pains to ensure that there are no concealed nuts which may be overlooked when an engine is being dismantled. This applies in particular when any such nuts are remote from the lifting point and thus permit leverage.

Another matter which designers should clearly keep in mind is that the water-inlet pipes of engines should not enter the cylinder jackets at right angles. When sandy water is used, this practice leads to serious erosion of the metal on which the column of sand-laden water impinges.

Those bearing troubles which obtrude themselves with modern oil engines are nearly always due to the use of insufficient or unsuitable lubricant. When a serious mishap occurs, such as a connecting rod smashing through the side of the crankcase, it is more easily repaired than is similar damage to a petrol engine. The explanation is that in present-day welding technique a heavy section (even where the thickness shows considerable variation) is less troublesome to handle than a light section.

Seager Refrigeration Development.

A compound pre-cooling refrigeration plant has recently been developed by Seagers, Ltd., combining high power economy with increased volumetric efficiency.

"The Marine Engineer", May, 1934.

Refrigeration plays a large and increasingly important part in ship operation at the present day, enabling a wider range of perishable foodstuffs and meat cargoes to be brought into Great Britain over long distances. Refrigerating plants thus comprise an important part of modern ship machinery, and improvements adding to their efficiency or reducing their size are to be welcomed.

An advance in design has recently been effected by Seagers, Ltd., Dartford, Kent, who have brought out a three-stage compressor which contains no more working parts than an ordinary refrigerating machine and yet is capable of dealing efficiently with high compression ratios such as are encountered in low-temperature refrigeration. The pre-cooling cycle is incorporated in this new machine to provide a first stage of compression, and to

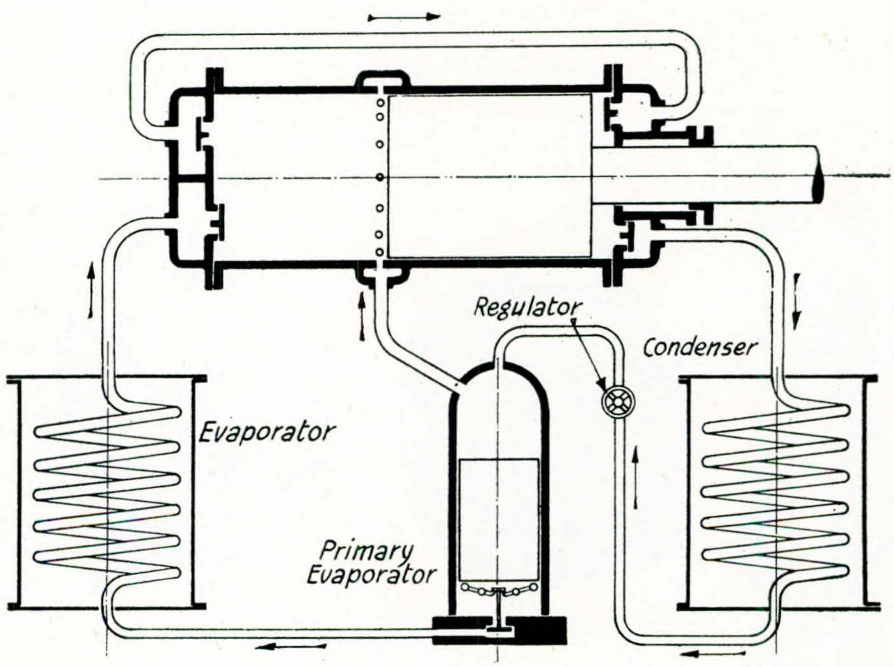


FIG. 1.—Diagram of compound pre-cooling cycle illustrating length of piston and arrangement of ports.

reduce to a minimum the usual losses associated with the reduction of temperature of the refrigerating medium at the regulating valve.

The ordinary compression machine when working down to low temperatures must evaporate approximately 50 per cent. of its total charge in cooling the remainder before it can commence useful cooling in the evaporator, but, if the charge

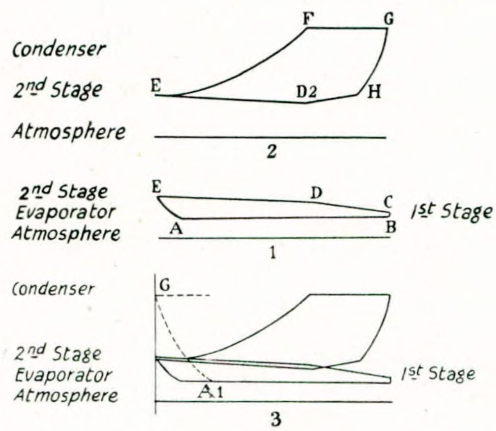


FIG. 2.—Typical indicator cards taken on a compressor as described.

is pre-cooled by primary evaporation, the temperature may be reduced to within a few degrees of that ruling in the evaporator, and only about 5 per cent. of the total charge entering the evaporator need be vaporised on passing the final regulator, leaving the remainder free to do useful cooling. The vapour formed in pre-cooling the working charge is returned to the compressor as a first stage of compression and circulates through the inter-cooler and condenser, where it discards the heat which it absorbed in cooling the remainder of the charge, and, as it is supplementary to the working charge, whose capacity is measured by the swept volume of the compressor piston, a much higher percentage of liquid is available in the evaporator coils for useful cooling, and the amount of refrigeration per unit swept volume is correspondingly greater than could be obtained by an ordinary compression machine, whether single stage or compound.

The new machine may be described generally as a compound compressor working with pre-cooling cycle, in which one compressor cylinder is made to handle three successive stages of compression, while the pre-cooling vessel enables two stages of expansion to take place.

As will be seen from Fig. 1, it follows very closely the lines of a double-acting CO_2 refrigerating machine, but is provided with a piston longer than the working stroke, and has near the centre of the liner a row of admission ports, through which gas from the pre-cooler is introduced into the cylinder at the end of the first suction stroke. The piston is formed with a large diameter piston rod, so that gas transferred from the large end of the cylinder to the under side of the piston is compressed, owing to the difference in volume between one end and the other. A full charge of suction gas is drawn in by the piston on its suction stroke, at the end of which the line of ports, already described, is uncovered and allows the second charge of gas from the primary evaporator at higher pressure to enter the cylinder, thereby compressing the entire charge to its own pressure and thus forming the first stage of compression. During the next stroke the combined charges are transferred through a connecting pipe or cooler to the under side of the piston, in which they are compressed, the volume of this space being smaller by the diameter of the piston rod. This forms the second stage of compression.

The piston now returns and compresses this charge to condenser pressure and delivers it into the condenser, where its heat of compression is removed and, if the temperature of the circulating water is not in the neighbourhood of the critical temperature of CO_2, it will be liquefied, and will pass through the first regulating valve into the

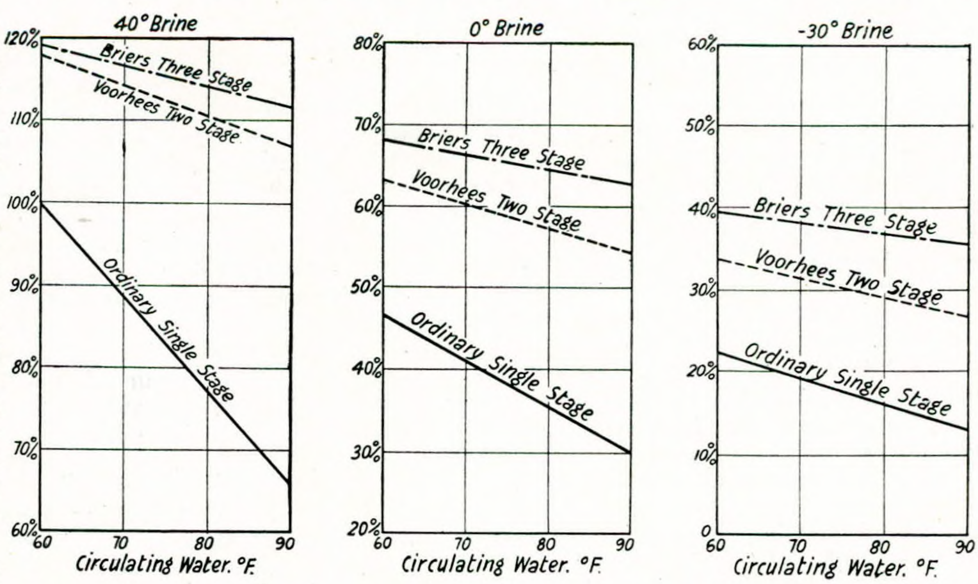


FIG. 3.—Comparative outputs for ordinary, multiple effect and three-stage compound pre-cooling cycles with high-temperature, medium and low-temperature brine.

primary evaporator. Here its pressure is reduced to something slightly above that ruling in the evaporator, and the reduction of temperature of the entire charge is accompanied by the formation of vapour which returns to the compressor and enters the first stage cylinder through ports, as already explained. The cooled liquid passes through the lower automatic float valve into the evaporator.

It will be noted that the ports are not on the centre-line of the compressor, but are so arranged that vapour from the primary evaporator only enters one end of the cylinder. It is, however, quite possible to arrange another stage of expansion in such a manner that a supplementary charge is added to the high-pressure end of the cylinder, thus making four stages of compression in the same cylinder, but the present machine is arranged for only one stage of supercharge. In the present compound arrangement the cold suction gas enters the large end of the compressor and the hot third stage delivery gas leaves at the other end, so that the suction end of the cylinder remains comparatively cool. The first stage of compression and the final stage actually occur in separate ends of the cylinder some inches apart, so that the cylinders never become unduly heated by hot discharge gases, this factor having a large and not easily measured effect upon the volumetric efficiency.

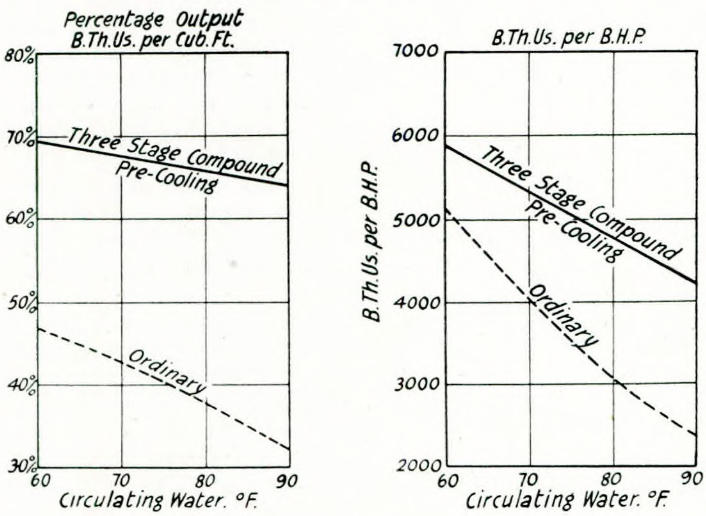


FIG. 4.—Comparative output and power consumption with zero brine under varying water conditions.

Fig. 2 shows some typical indicator cards taken on a compressor which had no inter-cooler coil, card 1 being the first and second stages A B C D E. The suction line A B is at constant evaporator pressure. At the end of the stroke the ports are uncovered and gas from the primary evaporator raises the pressure of the whole from B to C. As the piston begins to move the pressure within the cylinder is raised to D, at which point it has become equal to that at the other end of the cylinder, after which the pressure steadily rises in both ends of the cylinder, as the gas is transferred from one end to the other. The re-expansion line E A should particularly be noted; although this compressor had 6 per cent. clearance, the final pressure in the cylinder is comparatively low, so that the loss from re-expansion is slight and the period of stroke during which suction gas is drawn in is much greater than it would be had the final pressure been reached in one compression. For comparison, the final pressure and its re-expansion curve is shown by the dotted line G A.

Card 2 shows how the gas, which was left at pressure E at the end of the previous stroke of the piston, is now compressed to the final pressure ruling in the condenser and discharged along line F G through the delivery valve. Gas in the clearance spaces expands down to H, after which the gas remaining in the connecting pipe continues the re-expansion down to some pressure D2, at which it equalises with the pressure in the other end of the cylinder. At this point transfer from second to third stage commences and the pressure continues to rise steadily during the remainder of the stroke. The two cards superimposed are shown in card 3.

It is not generally appreciated that, although the amount of work done by any compressor is proportional to its suction-swept volume, in the pre-cooling cycle two distinct charges are in circulation, and the actual weight of gas circulated through the primary evaporator circuit is over and above that portion of the charge which circulates through the evaporator, and which is responsible for the useful cooling therein.

The amount of supercharge is not easily determined, as it depends on the percentage of charge in the system, on the dryness factor of the gas leaving the pre-cooler, and on the ratio of pressure between the pre-cooling charge and the charge coming from the main evaporator, and is, therefore, a variable quantity, but it will be readily appreciated that by removing from the working charge the necessity for cooling itself by its own evaporation and by adding sufficient gas to the system to effect this necessary cooling, the total swept volume required for any definite amount of refrigeration will be considerably less than is necessary when only one charge of gas is available for both duties.

Low-temperature Refrigeration.

There is a growing demand for low refrigerating temperatures, of which the rapid freezing of fish and other produce will serve as an example, and there is a wide field for a machine covering the temperature range from 0° F. to −50° F. It must, among other things, be low in cost and compact in bulk, if it is to interest the fishing industry, efficient in its power consumption and yet simple to control, so that anyone used to an ordinary refrigerating machine can handle it. The first low-temperature experiments made with this compound compression machine were carried out while circulating calcium chloride brine of eutectic strength and, during the earlier runs, with $-40°$ F. brine, very good stability was maintained; the only difficulty encountered at temperatures approaching the minimum was the tendency of the brine to sludge, owing to changes in brine density due to the absorption of moisture in open circuit at this low temperature. When a closed circuit is used, brine circulation at $-45°$ F. would appear to be practical where indirect cooling is desired, but for open-circuit work $-40°$ F. appears to be as low as is practical, unless special precautions are taken to control the brine density.

It must be borne in mind that with brine of eutectic composition a variation of 0·01 specific gravity either way will cause a rise in the freezing point of about 10° F., and the gradual absorption of moisture will readily lead to the formation of a thin film of ice or calcium crystals around the evaporating coils which must of necessity be held 10° or 15° F. lower than the brine itself. In order to overcome this difficulty and reach lower temperatures than were possible with brine, an insulated tank containing petrol, in which was a short evaporator coil, was arranged. Figs. 3 and 4 show the comparative output of Seager's compound and pre-cooling systems compared with an ordinary type refrigerating plant.

As a heat transfer medium, petrol has many objections. Owing to its volatile nature and the risk of fire, no attempts were made in this case to circulate it through the measuring tank, so that no B.Th.U. output figures are available, and as all the pipe work about the machine, the evaporator and its lagging were cooled down simultaneously, the actual work done by the machine was considerably in excess of that necessary to cool the quantity of petrol under consideration. Petrol has two advantages over brine for low-temperature work, its low specific heat which enables it to reach low temperatures rapidly, and its constant density which is not affected by the presence of moisture.

It was noted that during these runs any moisture which condensed on the surface immediately fell to the bottom as a fine sludge and had no other effect.

So far the low-temperature experiments have been confined to CO_2, but we are informed that other media will be tried out in due course for still lower temperatures.

Compound Compression for Tropical Service.

The range of usefulness of this compound compressor is not confined to low-temperature work. As has previously been indicated, wherever high ratios of compression are encountered, considerable gains will be obtained by compounding, and it has been found possible to apply this machine to tropical conditions in competition with both ordinary compression machines and multiple effect compression machinery. Although, since it embodies the pre-cooling system, its only advantages over the latter system (multiple-effect) will be greater power economy and higher volumetric efficiency, it has been found possible to use it very advantageously for the conversion of existing machines which are driven by prime movers of fixed power, such as existing motors or oil engines. In such cases under general tropical conditions, it is possible to replace an existing ordinary refrigeration machine by one having a swept volume of 25 per cent. less. The power consumption will be slightly less than that of the existing machine, whereas the increased refrigerating output will be from 30 to 50 per cent. greater, according to the temperature of the sea circulating water and brine, the greatest saving, of course, being made with high-temperature sea circulating water and low-temperature brine. The compound machine has also the added advantage that it will cope with a growing demand for lower temperatures, particularly for marine service in fish freezing, or for the manufacture and carriage of ice cream at sea, and its general usefulness in tropical parts should be considerably enhanced by the present developments which place it on a more equal footing with ammonia under tropical conditions.

Developments in Steam Reciprocating Engines During the Last 25 Years.

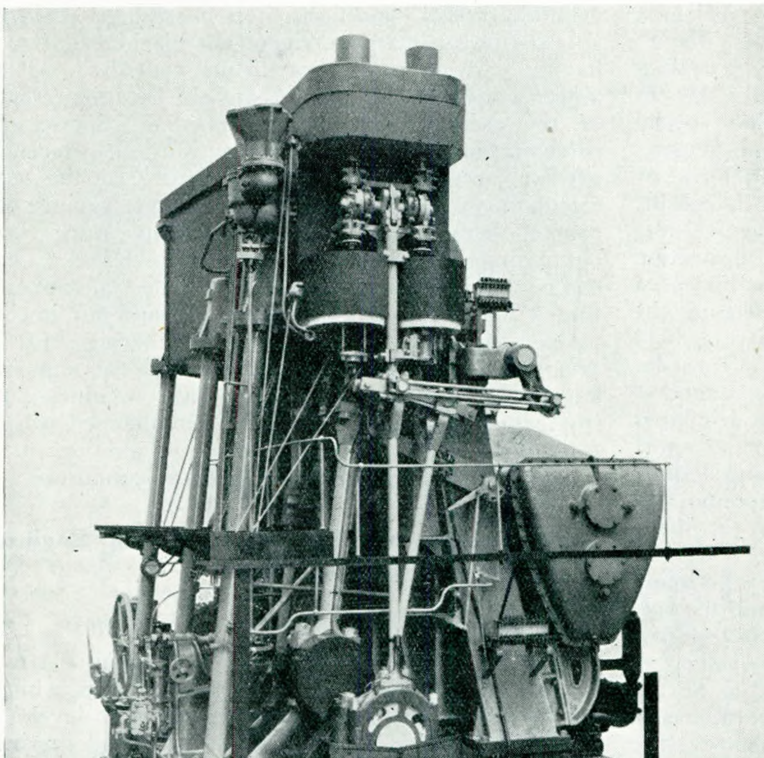
By Summers Hunter, Junr.

"Shipbuilding and Shipping Record", 3rd May, 1934.

It is interesting to look back upon marine engineering activities during the last 25 years, which has been a time of great advancement and development. About the beginning of this period marine engineering, so far as cargo boat machinery was concerned, had become more or less standardised, and except for size, one installation was not very different from another.

The triple-expansion engine taking saturated steam from Scotch boilers was almost universal, but it also might be said that this was the turning point when the industry left the old rut and once more forged ahead in the march of progress. It was just then that superheating was beginning to establish the claims made for it, and its introduction had a great bearing upon the subsequent design of the main and auxiliary engines and upon all the machinery which go to make up the installation of a ship's propelling plant. To begin with, difficulties were encountered from lack of proper lubrication; there were no really suitable lubricating oils available; but, thanks to the efforts of progressive oil companies, they got busy and produced suitable blends. Then, the larger quantities of oil necessary for internal lubrication became a menace to the boilers, and suitable filters had to be evolved for trapping the oil before it was picked up by the feed pumps. Piston rings and gland packings also did not take kindly to the higher temperatures, and again the market possibilities were realised by specialist manufacturers who produced more satisfactory rings and packings. Cylinder metal, piston rod, and other material also called for scientific attention, and greater precision became necessary in their manufacture.

The story is almost endless, but the introduc-



Triple-expansion engine with poppet-valve gear on h.p. cylinder.

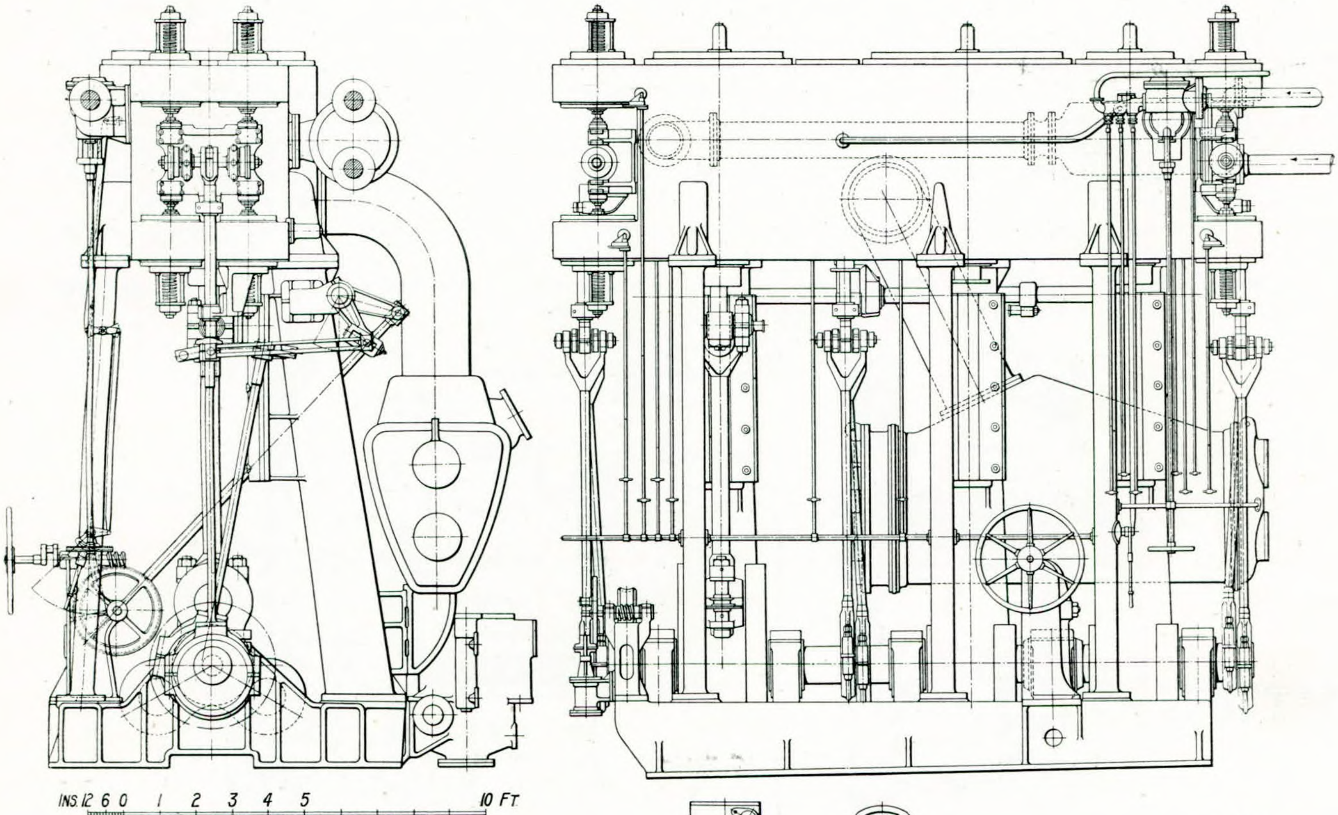
tion of superheated steam meant a wholesale reconsideration of the design and materials used in the construction of the parts affected. Another adverse factor of considerable importance was the prejudice against the system amongst those whose work was affected thereby, and in many cases superheaters were thrown out because they did not come up to expectations, this being chiefly due to the fact that they got neither the necessary attention, nor were the causes of troubles methodically investigated. It is interesting to note, however, that in many cases they have subsequently been re-installed with complete satisfaction.

Piston valves and flat valves also called for improvement; the distortion in the steam chests, produced by the higher working temperatures, destroyed their steam tightness. The flat valve in the m.p. cylinder was the first to be dealt with; this was replaced by the balanced valve, which has since given satisfactory service. It might here be mentioned that conversions from saturated to superheated steam in existing tonnage have been carried out where balanced valves were originally existing in the h.p. cylinder. These have been replaced by new ones of suitable material, and have worked quite satisfactorily. In other conversions, and also in the case of new engines, poppet valves have proved themselves to be the best solution. These work continuously for years without attention of any kind beyond that of lubrication of the spindles, which in some cases work through packingless glands. The higher steam temperatures now in vogue have almost ruled out the piston valve in the h.p. cylinder for new construction.

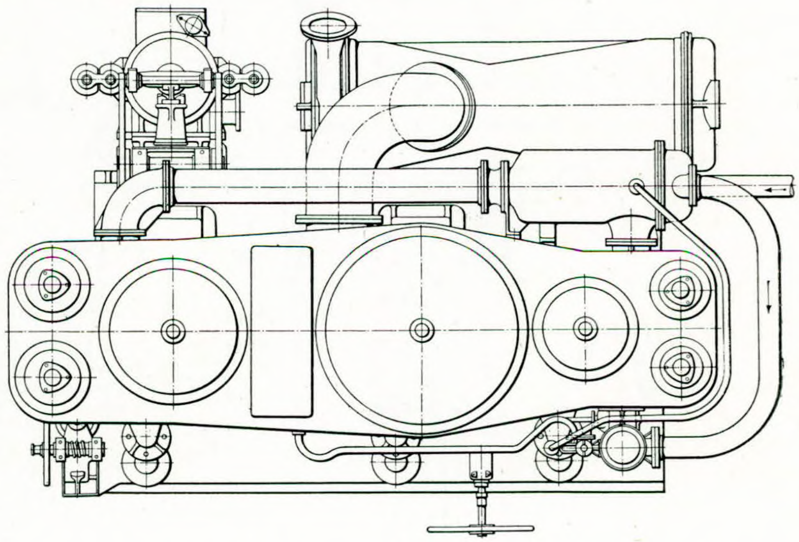
Due to all this development, the machinery installations of modern ships are so much more economical than those of the older ships that the owner to-day who wishes to continue to run his old tonnage must consider the question of converting the machinery to work under the higher temperature steam conditions of to-day.

With regard to the commercial side of the subject, the gain to be expected in the case of conversions depends largely upon the conditions existing under saturated steam. If the machinery and boilers are of good design and manufacture, a saving in fuel of 15 per cent. to 20 per cent. may easily be realised. If, however, there is any tendency to priming, anything from 25 per cent. to 30 per cent. is not exceptional. It is usually expected that the capital cost of such conversions may be regained out of fuel savings only in three years, but this is often reduced very considerably. Cases are by no means rare where the cost is liquidated in 18 months.

Poppet valves, previously mentioned, besides satisfying the mechanical requirements of superheated steam, are also a source of economy. The large areas obtainable for the passage of steam, combined with their steam tightness, produce this result.



General arrangement of triple-expansion engine with reheater for h.p. exhaust.



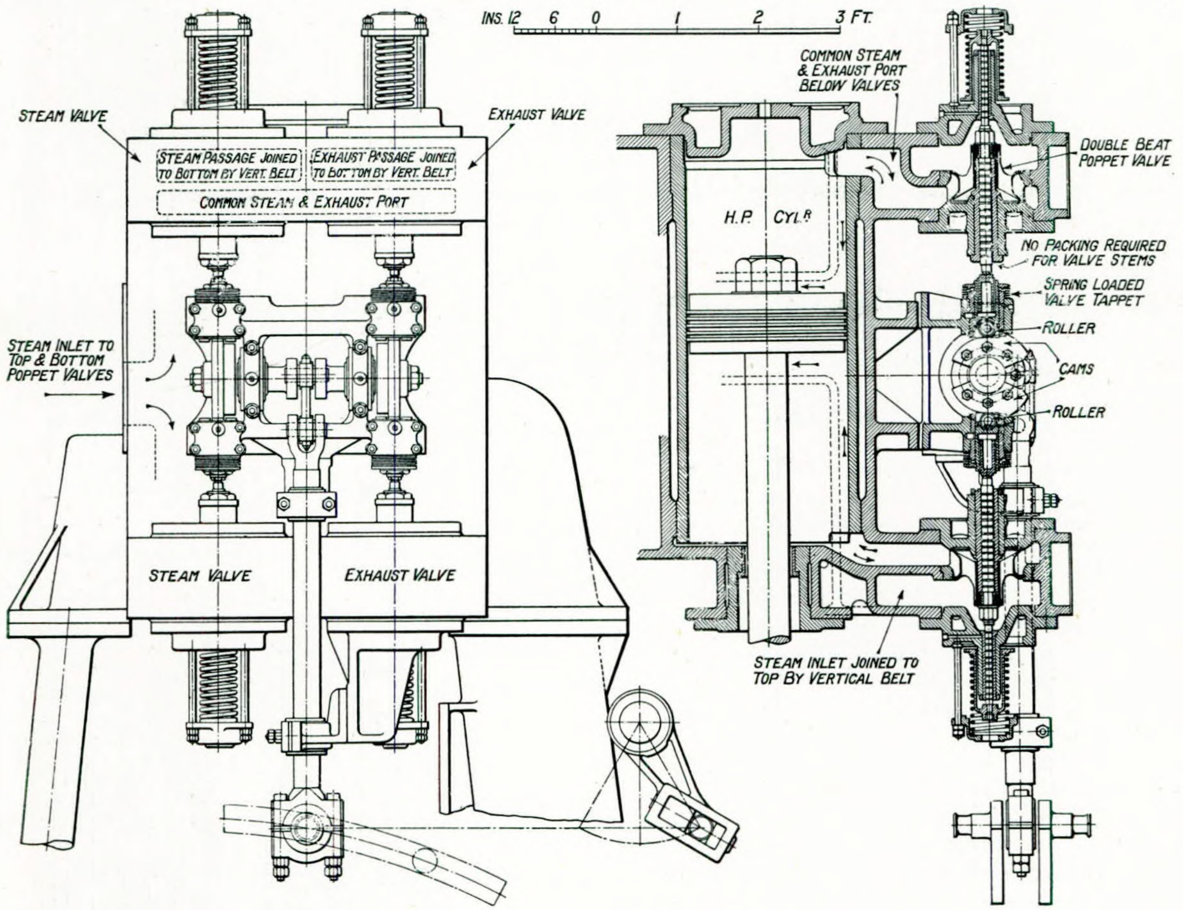
Feed heating as a source of saving has also received considerable attention. This is now usually effected in stages, generally two, primary and secondary. The first takes the auxiliary exhaust as its heating medium, which, 25 years ago, was invariably exhausted to the main condenser, its latent heat being discharged overboard with the cooling water. The secondary heater sometimes takes its steam direct from the superheaters, but greater economy is effected by using the h.p. exhaust, which is of sufficiently high temperature to raise the feed water to about 300° F. In this way the steam used has at least expended a large portion of its useful work in the main engine before being drawn off for feed-heating purposes.

As accessories to the main reciprocating engines, mention should be made of economies effected by the adoption of the Bauer-Wach, Parsons, and Götaverken low-pressure turbine schemes, all of which are too well known to need enlarging upon in this article.

With regard to possible developments in the near future, there is now definite proof that further economy lies in the employment of still higher superheated steam temperatures, and it is reasonable to suppose that the limit of usefulness, so far as temperature is concerned, would be that which, after it has finished its work, allows steam to exhaust from the l.p. cylinder in a dry saturated condition. There are two ways of accomplishing this, one by initially superheating the steam to such a degree that it remains dry until exhausted to the condenser, and the other by re-heating the steam between stages in its passage through the cylinders. The first method is not yet an economical proposition, chiefly because the necessary temperature is too high for the quality of materials and lubrication we have at our disposal. Thus the second method must be adopted. The reasons for this conclusion, that the steam must be kept dry through the engine, are briefly as follows:—

The economy so far obtained in superheated installations is, except for a very small fraction, due to the improved efficiency of the engine, and is the result of reduced condensation of the steam in the cylinders. So far, condensation has been entirely eliminated from the h.p. cylinder, and has been considerably reduced in the m.p. This is due to the steam inlet to the latter being still superheated, while the exhaust falls to saturated temperature. We also know that the l.p. cylinder in any saturated engine is the wettest of all, and, therefore, if kept perfectly dry we may expect a further very substantial gain. With this end in view, investigations have recently been proceeding, and new designs of superheaters have been evolved for the generation of highly superheated steam. Steam temperatures from ordinary Scotch boilers can now be obtained at between 700° F. and 800° F.

In a reciprocating engine developed for utilising these high temperatures, the steam is led to a reheater where it passes through a battery of elements on its way to the engine stop valve. These elements are surrounded by the h.p. exhaust, which is reheated in consequence; at the same time the boiler steam is lowered in temperature before it enters the high-pressure cylinder, and suitable means are provided for controlling the temperature. The system can be applied to one or any number of cylinders.



End view, looking on valve gear. Section through cylinder and poppet valves.

North Eastern Marine poppet-valve engine.

At the beginning of the period under review, the turbine and Diesel engine were gaining in popularity; it was then thought by some that the days of the steam reciprocating engine were numbered, but, aided by invention and research, it is now, for certain classes of cargo vessels, more firmly established than ever before, is more than holding its own as an economical reliable prime mover, relatively cheap to install, easy to operate, very accessible and retaining its efficiency at varying powers and conditions of service.

Double-acting Engine Piston Rods.

An Analysis of Causes of Failure. The Importance of the Size of the Bore in the Rods.

By Heinrich Becker, Chief Engineer, Maschinenfabrik Augsburg-Nürnberg*.

"The Motor Ship", May, 1934.

The following discussion is limited to the piston rods of double-acting two-stroke engines of large power in which the cooling of the pistons is effected by means of fresh water and the cooling medium is delivered through a hole bored in the piston rod. Fig. 1 shows the development of this design.

Much has been written concerning the piston rods of engines of this type in past years. From time to time, troubles have arisen and more or less deep cracks have developed or complete

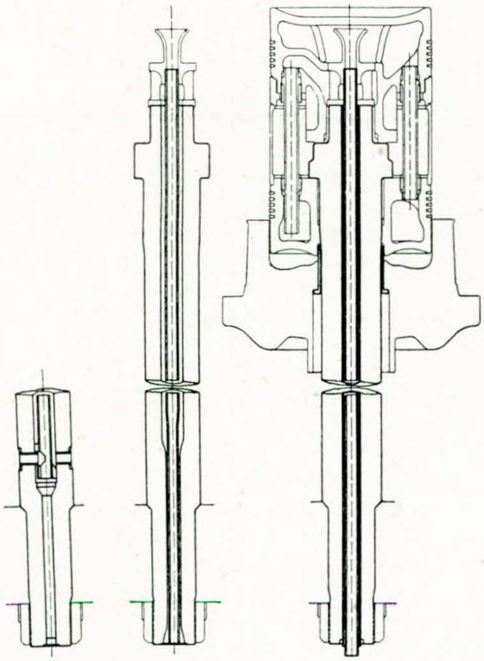


Fig. 1.—Piston rod development of the double-acting two-stroke M.A.N. engine.

breakage of the piston rod has resulted at the screw thread or some important portion of the piston rod assembly. These difficulties caused a certain anxiety among those concerned and were much discussed in lectures and articles.

In order better to understand the position, a short discussion may be given dealing with the experience of piston rod troubles earlier than three years ago, referring to the difficulties which had, up to then, arisen.

The M.A.N. delivered the first double-acting two-stroke marine engine in 1925. At the commencement of 1928, 70 cylinders had been placed in service. The design of the piston rods was based on experience of large gas engines, using carbon steel of 70 to 80kg. per sq. mm. tensile strength,

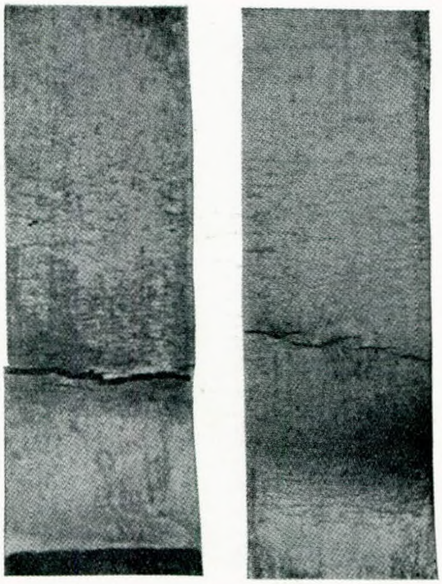


Fig. 2.
C steel — Cr V steel
20 kg. per sq. mm. load
3·85 million — 10·25 million
alternations.

having 0·5 to 0·55 per cent. of carbon, and also 1 per cent. nickel steel of equal strength. The inner bore of the piston rods had a diameter of 70mm. Up to the beginning of 1928 no troubles were experienced.

In the middle of 1928 troubles followed in rapid succession after about three months' running period; they arose from several piston rods breaking

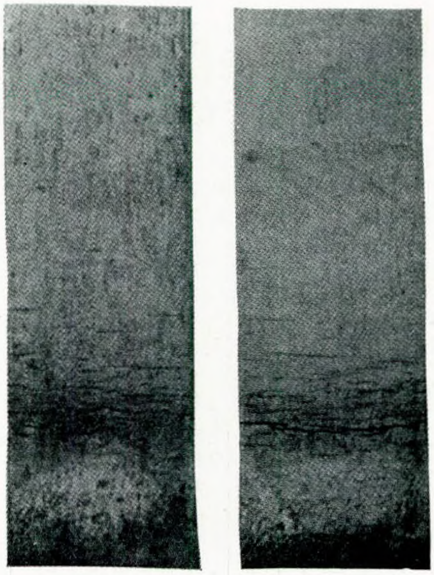


Fig. 3.
Carbon steel — Cr V steel
9 kg. per sq. mm. load
23 million — 40·3 million
alternations.

* Extract from a paper read at a meeting of the V.D.I.

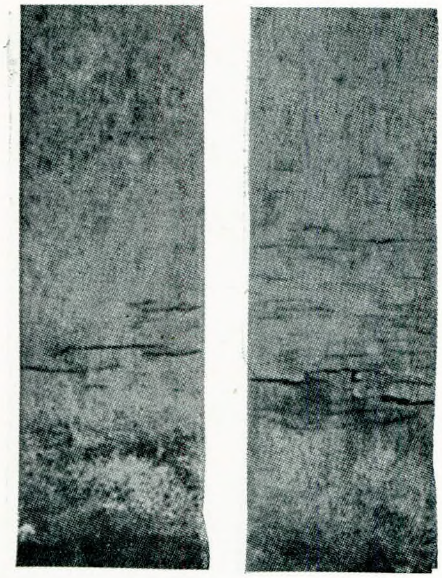


FIG. 4.
C steel Cr V steel
6 kg. per sq. mm. load
78·5 million. 87·5 million
alternations.

in the lower bores which serve for the delivery and discharge of the cooling water. These rods were of similar construction to those which had been in service several years in a similar type of engine. The only difference was in the material. With the intention of making an improvement, a special steel of 70 to 80kg. per sq. mm. tensile strength was used. All piston rods were changed to Siemens Martin steel of 55 to 60kg. per sq. mm. strength and 0·35 to 0·4 per cent. carbon, and to-day, after five years' running, they are satisfactory. From this point onward, the M.A.N. has only used Siemens Martin steel for piston rods.

In the following two years, a considerable number of piston rod failures occurred in a relatively short time with engines from other works, in the thread and at the point of maximum heat stress, therefore in the zone which, at the beginning of the combustion, was within reach of the upper ring of the stuffing box. These piston rods were manufactured of chrome nickel steel.

During the same period piston rods of engines of a foreign type broke after five months' running time. These were of chrome nickel steel and chrome vanadium steel. The cracks occurred in a position adjacent to the point of maximum heat stress.

Then unexpected failures occurred with two M.A.N. engines, in one case after a year's running and in the other six months. They were unexpected, because the piston rods were of the same steel as hitherto employed. There was only the apparently unimportant difference that the area of the inner bore was 16 per cent. of the cross-section of the rod, against 7 per cent. in the previous cases. I will refer later to the influence of the size of the bore, or rather, the water velocity.

This was the position three years ago. To amplify it, I may make the following points: up to that time about 300 piston rods of Siemens Martin steel were in service, in engines of the M.A.N. type, and 30 pistons of alloy steel in engines of other designs. The cracks in both cases were approximately the same in number, so that with alloy steel they were actually considerably more in percentage. The M.A.N. had examined many steels in its experiments dealing with corrosion, and particulars of the experiments may be published later. It is here only necessary to make reference to the practical results.

The first experiments showed that, in order to obtain information relating to resistance to corrosion, with various materials, stress alternations to the number of 10 millions were insufficient. The necessary apparatus was, therefore, provided for testing the effect of fresh water or sea water in its relation to corrosion effect, with alternations of load on the materials to the extent of 100,000,000. The experiments were carried out on an M.A.N. engine with corresponding corrosion apparatus fitted. The frequency was from 3,000 to 4,000 alternations per minute, so that for 100,000,000 changes of load a corrosion time of about one month was necessary.

In Figs. 2-4 are shown photographs of test pieces of carbon steel and chrome vanadium steel. With a stress of 20kg. per sq. mm. the chrome vanadium steel stood approximately three times as many alternations of load as with carbon steel. With a stress of 9kg. per sq. mm. the difference is smaller, and at 6kg. per sq. mm. (Fig. 4) there is little variation. The crack formation with the two steels is practically similar and diminishes with the stress. The corrosion effect with these test pieces develops in somewhat the same way as in many

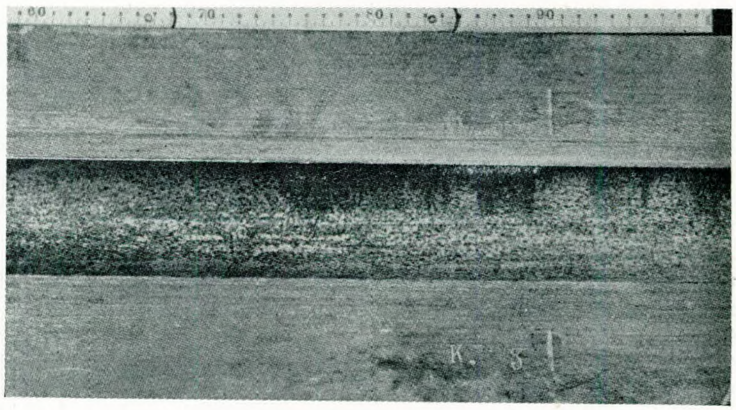


FIG. 5.—Cr Ni steel. Small bore. Distant corrosion marks.

piston rods. The test demonstrated that the corrosion for carbon steel was practically similar to that with alloy steel, and occurred at 6kg. per sq. mm. with sea water and 15kg. per sq. mm. with fresh water cooling.

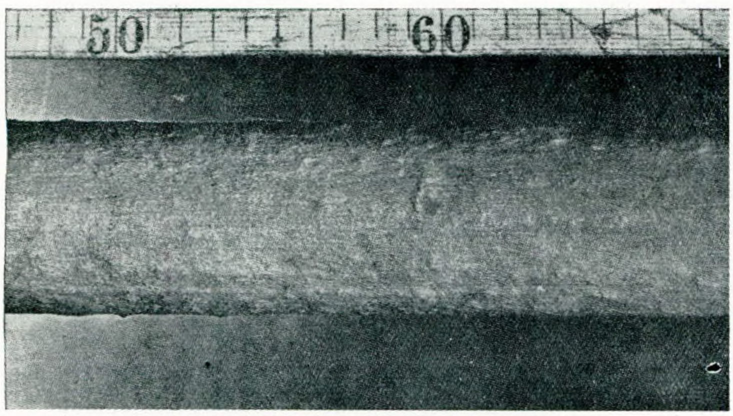


FIG. 6.—Siemens Martin steel. Small bore. No cracks.

I may now refer to the position in which the piston rod cracks occur, and the extent to which they develop with different materials. Piston rods of alloy steel have shown special liability to cracks at the threads. With piston rods of Siemens Martin steel, cracks at the ends of the threads have only occurred twice in several years, although the M.A.N. and their licensees have built over 650 cylinders. These two cases may be considered as exceptional.

The second series of cracks are those which occur at the position of maximum heat stress and which have arisen both with alloy and Siemens Martin steel. With the latter, however, there have been a relatively small proportion, and they have only occurred when the resistance is reduced through serious corrosion.

The third type of crack occurred at the point where the delivery pipe is attached. Electrolysis undoubtedly plays a part here, and possibly corrosion is also accelerated through the formation of whirling at this point. Breakdowns have only occurred after four or five years' service.

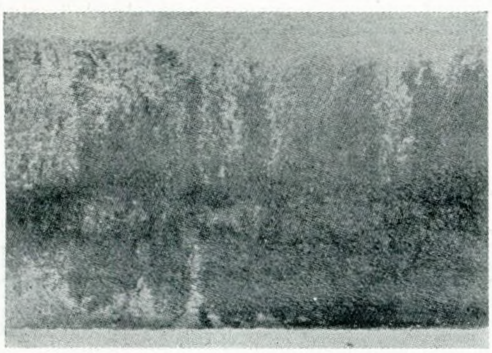


FIG. 7.—Cr V steel. Large bore. Many cracks.

Summarising the position with regard to alloy steel and Siemens Martin steel:—

1. Alloy steel is liable to cracks at the thread. This can be prevented only by special design of the thread and the nuts. Siemens Martin steel is less liable to cracks in this respect, making the expedient mentioned unnecessary.

2. Cracks at the point of maximum heat stress are developed earlier in alloy steel, under similar conditions, than with Siemens Martin steel, but always only when corrosion is a predisposing cause. Corrosion must, therefore, be prevented in both cases, either (1) through the employment of oil cooling, (2) by protecting the inner bore against corrosion by means of an inserted corrosive-proof pipe (when water is used), or (3) the addition to the cooling water of an anti-corrosive fluid or other means.

By the employment of an inserted pipe, the cracks which may arise at the junction with the delivery pipe are also prevented.

For the illustrations which are given, I have chosen those, in connection with M.A.N. experiments, which show the results of the various influences. These influences include the variation in the size of the cylinder bore, i.e., the varying water velocity, the employment of hard or soft water respectively, and the use of water with a high salt content.

It is to be noted from the illustrations that

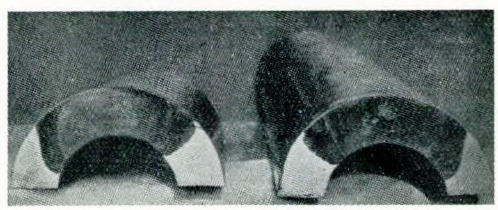


FIG. 8.—Cr V steel. Piston rod fractured surfaces.

with large bores, and therefore low water velocity, the corrosion is definitely more quickly developed and is deeper than with small bores and high water velocity. Corrosion with soft water is more serious than with hard water.

Fig. 5 shows a piston rod of chrome nickel steel with a small bore, in which distinct corrosion marks are to be seen, below which are also small cracks.

As a comparison, Fig. 6 shows a piston rod of Siemens Martin steel with a smaller bore. In spite of the fact that the running time was twice as long, there are no cracks.

The influence of a large bore, and, therefore, low water velocity, is seen in the piston rod illustrated in Fig. 7. The material was chrome vanadium steel. This was a rod which developed cracks after

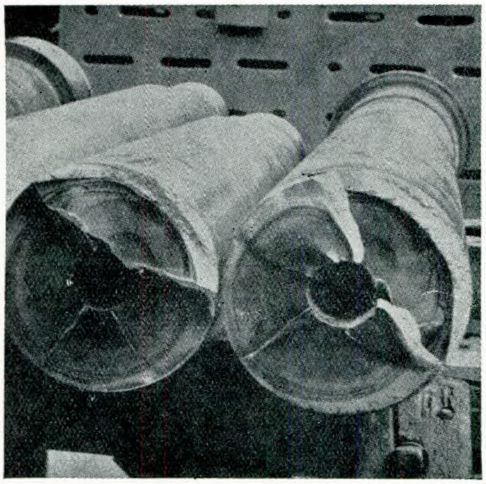


Fig. 9.—S.M. steel. Piston rod fractured surfaces.

a running period of five months. The broken surface is seen in Fig. 8. The fractured surface of a piston rod of Siemens Martin steel (Fig. 9) shows the widely spread cracks.

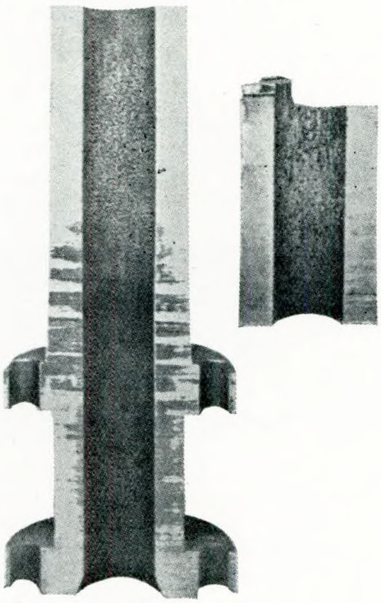


Fig. 10.—S.M. steel. Large bore. Heavy corrosion.

Two examples in which the influence of high and low cooling water velocity is apparent are now shown. The piston rod, of Siemens Martin steel in Fig. 10, with a very large bore, had a running time of only five months. The strongly marked corrosion is visible. It is interesting that these rods were changed for rods of similar material but a smaller bore, and have been running four years without trouble. Nothing was altered in the cooling water system.

The foregoing facts relating to the influence of water velocity are confirmed by experiments on one of the same piston rods (Fig. 11). The material is Siemens Martin steel. In the left illustration

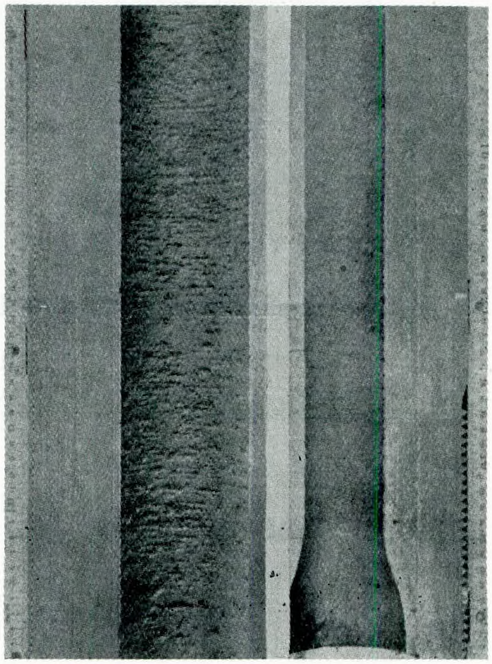


Fig. 11.

Corrosion and cracks. Upper large bore. — No cracks. Lower small bore. — of the same rod.

strong corrosion marks and cracks are noticeable. In the right, with a smaller bore, only light corrosion marks are visible, and no cracks.

With the use of very soft water, definite corrosion was experienced at the end of one year's running time (Fig. 12). The rod illustrated is of Siemens Martin steel. The stress with this rod was about 20 per cent. lower than with the rod illustrated in Fig. 13. Nevertheless, this rod had to work under the same conditions.

The foregoing description mainly deals with the behaviour of alloy steel and Siemens Martin steel in relation to the bore of the piston rod; also the influence of the cooling water velocity and the

Fig. 12.—S.M. steel. Large bore. Heavy corrosion. Influence of soft water.

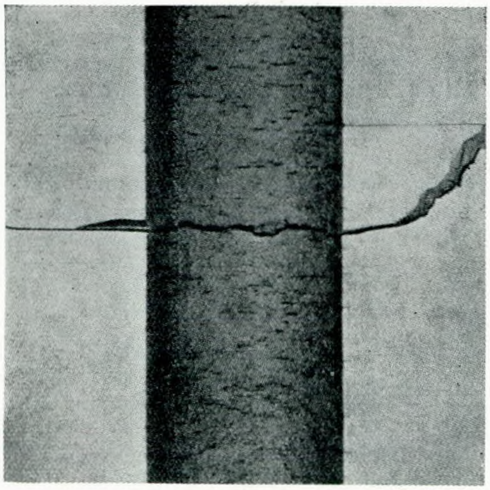


Fig. 13.—S.M. steel. Fracture through high alternating stresses. Corrosion on account of soft water.

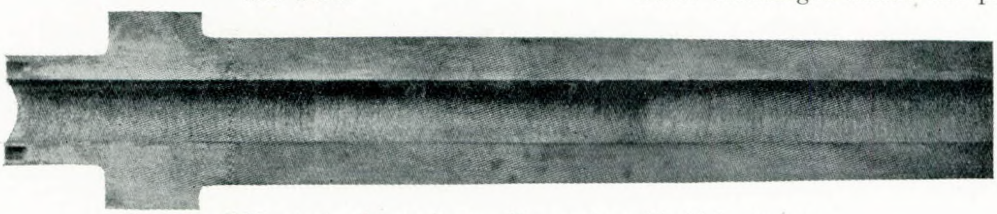


Fig. 14.—S.M. steel. Large bore. No cracks with high stresses.

hardness of the water, and the following details will concern the behaviour of the piston rod at the point of maximum heat stress. Corrosion and cracks are not to be seen in the rod illustrated in Fig. 14, which shows the centre portion of the rod. In the upper and lower parts, however, there were distinct and deep cracks. It is noteworthy that the bore of this rod has increased 3mm. during a period of three years. This has been noted with a number of piston rods of Siemens Martin steel. Despite the strong "washing out", as Fig. 15 shows, there are no cracks within the bore. This bore is also increased with time, actually to the extent of 5mm. in three years. The rod in question was subjected to particularly high heat stresses, since it was burnt on the exterior surface and showed deep cracks.

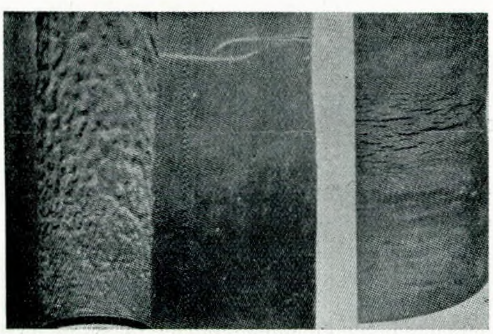


Fig. 15.—S.M. steel. Burnt piston rod. Cracks only on the outside.

The reason for cracks in the piston rod at the point where the junction is formed for the delivery pipe has already been mentioned. It should be added that such cracks occurred after four to five years' running time.

The corrosion marks in a delivery pipe showed that the temperature of the cooling water has a considerable influence upon the extent of the corrosion. This refers to a delivery pipe within the bore of the piston rod. The cooling water was delivered inside the pipe and discharged between the pipe and the piston rod. The corrosion marks on the outside of the steel pipe are much more definite than on the inside. The cooling water in this case contained some salt through passing through a leaky cooler. Even if fresh water cooling is used, the possibility of such corrosion must be reckoned with. This result was the reason for altering the cooling system, so that the cold water was delivered between the piston rod and the inserted pipe, and the warm water discharged inside the pipe, which was made of a corrosion resistant material.

The foregoing experiments, followed through in actual service, show that piston rod failures depend, not solely upon the correct choice of material, but also to a very marked extent upon accurate designing, which, in particular, should prevent corrosive action from taking place.

Limiting Factors in Heat Transfer Apparatus.

By Bernard C. Oldham, F.R.S.A.

"Ice and Cold Storage", February, 1934.

The old proverb concerning the weakest link in the chain is never so true as in the case of heat transfer apparatus, such as the condensers, evaporators, and brine circulating coils of refrigerating plants, where there is an almost unending variety of combinations, and states, of substances to be cooled and heated, and of the wall of tube or plate through which heat transfer takes place. In addition to these three major factors offering varying degrees of resistance to heat transfer, there are the effects of surface conditions on both sides of the heat transfer wall; scale and oil films are *betes noirs* which must be provided for; results of laboratory tests carried out on clean tubes can never be duplicated under working conditions; incrustations and non-condensable gases also play their part in reducing heat transmission.

The student, dabbling for the first time in problems of heat transfer, consults data in reference books giving conductivities of metals, and from these he expects that copper coils need have only a fraction of the surface of iron or steel coils; he is surprised to find that practical engineers make very little, if any difference in this respect. It is, of course, not only the conductivity of the mechanical structure, but the overall coefficient of heat transmission per unit area, temperature difference, and time which matters, taking into account all the factors already mentioned.

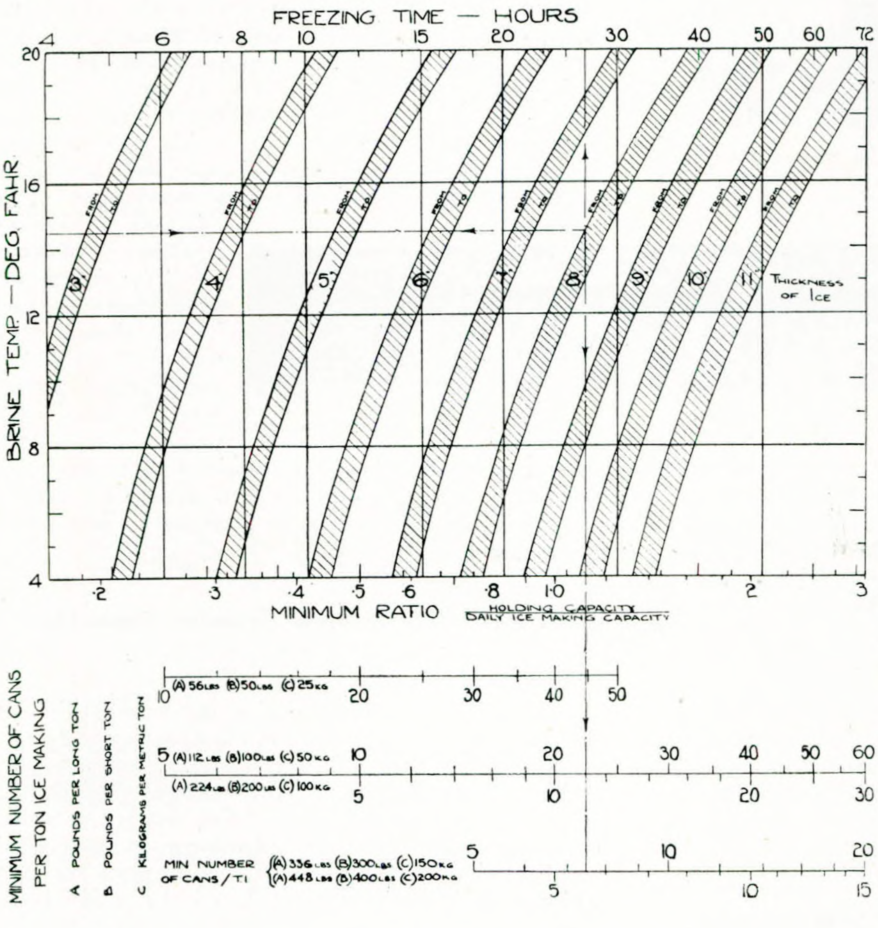
Examples of Limitations.

However good the conductivity of a metal wall may be, it cannot transfer heat from one substance to another at any greater rate than heat can be supplied to and taken from it. This can be compared with the transparency of window glass; the glass in itself offers practically no resistance to the passage of light rays; one side of the window may be so dirty as to obscure the vision; in that contingency, irrespective of how much the other side may be cleaned and however efficient it may be in itself as a conductor of light, it cannot pass any more light than is given to it by the dirty side. The latter is the weak link in the chain of light transmission. Take as a further example, a kettle of water on a gas ring; the supply of heat presented on the outside (the gas side) of the kettle may be unlimited; but heat cannot be taken up by the water inside any faster than the water can take it up; surplus heat passes by unused.

Refrigeration Examples.

Such instances recur throughout the whole field of heat transfer. A cooling medium can never, even under the most favourable conditions, remove any more heat from its side of a tube or plate the substance which is being cooled can put into the other side of that tube or plate. Take, for instance, the cans in an ice-making tank; the thermal conductivity of ice in relation to its latent heat is the all-important limiting factor, and apart from permitting the mean brine temperature to be raised, improved conditions on the brine side of the cans is of small avail; everyone connected with the operation of an ice-making plant knows only too well the disturbing effect of cans freshly filled with water, and the proverbially long time taken to freeze the last of the core. The cans become relatively warm in the process of thawing out the previous batch of ice, and additional heat is added by the supply of water for the new batch. There may be, in the form of sensible heat above the freezing point and in the metal of the cans, 45 B.t.u. eager to discharge through the small portion of the ice can wall accounted for by one pound of ice; apart from the multiplication of heat transfer due to the temporarily high thermal heat, the coefficient, *k*, is for the time being, equivalent to that between circulating brine and water; after the freezing point is reached the thermal heat is practically steady, but *k* not only decreases as soon as a crust of ice forms on the walls of ice can, but continues to decrease as the thickness of ice increases, and the 142 B.t.u. of latent heat are very much slower travellers.

Thus the ability of brine to remove heat from the outside of the ice can is always greater than the ability of the ice can water to pass it to the inside walls of the ice can, and the only benefit to be derived by a scrubbing of the outside of the



ICE MAKING — FREEZING TIMES AND CAN RATIOS ice cans with faster brine circulation is the elimination of local differences in brine temperature between the ice and the brine film on the outside of the cans. The length of freezing time of an individual ice block of a certain thickness must remain directly proportional to the true temperature difference.

Condenser Limitations.

In the case of condensers, the limiting factor is the heat removal ability of the cooling surface, i.e., the water or air side; the conditions on the condensing side can, in general, form a secondary consideration, as all refrigerants are more capable of imparting their latent heat in a condensing film on to a metal wall than either water or air are of removing it from the other side. This is exemplified in two ways. Firstly, the dominating factor in selecting the area of a condenser is the method of heat removal, whether by (1) sensible heat of water (shell and tube, multiple tube, or double pipe condensers), (2) latent heat of water (atmospheric), or (3) sensible heat of air. The general form and standard area of condenser according to these classifications being decided upon, the speed and temperature rise of water or air plays the final part in determining the actual surface of classes (1) and (3); class (2) depends on the prevailing humidity of the ambient air.

Secondly, the surfaces employed for any form of condenser in the case of one refrigerant can be employed almost without modification with other refrigerants, in spite of the great variation in the heat transmission capabilities of individual refrigerants. In reporting upon recent experiments at Karlsruhe, Dr. Linge gives widely varying values, ammonia being the best and CO_2 the worst. Taking water as a standard for comparison, he gives ammonia as 95 per cent. and CO_2 as 38 per cent., with SO_2 and methyl chloride in between. From a reading of his treatise it might appear that a 38-ton CO_2 condenser requires as much surface as a 95-ton ammonia condenser. Practical engineers, however, know that this is not the case, and the explanation of the apparent discrepancy between science and practice doubtless lies in the fact that the laboratory experiments were such as to bring out the characteristics of the refrigerants only, and were not affected by the limiting factors provided on the other side by the water or air.

The ratio of volume of liquid to latent heat plays an important part in the rate of condensation when the condensing surface is restricted. A condensing film transmits heat at a much greater rate than a layer of liquid; therefore, the smaller the volume of liquid for the same number of B.t.u. eliminated, the more effective the condenser. The following is a typical comparison of the volumes of liquid produced with different refrigerants per 1,000 B.t.u. in condensation.

NH_3	... ...	0·053 c. ft.
SO_2	... ...	0·069 c. ft.
CH_3Cl.	... ...	0·107 ,,
F12 (Freon)	...	0·206 ,,
CO_2	... ...	0·44 ,,

Linge gives the same order as the result of the experiments referred to above, and this comparison emphasises the necessity for removing the drops of liquid from the condensing surface as quickly as possible after formation. Subcooling is not possible at the point of condensation, owing to free contact with the vapour space of the condenser, but it takes place where, after collection, the liquid subsequently passes a watercooled surface at a lower temperature. For this reason the vertical shell and tube and the atmospheric types of condensers require separate aftercoolers if subcooling is desired. An overcharged condenser, therefore, produces the well-known symptoms of high gauge reading and high power consumption by reason of restriction of condensing surface, the liquid covered surface being relatively inoperative. The flooded type of condenser which enjoyed a measure of popularity several years ago would therefore appear to be based on unsound principles, quite apart from difficulties in operation.

Evaporator Limitations.

Passing now to evaporators, heat transfer problems are unending owing to the enormous variety of applications of refrigeration. Reference book data on coefficients of heat transfer can only be based on observations under very limited conditions; if considered apart from these conditions they become most confusing, and are, *prima facie*, inaccurate. Manufacturers, therefore, find it essential to carry out tests on each type of evaporator under various conditions. Generally speaking, the major difference in the heat transfer problems of the refrigerant sides of condensers and evaporators is that a condenser has a film continually forming and reforming, and an evaporator has a boiling liquid; the surface of the latter, therefore, is covered partly by liquid (which has a heat transfer characteristic inferior to that of a film) and partly by bubbles of vapour which have a still worse heat transfer. For condenser and evaporator conditions which might appear to be similar, the evaporator has, in consequence, a much lower heat transfer coefficient.

The extent of the boiling action affects the issue according to the evaporating temperature. Although the weight of any one refrigerant evaporated per 1,000 B.t.u. is approximately the same throughout the range of temperatures employed, the bubbles of vapour are smaller at higher temperatures, due to increased density of vapour; at low temperatures the bubbles are much greater in size. Heat transfer from a metal wall to vapour is less than from a metal wall to an agitated liquid, and, in consequence, lower temperatures require larger surfaces in those types of evaporators, such as water or brine coolers, in which the transfer of refrigerant to wall is less than the capabilities on the other side.

In air coolers at temperatures above about 0° F., the weakest link in the chain of heat transmission is the air side of the coils; it is for this reason that air coolers for chill temperatures are frequently fitted with fins or plates, just as in the case of air-cooled condensers, in order to endeavour to bring them nearer the capacity of water cooling or water-cooled coils.

In evaporator systems where the refrigerant side (usually the inside) of coils have more liquid refrigerant in circulation than is in course of evaporation (flooded systems), the heat removal capacity is increased. However, it can readily be seen that, unless the air side is heavily finned, no improvement of importance is likely with air coolers, just as in the case of a dirty window it is useless to clean one side and leave the other obscured. In water or brine coolers or in ice tanks, these flooded systems may be of decided advantage. Pumping of the refrigerant liquid through the evaporators by means of externally operated pumps is in vogue in certain quarters; it is, however, necessary to judge carefully where these may be of value. As pumps require power to operate them, it is obvious that pressure must be applied. Unless wisely used, this pressure may be exerted in such a way as to hamper the suction of the compressor. Washing of evaporator coils by means of liquid pumps requires such large volumes, to be effective, as to be of questionable economy unless the liquid can be fed in at the top of a coil to run by gravity down to a collector header. There are comparatively few layouts which permit this. Assume, for instance, an ice cream hardening room with grid coiling and wall coils and pipe shelves, with 9ft. difference in level between outlet and inlet. If, as is quite usual, it is not possible to arrange a gravity flow, the pressure in the bottom of the coils is increased by at least a 9ft. column of vapour and liquid, or from $1\frac{1}{2}$ to 2lb. difference of pressure. At these low temperature conditions a small difference of pressure is a serious matter, and an incorrectly designed liquid pumping system may easily cause a plant to operate with a suction pressure equivalent to −30° F. in order to pull against a 2lb. pressure column of ammonia for the purpose of actual evaporation at −25° F. In low temperature work, despite heavily frosted coils, the small volume of liquid and relatively large volume of vapour causes the conductivity of the refrigerant to the metal to be the limiting factor, and the use of gravity feed, but not liquid forced feed, can be of decided advantage.

Hydrogen-driven Centrifuge.

1,200,000 r.p.m.

"Journal of Commerce", 19th April, 1934.

At the 14th Exposition of Chemical Industries in New York City, considerable public interest was aroused by an exhibit, in the booth of the Sharples Specialty Company, of a centrifuge that has been operated at a speed of 20,000 revolutions per second, says the "Marine Journal".

This represents a centrifugal force of 7,600,000 times the force of gravity, and a peripheral speed of 1,390 miles per hour. It is said to be the world's fastest rotational speed for any man-made article, without qualification as to type or category.

This ultra centrifuge was designed by Dr. J. W. Beams for the Sharples Specialty Company, makers of Super-Centrifuges, and the unit exhibited contained a number of refinements for which Dr. Beams is responsible, although the basic principle was developed in France as early as 1925 by MM. E. Henriot and E. Huguenard.

The rotor is of conical shape, having a maximum diameter of one centimetre. It is mounted in a cup, also of conical shape, but of slightly different angle, so that the rotor can contact the cup only at its largest diameter. The cone is grooved with a series of flutings and apertures are provided in the cup so that compressed air or gas may be directed against these grooves at such an angle as to cause rotation.

It is obvious that such a speed cannot be attained if there is bearing resistance, and the unique feature of the centrifugal is that the rotor rides entirely on a bearing of gas. The air that is used to cause rotation escapes between the cone and the cup at high velocity and floats the rotor free of any mechanical contact, yet there is an apparent suction that holds the rotor from coming entirely out of the cup even though the entire machine should be inverted.

This principle was first described by Bernoulli, whose equation shows that if the velocity of a stream of gas is increased, its pressure is decreased in such a way as to keep the energy constant. A familiar experiment along this line is as follows: Hold a card against the end of an ordinary wooden spool. Now force air pressure through the hole in the spool so it blows against the card. Although the air pressure will lift the card just out of contact with the spool it will require a considerable pull to get the card entirely away from the spool.

Method of Drive.

The maximum speed so far attained has been developed by the use of hydrogen as a propelling medium, delivered at 160lb. per sq. in. The advantage of hydrogen over air is, first, the velocity of the hydrogen molecule is about three and a half times that of air, and second, hydrogen has about one-half the coefficient of viscosity, which reduces gas friction. The maximum speed attained with air at 140lb. per sq. in. was 12,000 revolutions per second.

Most observers of the centrifugal were sceptical that one could measure speeds of this magnitude, and the first questions were usually as to how this could be done. A number of methods have been utilised. One is to place a magnetised needle in the rotor, which induces alternating current in a pick-up coil. The most satisfactory method, however, is as follows :—

Speed Measurement.

A white spot is painted on the top face of the rotor at a point eccentric to the axis. A light is focussed on this spot. A mirror is located in a position where it can reflect the image of the white spot into a telescope placed horizontally. The mirror is rotated at a fixed speed. The rotation of the mirror makes each recurring image of the spot appear at a different point in the telescopic field.

The speed of the rotor can be accurately determined by measuring the distance between two successive images of the spot, finding what arc of the mirror rotation this distance represents, and computing the unknown speed of the rotor from the known speed of the mirror. A graphic illustration of the amount of centrifugal force generated is the fact that frequently the paint spot will be thrown off before the rotor reaches full speed.

The high-speed rotor is not entirely a toy. Some extremely difficult centrifugal separations have been accomplished in units of this type, made in larger sizes and hollowed out to afford a recess for the liquid.

Water Hammer Again.

"The Engineer", 27th April, 1934.

Despite the accumulation of knowledge, water-hammer is still a potential danger in steam pipe installations. The causes and nature of the action are now fairly completely understood, and the possibilities of its occurrence have been appreciated since Stromeyer wrote his Reports to the Manchester Steam Users Association in 1908 and 1909. In those Reports he estimated that possibly 25 per cent. of all steam pipes were so arranged that water-hammer might at some time occur in them, and in a remarkable table in the second Report he recorded fifty-five cases, between 1889 and 1908, in which failures were caused by the draining of steam pipes. If the latter Report has been forgotten by engineers of the present day, they may be earnestly advised to re-examine it, for as long as steam must be conveyed in pipes the danger that water-hammer may occur will always exist. On shore it is generally easy so to arrange the steam pipes that an accumulation of water is impossible, and if additions were never made to existing mains and connections without sufficient experience or knowledge, failure from this cause ought never to occur. But at sea the case is different. The restriction of space renders the arrangement of steam pipes difficult, and unless continual vigilance is exercised a condition favourable to water-hammer may be allowed to occur. And when an accident of the kind does happen in an engine-room or stokehold the casualties are nearly always severe, owing to the inability of the men to escape rapidly.

A deplorable accident of the kind happened on s.s. "City of Cairo" in the Mediterranean in November, 1933, and is the subject of a Board of Trade Report just issued. The "City of Cairo" was built and engined by Earle's Shipbuilding and Engineering Company, Ltd., in 1915. She has a single set of quadruple-expansion engines, which are supplied with steam at 225lb. by three main Scotch boilers and one auxiliary boiler of the same type, but a little smaller. This third boiler is connected to the main steam pipe by steam pipes and stop valves. It provides saturated steam only, but superheaters are fitted to the main boilers. In May, 1929, ordinary voyage repairs were executed and new superheaters fitted by Cammell Laird & Co., Ltd. In order to be able to de-superheat, if necessary, a new connection was made to the auxiliary boiler, but as a matter of fact it was found so unnecessary that it has now been removed. For this connection a tee piece on the 4½in. pipe connecting the auxiliary with the main boilers was provided with a 3in. branch for admitting saturated steam to the superheated supply. At the same time a new 4½in. steel steam pipe was supplied. It bends at an easy radius through 90 deg. from the tee piece, then has a large expansion bend, and finally joins the main stop valves at a good angle. It will be seen that there is no question of its flexibility. In fact, it would be described as a good example of ships' pipe work. It must also be observed that only in a very remote contingency could the tee piece be subjected to high-temperature steam. Yet the tee piece was specified to be cast steel and would have been of that material had not it been decided to employ cast iron in order to save time. The scantling was altered to suit the weaker material and the piece was duly fitted. It caused the accident by breaking through the 4½in. neck on the boiler side. High-pressure steam then flowed rapidly into the boiler-room, killing several men and injuring others. There is, however, no question that cast iron was a suitable material and no one can be blamed for using it. It failed only because it happened to be the weak link in the chain. It is to the history of the steam pipe that we must look for further elucidation. In September 26th the stop valves chest on the auxiliary boiler cracked "through its auxiliary steam outlet part and through its cover". Fortunately, no harm resulted. A new chest was fitted in Hamburg. A year later the pipe again gave trouble and part of it was renewed. In March, 1932, the new part split in two places "on opening one of the main boiler stop valves whilst the pipe on the forward (auxiliary) boiler was full of water". It now appears that Cammell Laird & Co., Ltd., "were not aware of the history of the failures in this auxiliary steam line, and in this case they were simply carrying out alterations ordered by the owners; but if they had been made aware of the history of this pipe and its connections, or even if they had been induced to look into the design of the pipe line and advise upon the general effect of fitting tee pieces and other fittings as proposed, it is quite possible that they would have suggested a special form of casting for the position in which the one in question was placed". We may presume that the B.O.T. Commissioners have informed themselves on this point, but we may say that as far as examination of the drawings given in the Report will permit, the pipe arrangement does not appear to be unsatisfactory. In the opinion of the Commissioners a specially designed piece was desirable, or, alternatively, the forward end of the pipe should have been anchored to "take the strain caused by racking or bending". Presuming that the pipe was adequately slung—it was about 28ft. long—the drawings do not show any necessity for a special arrangement. We may add that if, as the Commissioners state without argument, the failure was "undoubtedly due to water-hammer action", the defect would not have been cured by fitting a specially designed piece or anchoring it. The only right course would be to remove the cause of the water-hammer. If that had been done—always accepting the Commissioners' explanation—the pipe and its connections would have been quite appropriate to the service. We may add that an inspection of the drawing seems to indicate that arrangements for draining the steam pipes was in accordance with good practice.

It has been necessary to repeat this rather long story in order to lead up to what may be regarded as the principal aspect of the Report. It is that the Board of Trade was not informed about the earlier mishaps. In the view of the Commissioners the failures of 1926 and 1932 were explosions within the meaning of the Act and ought to have been reported. They complain that the Board of Trade "could not do their duty efficiently unless they were kept informed of all that was going on", express a desire for "better *liaison* between the Board, shipowners, and ship repairers", and venture to hope that this case "will result in engineers becoming better informed in regard to the possibilities of serious explosions resulting from water-hammer action, nearly all of which are preventable if proper precautions are observed". We are surprised that such an observation should be called for at the present day, for it might be reasonably supposed that the veriest beginner in the operation of steam plant was now familiar with the danger associated with water-hammer, and that in steamships, and particularly passenger vessels, the engine-room staff is taught the steps that must be taken to avoid it. With regard to the reporting of accidents, we suppose the Board of Trade has it in its power to see that failures of steam pipes are brought to its notice, since other accidents frequently of a less dangerous nature are now reported to it. But marine superintendents cannot be expected to exhibit any anxiety to disclose mishaps and may not unjustly claim that, being men of experience, they are capable of taking the right steps, on their own initiative, to prevent the recurrence of failures. In conclusion we may echo an opinion expressed by Stromeyer many years ago. The published Report would be more instructive to engineers if it were more technical. It may warn, and we trust it will warn, marine engineers to pay ever closer attention to steam hammer. But the evidence that steam-hammer was the cause of the failures of the pipe is not given, and an impressive opportunity for demonstrating how accidents of the kind are brought about is missed.

Boiler-scaling Plant.

"Shipbuilding and Shipping Record", 26th April, 1934.

In considering the design of boiler-scaling plant there is, perhaps, rather too great a tendency to consider only the actual cutter and not the motor which drives it or the shaft connecting the two. This certainly cannot be said regarding an improved design of boiler-scaling unit which has just been placed on the market by a Liverpool firm. The unit comprises an electric motor which with its control gear is mounted on a trolley, the motor end of the flexible shaft being supported by a bracket, secured at the end of the trolley, carrying a floating roller bearing which compensates for any difference in the degree of flexibility in the shaft and its casing and also for any stretch that may develop in the latter after it has been in service for some time. But the most important feature of the unit is the provision of push-button control in conjunction with a contactor-type starter. Thus, instead of having to take the motor inside the boiler or combustion chamber as the case may be, or, with heavier equipment, having a labourer standing by the motor, it is only necessary to take the control box, which measures 3in. by 3in. by 2in., and the operator has both the cutting head and the driving motor under his immediate control. The plugs and sockets are of the water-tight pattern and the motor and trolley are earthed through the extra core in the supply cable.

The late Sir JAMES KNOTT, Bt. (Past-President).

Photograph by BARRETT'S PHOTO PRESS, LTD.

OBITUARY.—The late Sir JAMES KNOTT, Bt. (Past-President).

It is with regret that the death is announced of Sir James Knott, Bart. (Past-President), which occurred at his home in Jersey on Friday, June 8th, 1934, after a short illness.

Sir James Knott was born at Howdon-on-Tyne in 1855. On leaving school at the age of 14½ he entered the office of a shipbroker at Newcastle-on-Tyne. When only 20 he struck out on his own account and acted as broker for the Whitby and Robin Hood's Bay shipowners. Two years later he bought his first ship, the "Pearl", a brig of Scarborough, for £198. This small vessel formed the nucleus of a fleet of nearly 40 vessels which he acquired in the course of a few years at a time when the purchase value of sailing vessels was depreciating because of the advent of machinery as the motive power. The vessels were placed in various trades and success crowned his efforts.

In 1881 a change was made from sail to steam, when the "Saxon Prince" was built—a steamer which, it is recorded, was launched on a Friday, started away on a Good Friday, and finished a year's work on a Friday—and yielded a return of 40 per cent. She carried 1,250 tons and was fitted with compound engines.

Four years after the building of the "Saxon Prince" Mr. Knott turned his attention to law, and was called to the Bar at Gray's Inn in 1889. He practised for a time, but then decided to devote the whole of his time to commercial pursuits. He built many more vessels of the type of the "Saxon Prince", practically all being tramps, until in 1895 the policy of placing the steamers on regular lines was inaugurated. Services were eventually maintained by a fleet of 43 vessels to the River Plate, Brazil, South Africa, China, Japan and the Mediterranean, and also from the Mediterranean to New York in the passenger and emigrant services.

His early experiences in shipowning and the changes which he saw during the first part of his career as a shipowner were recounted by Mr. Knott in his presidential address before The Institute at Stratford—at that time the headquarters of The Institute—in 1907. Mr. Knott was elected President in that year and was succeeded by the late Mr. James Denny. In his address he characterised the changes which had occurred in his then 30 years' experience as "almost incredible". His life, he said, had been spent on the banks of the Tyne, and he could still see in his mind's eye the fleets of sailing ships arriving and sailing with the fair winds. At that time one saw a steamer only occasionally. In the first period of his shipowning, he recalled that while there were still large numbers of sailing ships, steamers were beginning to make their presence felt, and compound engines were the great engines of that time.

Sir James Knott—he was created a baronet in 1917—gave up shipowning in 1916, when the Prince Line was bought by Furness, Withy & Co., Ltd. He lost two sons during the war, and it was generally believed that his retirement from business was the result of his bereavements. Sir James was at one time keenly interested in politics. He contested Tyneside in 1906, and in 1910 was returned in the Conservative interest for Sunderland. He was a Knight of Grace of the Order of St. John of Jerusalem in England.