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Notes on The Care and Maintenance of the Solid Injection Diesel Engine.

BY MR. DAVID P. PEEL (Member).

READ

Tuesday, December 23, *at* 6.30.

CHAIRMAN: MR. B. P. FIELDEN (Chairman of Council).

The CHAIRMAN: To-night we have a paper by Mr. Peel on the "Care and Maintenance of the Solid Injection Diesel Engine," but as the author cannot be present Mr. Adamson will read it, and as both this paper and Mr. Baxter's on "The Development of the Internal Combustion Engine" deal with oil engines they can be discussed together.

THE following consists of some notes, based on the writer's experience with the Vickers' Solid Injection Submarine Diesel Engine. The different points will be taken in the following order:—

1, Smoking; 2, Knocking in the Cylinders; 3, Bearing Lubrication; 4, Cylinder Lubrication; 5, The Governor; 6, Water Cooling; 7, Fuel; 8, Setting Sprayer Valves; 9, Diagram of Operations.

Smoking.—There is no doubt that one of the greatest evils to contend with in this class of engine is smoking, the causes of which may be noted as leading to white or black smoke, the latter being more in evidence.

White Smoke is caused by too much air, and is easily stopped by partly closing the air inlets or louvres in the air supply trunks.

Black Smoke is more troublesome, as it may be caused in so many different ways, and consequently much more difficult to locate the cause. It may be due to one or other of the following:—

(1) Too much lubricating oil supplied to the cylinders. When this occurs there is a tendency for the oil to deposit on the piston head, where, owing to the heat of compression it partially vaporises, and the cylinder already having had its full charge of fuel thus the added vapour being unconsumed passes through the exhaust as thick black smoke. The remedy for this is to cut down the lubricating oil carefully to the lowest point of safety.

(2) Where insufficient air is supplied to the cylinders the burning mixture will not be in the correct proportion for complete combustion when the fuel is injected, with the result that a certain quantity of fuel, although vaporised, cannot be burnt and is passed off through the exhaust as black smoke. One cause of this may be the throttling of the air supply by the louvres, or again, the passage of air may be restricted thus:—

Where there are sharp bends in the air line, any dirt or dust, which may be drawn in with the induction, tends to lodge in these bends and, in time, forms a bar to the ingress of the air, as in Fig. 1; and thus, the effective area of the inlet pipe is materially reduced.

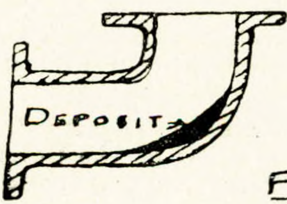


FIG. 1.

This trouble is particularly prevalent where a pipe is led from the crank pits to the induction line, for the purpose of clearing the pits of any accumulation of explosive gas which may be generated by the running heat tending to vaporise the lubricating oil.

The air drawn in this way is generally of a greasy nature, and so assists to coat the pipes with dust which would otherwise pass right through the engine.

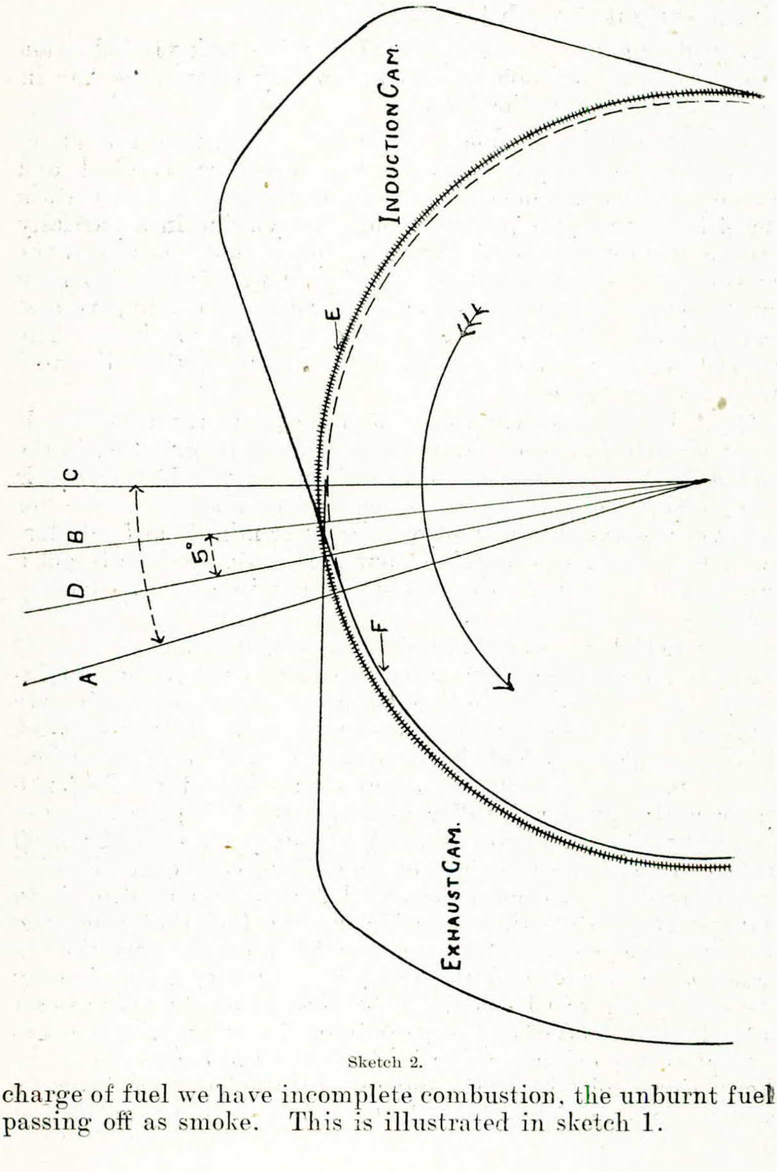
A grid or gauze is usually fitted in this crank pit induction pipe, but it is not sufficient to thoroughly cleanse the air in its passage through the inlet.

(3) If the fuel injection pressure is too low, then the oil, in its passage through the sprayer is not properly pulverised, and so, not in a condition to burn readily, consequently a certain quantity of fuel just passes through the engine in a partially vaporised state, and is discharged as black smoke, so also if the pressure is too high a larger quantity of fuel is injected than can be burnt, with the same result. The pressure to give best results is about 3,000 lbs. to 3,500 lbs. per square inch. The correct pressure is obtained by adjusting the lift of the fuel pump suction valve.

(4) A leaking sprayer valve has practically the same result as too high fuel pressure, and can be rectified by grinding in the fuel valve. The best grinding mixture for this purpose is smooth carborundum paste. When testing a sprayer valve for leakage, a maximum leak of one drop per minute at 5,000 lbs. per square inch is permissible, but it is quite possible to get a valve tighter, still within this limit, it will give satisfactory ning.

(5) The following has been cited to me also as a cause:—"If the maker's clearances were altered in the adjustment of the induction and exhaust valve lever push rods, there is a liability to smoking," but no reason was assigned. I investigated this on the engine I had charge of, and came to the conclusion, which may be open to argument:—that the clearance between the push rod roller and cam on this gear averages 30/1000 to 35/1000, supposing these valves are set at 20/1000 instead, so as to reduce clash of gear, then, each cam will pick up the push rod so many degrees before time and drop it so many degrees after time, considering the fact that when the rods are set at correct clearance, the difference between the exhaust valve closing and the induction valve opening, is only five degrees, it will be easily understood when the rods are set at 20/1000 instead of 30/1000 the induction valve will be opening before the exhaust valve is shut, and the engine being on the suction stroke, a certain amount of the exhaust gas is drawn back into the cylinders (Sketch 2), and being unfit for further

combustion, occupies space in the cylinder that ought to be filled with pure air, and as the cylinder is still getting its full



Sketch 2.

charge of fuel we have incomplete combustion, the unburnt fuel passing off as smoke. This is illustrated in sketch 1.

Circle E, is the clearance exaggerated with the radial line D, marking on the clearance circle the point where the exhaust valve should shut, and the line B marking where the induction valve should open. If we cut down the clearance until the roller is on the line F, instead of the induction valve starting to open at B, it is starting to open at A, while the exhaust valve has still to go from A to C to shut.

Knocking in the Cylinders.—At times we may hear alarming knocks in the engine due to one or other of the following causes:—

(1) The packing of the sprayer valve may become hard and tight, gripping the spindles so that it cannot return to its seat after being raised by the cam, thus supplying fuel to the cylinder all the cycle. This will not do any damage on the exhaust and induction strokes, but on the compression stroke, the charge is fired immediately the flash point is reached, the result being an enormous premature explosion as this point is reached some time before the proper fuel injection time. This explosion puts a severe strain on the engine, not only towards reversing the direction of rotation against the normal, but also endangering the cylinder cover. The defective cylinder must be immediately cut off, before serious damage is done, then slack back the gland of the sprayer valve, and get free movement on the spindle, after which the cylinder may be reinstated. Sometimes it is not necessary to overhaul the gland, as a few minutes idle running without the oil pressure in the gland will correct the trouble.

(2) The weakening of the sprayer valve spring will give similar trouble, as when the valve is lifted by the cam, the oil pressure in the sprayer acting on the under side of the valve will not allow the valve to return to its seat, the pressure of the oil being greater than that of the spring in its weakened condition. The remedy is to increase the compression of the spring, or fit a new one. In the former case care must be taken not to choke the spring as the valve gear might be damaged by too much compression.

(3) Where the engine is so designed that when the exhaust and induction valves are full open, these project into the cylinder within the stroke of the piston and there is sometimes trouble owing to a deposit of carbon forming on the exhaust valve spindle, thus the spindle becomes so stiff in the bush that the spring is unable to return the valve to its seat after being

opened, and the valve head is struck by the piston on reaching the end of the stroke, and knocked violently to its seat. A little paraffin placed around the valve spindle will free it from the deposit and overcome this trouble. Fuel will suffice if paraffin is unobtainable; on no account must lubricating oil be used, as this aggravates the trouble. A weak spring is another cause of this knocking, making the action of the valve too slow.

(4) Too liberal cylinder lubrication is another source of mischief, as a certain quantity of the oil strays past the piston, and is vaporised and fired with the charge, causing a severe explosion.

Lubrication (*Bearing*).—Any engineer will readily understand the vital importance of efficient lubrication, as a high-speed Diesel engine will not run many minutes if the lubricating system fails. The engineer ought to know the system so well that he can locate a fault at once, and perhaps save stoppage of the engine. By knowledge and study an engineer is often able to detect a coming fault and anticipate it. In the bearing oil system there are usually three sets of strainers, and two gauges, one strainer in the end of the crank pit strains the oil on its return to the oil drain tank. A second is in the oil pump suction line between the tank and the pump suction valves. A third is on the delivery side of the pump to the engine. One gauge is combined pressure and vacuum, and is tapped off the line between the suction strainers and the pump. The other gauge, pressure only, is tapped off the line between the discharge strainers and the engine. By observation of these gauges and a knowledge of where they are tapped from, one can tell what is happening at any point of the oil system. As for instance, knowing there is plenty of oil in the drain tank, on seeing both gauges register below normal, one may conclude the drain tank strainer is fouling, and immediately take steps to clear it. Should the vacuum gauge show higher than normal while the discharge pressure remains correct, then the suction strainers are becoming clogged, and it so follows, if the vacuum gauge is normal and the pressure is low, then the discharge strainers require attention. If both gauges show low and all strainers have been cleaned, then sound the oil drain tank, as a quantity of oil may have been lost through leakage. Some engines are fitted with a valve on the drain tank strainer, to trap the oil in the crank pit that the drain tank may be cleaned. This valve is apt to be overlooked when starting up, and after a few minutes running the oil pressure falls to zero as the drain tank is emptied into the crank pit; this may lead to shutting down the engine if the engineer is not immediately able to trace the cause of the loss.

Cylinder Lubrication.—There are many methods of cylinder lubrication, two of which I will deal with.

(1) Where a separate small pump is fitted for each cylinder and actuated by a small cam on a roller let into the ram head. The cam forces the ram down on the pressure stroke, a spring returning it on the suction stroke. According to the number of cylinders, so are the pumps arranged to work by suitable means from the main cam shaft. With these pumps the main trouble is the breaking of the return springs, in which event the ram remains at the bottom of the stroke. The pump is so fitted that a spring may be renewed whilst the engine is running. This class of pump requires a good deal of attention as the valves are so small that the slightest particle of grit on the seat will put the pump out of action.

(2) An ordinary rotary cog pump may be fitted to supply oil to the cylinders, through sight-feed lubricators fitted on each one and practically the only trouble is the side wear of the cogs with consequent diminution of pressure.

The Governor.—In some classes of governored engines, where all the cylinder heads are coupled solid with each other and the governor is fitted on the end of the engine, supported by the end cylinder—I have found that owing to the unequal expansion of the cylinder tops relatively to the bedplate when the running heat is attained, the governor shaft, if driven off the main shaft by bevel gearing, is liable to be thrown out of line, causing jambing of the bevel wheels, and gripping of the governor shaft in its bearings, resulting in damage to the bevel wheels and excessive overheating of the bearings. This may be overcome by scraping the bearings on the angle sufficient to allow for free movement when the engine is hot. This trouble is not experienced where the governor is in the centre of the engine and where the cylinders are quite separate.

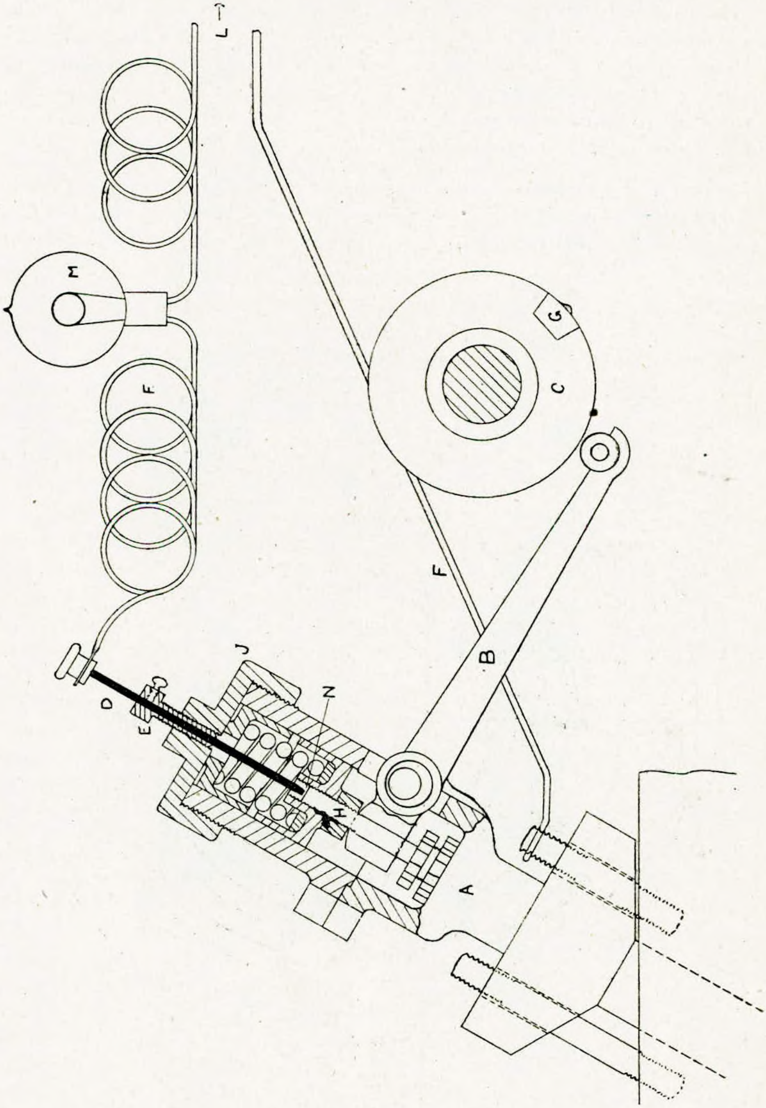
The Water Cooling arrangement gives little or no trouble, but as a precaution in case of a leak into a cylinder, it is advisable before starting to turn the engine at least two complete revolutions by hand, or dead slow on compressed air, with all explosion cocks open, to see that all cylinders are clear. If water issues from an explosion cock, turning by hand will effect the desired end. No attempt should be made to start while there is the slightest suspicion of water or when the water system is charged with air, as there is a possibility of steam locks forming and stopping the flow of cooling water which must be guarded against.

Fuel.—In the case of marine Diesel engines there is a possibility of getting water into the fuel tanks owing to the straining of the ship's plating in bad weather. It is best to keep a sharp eye on the gauge glass of the fuel gravity tank, and if any water shows, open the drain cock at once; this will assist to keep the water below the level of the engine supply pipe, which is fitted well up the tank, just long enough to charge into another tank, after which the first must be cleaned.

Timing Sprayer Valves.—There are two methods of setting the sprayer valves:—

(1) Disconnect the fuel supply pipe to the sprayer valve, and then connect a flexible hose to the air starting bottles. Take out the explosion cock and turn the air pressure to the sprayer valve. When trying No. 1 sprayer engine fully retarded, that is, starting to open 4° before the top centre, have the engine turned by hand in the direction of rotation dead slow, listen at the explosion cock hole, and the instant the sprayer valve is heard to blow cease turning, and note on the flywheel graduations the number of degrees between the mark on the flywheel top centre No. 1 and the pointer fixed on the frame marked top dead centre, this number of degrees should tally with the 4°, if not, the toe piece on the sprayer valve cam must be moved forward or backward as the case requires, and the process gone through again until the correct point is attained.

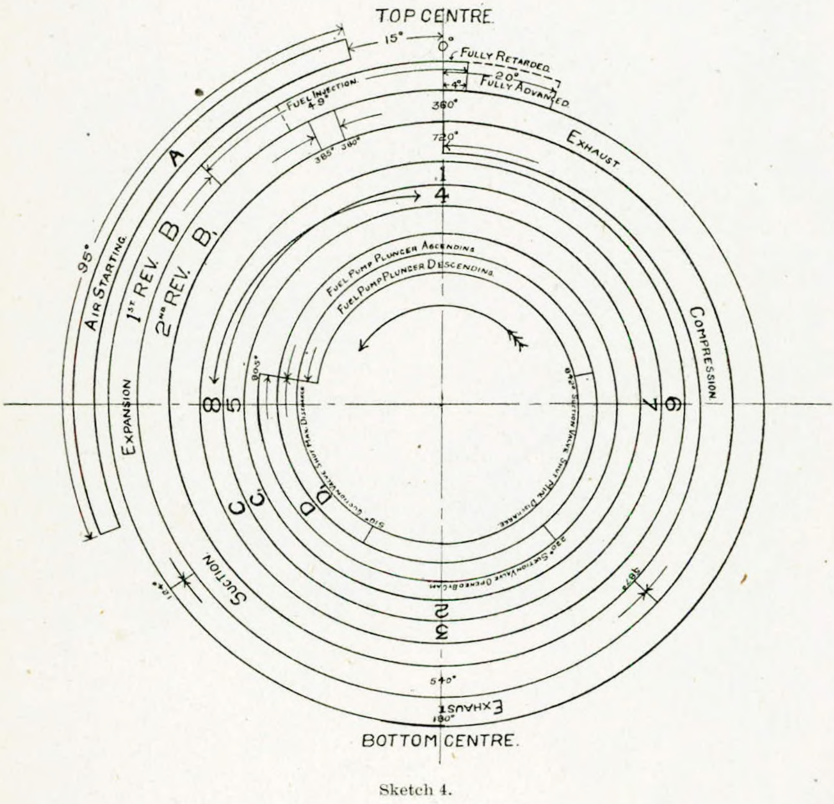
(2) Sketch 3 illustrates where A is the sprayer valve complete, B is the actuating lever, and C the cam with toe piece G; H is the valve spindle. The brass rod D is led through the cap J and insulated from it with the sleeve E made of non-conducting material, and screwed through the cap for fine adjustment. The rod D is set as close to the spindle H as possible without allowing an electric current to jump the gap. An electric wire F is led from the rod D and from the body of the valve to a lighting circuit or battery, with the lamp M in the circuit. The circuit is now complete except for the gap N. Let the engine now be turned by hand dead slow, and as soon as the toe piece G picks up the roller on the lever B the gap N will be



Sketch 3.

closed and the circuit completed, lighting the lamp M, then the flywheel graduations are noted as previously with the air. The disadvantage of the first system is the loss of starting air; the second is not so accurate, as the valve has to be raised a certain amount to close the gap before the lamp will light, when one degree or perhaps two will not be recorded.

Sketch 4 comprises a diagram of: A, Air starting. B B Running cycle. C C_1, Sequence of firing D D_1, Cycle of fuel pump of Vickers 100 h.p. unit engine with eight cylinders.



Sketch 4.

DISCUSSION.

The Chairman: Many ships are now burning oil instead of coal to generate steam, but when one considers that the consumption of oil to do this is about three times the amount required for an equivalent horse-power developed in an internal combustion engine it is reasonable to conclude that the number of such engines used in the future will increase.

Owing to saving in weight of machinery but principally owing to the lesser weight of fuel to be carried for an equal distance travelled, a ship can carry considerably more cargo when fitted with internal combustion engines, and this is another reason why this type of engine is bound to be developed in the future.

At the present time there is a limit of size for oil engines, but this I believe will be increased. We are apt to compare oil engines which are in a state of development with steam engines which are the result of many years' experience. There were plenty of troubles with steam machinery and we still have a few, and we must expect to have others whilst progressing with the oil engine. The solving of difficulties and avoidance of the cause of these in future designs are factors which assist us to improve.

I shall be glad to know whether there is any limit of size of the cylinder to which can be fitted solid injection of fuel, because we would like to dispense with air compressors for Diesel engines, but I suppose we will have to retain the compressors for making sufficient air under pressure to start or manœuvre the engines. We have found that the majority of difficulties occur whilst the engines are being manœuvred in or out of ports and there is a possible solution of this difficulty by the adoption of the scheme proposed by Captain Durtnall, who recently read a paper on "Electrification of Ships." If the Diesel engine was coupled electrically to the propeller's shaft we could leave the engine running after stopping the propeller. Electrification also appears to be one way of increasing the horse-power by Diesel engines. For example we might have four Diesel engines each developing 5,000 h.p. with two coupled to each propeller shaft of a twin-screw ship.

In regard to cylinder lubrication it is now common practice to cool the pistons of marine sets with water rather than with oil. We commenced with oil-cooled pistons, and with the bottoms of the cylinders open to the crank case, but we found the consumption of lubricating oil heavy through carbonisation; later we had distance pieces fitted between the crank case and the cylinders and now the pistons are water-cooled and the under sides of these are open to the engine room so that it is known immediately when a piston is leaking. Each cylinder has its own sight feed lubricator.

Marine Engineers will be indebted to oil engine designers if they will give us more accessibility. We do not like having to take part after part away before we get to the one we desire to adjust or overhaul. Simplicity for overhaul saves time and money.

We owe our thanks to Messrs. Baxter and Peel for placing before us their experiences of oil engines, and from which, I feel sure many of our members will benefit.

Mr. Adamson then read the following communication:—

Mr. Stephen H. Terry: In his "Development of the Internal Combustion Engine" Mr. Baxter, on page 449, when dealing with the starting problem, refers to the automobile practice of turning the fly-wheel by means of an electric motor supplied with current from an accumulator. It is true that this system generally works fairly well on land, but it has two inherent drawbacks, the one, mechanical, the other, electric. The mechanical drawback is one of construction, the motor being necessarily small for purposes of economy in weight and cost, has to revolve at high speed to give out sufficient torque to crank the engine, consequently the ratio of pinion to gear wheel must be high, thus necessitating a fine pitch of teeth, if more than one of them is to be in gear, thus we get a flywheel with a number of very fine teeth on its periphery, in a position subject to damage. There is also the certainty that the spaces between the roots of the teeth in the wheel may become choked with dirt and dry grease, absorbing so much power that the motor fails to attain the speed necessary for firing the charge, under these conditions short circuiting will probably take place and the battery be rapidly discharged, it being then necessary to resort to hand cranking, meanwhile the battery is partially run down, and is not efficient for lights or horn or for sparking (if the battery system be fitted for this). The above are some of the serious objections to electric starting gear in the closed-in bonnet of a motor car. On board ship and more especially in half-open and open-boats they are accentuated, and in the open boats there is the further risk of failure from water damaging the circuits and terminals.

From the above it seems clear that the more compressed air can be utilised for starting and reversing the better for efficiency. The absolute certainity that the desired movement of the propeller can be obtained as, and when, required, is of paramount importance on board ship. Reservoirs containing compressed air have been in use in oil engines for probably more than 20 years. I used them in some 25 B.H.P. Hornsby-Ackroyd oil engines installed as power and lighting plant, at Polesden Lacey, then the property of the late Sir Clinton Dawkins in 1903. The installation in duplicate was fully described in *The Engineer* in 1907, Vol. 103, under the heading of "The Engineering of a Country House." These engines, after warming up with a lamp, when stopped in a proper position, were started without any other help, by turning on the compressed air from the reservoir; the reservoir was made in Antwerp, and arrived charged to 150 lbs. Pressure was maintained by a small air pump worked by the engines when required. On a vessel it would be necessary to provide an efficient hand-pump as an additional precaution, such pump if on the triple compression system with three cylinders as made by Messrs. Hatterley and Davidson, Sheffield, for tyre purposes, is easy to work.

In regard to silencing I have found that the gradual increase of the diameter of the successive lengths of the exhaust pipe effects this. On board ship the weight precludes any great length of pipe, but I believe something might be done on the principle of the musical instrument known as ophicleide. A pipe increasing continuously in diameter is curved into one or more circles. On board ship these coils must lie in a horizontal plane to avoid water trap. The same coil system, if adopted on the petrol pipe leading from the distant tank to the engine, would probably prevent the fracture of such pipe from vibration, it also provides for expansion and contraction. Mr. Sopwith, to whom I recently suggested it, told me that he has used it for petrol pipes for several years with complete success in his aeroplanes.

In regard to fuel economy, much can be done by the utilisation of some of the heat in the exhaust gases. Four years since I fitted to the engines of my Overland car an air-heater of my own design. A concentric sheet steel casing fits over the horizontal length of the exhaust pipe form end to end, this casing is hinged at the top for easy fitting, nearly airtight over each of the four exhaust duct branches, a further casing is fitted to the exhaust pipe after its downward bend, the concentric casings thus formed communicate with the induction pipe a few inches above the carburettor, so as not to heat it. A plug cock controlled from the steering pillar regulates the supply of hot air which attains a temperature of 400° F., raising the temperature of the whole mixed vapour by over 100 degrees.

This apparatus was covered by a patent I took out in 1894, it increased my mileage per gallon from 15 to over 18, even on our bad roads. I can go up most hills on top speed, and sparking-plug troubles have ceased, for it is easy to secure a reducing flame, by which all carbon deposits are burnt off, if they form; it appears that this arrangement, wherever possible, would be equally efficient in marine motors. I have found in heavy sea-fogs near the coast that the turning on of the hot-air cock, immediately gave results as good as on the driest day in summer. It is now always in use, and has caused no trouble with lubrication from the highest temperature of combustion (if the heaviest oil such as the Vacuum Co's B be used) the apparatus does for the internal engine what feed heating and superheating do for the steam engine. The cost in my case was £2 10s. out of pocket, and my own time fitting it on and making the link and lever connections.

Mr. P. H. Smith: I have not an intimate acquaintance with the solid injection engine as described by Mr. Peel, but can claim to possess considerable knowledge of the Diesel engine as applied to German submarines. I think the solid injection engine is unlikely to be a commercial success except possibly in small sizes. Undoubtedly its system of securing pulverisation of the fuel is highly efficient but there is an absence of turbulence. The oil is injected into the cylinder and remains more or less stationary in the combustion space. This militates against the attainment of a high M.E.P. with reasonably moderate maximum cylinder pressure and good combustion. On the other hand in the Diesel engine, the fuel injection into the cylinder is followed by a blast of air which swirls the fuel in the combustion space, ensuring close inter-mixing of fuel and air, admitting of a bigger output per unit of cylinder capacity. That is the difference between the solid injection engine as used in British submarines during the war, and the pure Diesel as adopted by Germany.

Apparently at the commencement of the war, there were five or six different makers supplying Diesel engines to the German Admiralty. Towards the end of the war it would appear that Germany relied entirely on two makers only, namely, Krupp for two-stroke engines and M.A.N. for four-stroke units. The two-stroke machines appear to have been favoured mainly for short radius of action, *e.g.*, work in the North Sea and Mediterranean and reliance was placed on the four-stroke boats for a more extended radius of action. The former are lighter, power for power, and the earlier units were constructed largely of manganese bronze and aluminium in place of cast iron, though as the war progressed there is ample evidence supplied of Germany's shortage of these materials because cast steel replaces manganese bronze crank cases and frames in the later two stroke units.

The four-stroke units throughout the war were mainly constructed of cast steel and as the war progressed one surveys with interest the efforts made by the Germans to secure a greater horse-power per unit of cylinder volume. Thus, in the latest designs two fuel valves per cylinder are employed to augment the M.E.P. and pistons so small as 15in. bore are oil cooled. Likewise, in the larger units, main bearings are cooled to admit of running the sets at the very high piston speed of 1,300 feet a minute. There is evidence to show that engines were not often run at this terrific speed, and probably the Germans only resorted to it in time of dire emergency.

There is a marked difference between English and German practice of building the engine into the hull. In the English submarines the hull is made virtually part and parcel of the engine and the latter cannot easily be dissociated from the hull. In the German boats the engine is quite a self-contained unit with a substantial bedplate bolted down to suitable joists in the hull. It has therefore been possible to remove German engines from the boat and apply them industrially for land work, and I very much doubt if it will be commercially feasible to apply English engines similarly.

During the year 1919 my firm has taken out 40 or 50 German engines and are engaged on the erection of a large number for generating electricity. The experience so gained convinces me that in the four years of the war Germany advanced Diesel engine design more than would have been accomplished in 20 years of peace. One of these sets in particular appears to have been used experimentally, for there were a number of devices fitted, the object of which could not immediately be seen. For example, a little thing which puzzled us for a long time was a branch from the exhaust silencer to the air suction to the cylinders, by which a proportion of exhaust gases could be admitted to the cylinders or entirely cut off at will. I think the explanation of this device is to reduce the noise of the exhaust when travelling on the surface at cruising speed, for the reason that when we were experimenting on land engines to burn tar oil, we found that the admission of hot exhaust gases to the cylinder when the engine was running at small loads, not only allowed the engine to run more steadily, but also greatly reduced the noise of the exhaust.

The Chairman: In regard to solid injection. Is it a question of weight for the submarine engine? Is it that we want to save weight?

Mr. P. H. Smith: The object of the designer is to secure the maximum power per unit of cylinder volume and with the minimum weight.

Those who advocate the solid injection engine generally refer to the extra complication of the Diesel Engine by virtue of its having a compressed air plant attached thereto. I think there is very little foundation for this complaint. A properly designed Reavell compressor can operate 4,000 hours without examination whatever. Certain other compressors require much more frequent examination and their valves have to be cleaned every 200 hours or there about. Hence, by employing a really good compressor, and I am very partial to one of the Reavell types, the extra complication gives no cause for complaint.

The Chairman: There is a certain amount of weight added by installing the compressor?

Mr. P. H. Smith: On the other hand the better combustion secured by the air pulverisation and turbulence consequent upon the inclusion of the compressor admits of the adoption of a higher power output which reduces the specific weight of the engine.

The solid injection engine appears to have reached its present useful limit in the 14in. cylinder. Even so the indicator card is very peaky and its reliable M.E.P. in the 14in. cylinder is probably round about 90 lbs. per square inch. In the case of the

17in. cylinders on the monitors there was a great difficulty experienced and such an engine is possibly fully rated at 65 lbs. per square inch M.E.P., and even then the indicator card is excessively peaky. One of the artificers on board told me they were greatly troubled with seized pistons and often had to resort to the hose pipe to cool them down. On the other hand, the Germans appear to have evolved a design of Diesel engine which has worked, at least for short periods, at a mean effective pressure ranging round 120lbs. per square inch.

In any case the solid injection engine is quite untried for commercial purposes and is undeveloped, nor do I think it has a commercial future, except in quite small units.

Mr. J. L. Chaloner: Although it is not my privilege to be a member of your esteemed Institute, I take considerable interest in Internal Combustion Engines, and with your permission, would like to say a few words with reference to both Mr. Baxter's and Mr. Peel's papers.

Looking at the general development of oil engines you will find that there is a tendency for the so-called Semi-Diesel engine and the Diesel engine to meet each other inasmuch as the former is employing gradually higher pressures, whereas with the latter it has in recent times been attempted to reduce same. In the initial stage of the development of the Semi-Diesel engine the hot bulb represented a factor of ignorance on the part of the designer inasmuch as he was incapable of designing a cylinder head suitable to withstand varying temperatures. Water injection was added to prevent the hot bulb from attaining too high a temperature at full load and the advantages of water injection were advocated most extensively by all manufacturers. To-day with the advanced knowledge of the designer the hot bulb as an uncooled portion of the cylinder has disappeared and with it the water injection system which is now admitted to be an inconvenient and obsolete design.

If you want to atomise, pulverise or vapourise any fuel satisfactorily one of the essential factors is heat, and by removing the uncooled hot bulb the designer was faced with the alternative of having to increase the compression pressure.

With the Diesel engine in which already high pressures have been utilised it has so far been found necessary to inject the fuel by means of compressed air in order to get satisfactory atomisation. What the hot bulb is for the Semi-Diesel the air compressor is for the Diesel engine and these weaknesses have been recognised. There is now a tendency to design an engine which will dispense with the air injection system of the fuel and utilise the same method as in the Semi-Diesel engine, *i.e.*, the solid injection principle. It is stated that solid injection will never be capable of atomising the fuel as finely as air injection but my actual practical experience has already convinced me of the contrary. I have had the privilege of attending tests of some of the latest solid injection engines which, I am pleased to say are purely of British origin, and find that they are not only capable of atomising any fuel satisfactorily, but that they are even capable of atomising heavier fuels than the present design of Diesel engines employing air injection. With air injection each particle of oil must be surrounded by particles of air and consequently on entering the cylinder the heat of compression must be imparted to the globules of oil through the surrounding layer of air. The more finely the oil is atomised the more important becomes the time limit for passing on the required amount of heat to each globule. Mr. Smith has expressed himself against solid injection. He has invented a most excellent pulveriser, known as the Sleeve Pulveriser, in connection with which he attaches great importance to the sharp edged flame plate, and I consider that his system is a combination of mechanical atomisation and air injection atomisation. Again take the present method of burning Tar Oils by means of pilot ignition. A pilot jet is arranged in such a manner in the fuel valve casing that there is no possibility of it coming in contact with the air and consequently atomisation of the pilot jet is purely mechanical. Of course, it should be admitted that, the pilot ignition oil being of very good quality, very little atomisation is required for its complete burning, but it shows that the designer is quite aware of the retarding effect of the atomising air on the transference of the heat from the highly compressed air to the globules of oil.

The question of accessories is of greater importance on board a ship than in land installations. A plant which requires very close supervision—may be, it is technically a very sound proposition—is not considered a running job by the marine engineer. There is no question that the least number of accessories are an essential condition and every one of the various accessories which a designer can dispense with will help to popularise the internal combustion engine with marine engineers.

The opponent to the solid injection system will say, this is all very well, but what about your high fuel pump pressure. In my opinion it is easier to design a fuel pump for a working pressure of 3,000 per square inch than a three or four stage air pump working at 1,000lbs. per square inch.

Mr. Peel does not say anything about the question of fuel. It has been stated against the Vickers' engine that unless adjusted very carefully it will give a smoky exhaust. It is admitted that conditions in that direction are not perfect, but it is only a matter of experiment, and there are in fact solid injection engines which can burn any fuel such as used under boilers in a most satisfactory manner. To-day with the high price of labour it becomes a question of material, and it is absolutely essential that an engine should be capable of burning any grade of oil without losing in efficiency. If you have to go into a Port and spend say a day in adjusting your fuel pumps to suit any particular oil such a state of affairs is not satisfactory and the position to-day is that we must adapt the engine to suit available fuels and unless an engine is flexible with regard to burning any kind of fuel it cannot be considered a commercial proposition.

Mr. Shanks: It has been very interesting to hear the discussion raised by the last two speakers. I really did not know the essential principles of the solid injection Diesel engine, but I shall leave to-night with a knowledge that is valuable. We came here to be educated in internal combustion engine principles, and Mr. Baxter's paper is the principal thing before us; it is one of the most valuable contributions that I have ever seen published. It covers the full scope and progress of the internal combustion engine, and we, as marine engineers, have got to make ourselves conversant with the internal combustion engine of every description. We must not only be able to take charge of Diesel engines for propelling ships, but also auxiliaries driven by other types of internal combustion engines. If the discussion is not extended too long I would like Mr. Baxter to enlighten us on several points in connection with his paper. The marine engineer is, I think, conversant with the ordinary cycles of the internal combustion engine. Mr. Baxter asks us to note a cycle introduced by Mr. Durtnall, a diagram of which is shown in the paper, and in connection with this I was in doubt about its value. I have, however, got an explanation from a friend, who writes as follows:—

The cycle suggested by Mr. Durtnall is simply the constant pressure cycle of thermodynamics in which expansion is carried down to atmospheric pressure, but modified by the creation of a vacuum from B to C and back again from C to B

This vacuum retards the piston at the end of the admission stroke and similarly helps it forward at the beginning of the compression stroke, so that it does not directly bring about any net loss or gain of energy.

The thermodynamic efficiency of the cycle in which expansion is carried down to atmospheric pressure is certainly rather higher than the usual constant pressure cycle in which expansion is only carried as far as the point F, but the actual practical efficiency is, however, decidedly less, for the reason that the mean effective pressure is less than half, owing to the very low average pressure above atmosphere of the part of the diagram F B G.

Dugald Clerk has compared the two constant pressure air cycles—

(a) With expansion carried to atmospheric pressure.

(b) With expansion carried only to the point where compression starts, *e.g.*, point B on the Durtnall cycle.

The efficiency of (a) is 64 per cent.

The efficiency of (b) is 56 per cent.

While M.E.P. of (a) is 56lbs. per square inch, and M.E.P. of (b) is 117 lbs. per square inch.

In the above cycles a maximum pressure of 500lbs. per square inch has been assumed.

To obtain a given power, the size of the engine has thus to be more than doubled and the small thermodynamic saving is more than dissipated in friction, first cost, etc.

I would like Mr. Baxter to enlighten us if that deduction is correct. There is one further point I should like to refer to. Mr. Baxter deserves the greatest credit for the completeness of his paper from beginning to end, and I want to emphasise the importance of marine engineers making themselves thoroughly conversant with the question of ignition. I am surprised to find that we have not yet mastered that problem. And here we have it all thoroughly explained.

Mr. Charles Baxter: Mr. Chairman and gentlemen; I must first of all thank you for the kind way in which my paper has been received. I am sure that it is very gratifying to learn from the various speakers that my paper has been found interesting. I have jotted down a number of remarks upon paper and will reply to the various points raised.

Mr. Smith discusses the solid injection system versus injection by means of compressed air, and in this particular, I must say that I fully agree with Mr. Chaloner: the efficiency of the solid injection engine is fairly high and I see no particular reason why it should not be brought up to that of the Diesel engine. The impression that each globule of oil should be surrounded by a certain indefinite number of atoms of air is more or less a fallacy. There is one point to notice and that is, that so far, with compressed air injection, it appears easier to vary the diagram area than with solid injection. With the solid system we get a peaky diagram, and when it comes to cutting down the injection it is found to be a delicate business.

The Chairman: Not the latest type.

Mr. Baxter: My experience is that it needs very fine workmanship and better design than is put into it at present. The ease with which the Diesel engine cuts down its diagram is shown by Fig. 65 in my paper.

Another point raised concerns the term "Semi-Diesel" and I would draw attention to the fact that I pointed out in the paper that this was perhaps an inappropriate term to use.

With regard to the remark by Mr. Smith as to certain fittings on a German submarine engine, the object of which it was difficult to discover, the fitting admitting exhaust gas, I would say that I have used the same device. I found that by taking in inert gas the explosion is considerably cushioned and in certain engines I found that I could get rid of knocking pretty well without the use of water, which is often very inconvenient.

Mr. Smith: We knew what the object was: but what it achieved was not clear, but on experimenting we found that it reduced the noise of the exhaust appreciably.

Mr. Baxter: This follows as a matter of course, because the inert gas reduces the diagram area and the engine exhausts nearer atmospheric pressure.

Mr. Smith: We took curves and could not detect any difference, the exhaust was very quiet.

Mr. Baxter: To refer to the discussion on my own paper I would first like to add a few words to what I said about combining steam and internal combustion engines. Lately a great deal has been heard of this type, as the "Still" engine is of this variety, but it was by no means the first.

Professor Spooner some years ago constructed an engine upon this principle, which had four valves per cylinder, two steam valves, admission and exhaust, and two for the explosive mixture, inlet and exhaust. On the first outward stroke the engine inducted a charge of mixture, compressing, firing and exhausting it on the following three strokes, as is usual practice. Steam was then admitted on the fifth stroke and exhausted on the sixth.

By these means he constructed an engine in which better economy could be maintained, as from a thermodynamic standpoint the two sides were mutually helpful. The only difference between this and the "Still" engine is that in the "Spooner" engine the steam and combustion cycles took place on the same side of the piston.

The "Spooner" engine was of very simple construction and the patent specification, number 26271 of 1906, is well worth perusal.*

With regard to Mr. Terry's communication, I agree with his remarks in many respects. He speaks of starting engines by an electric motor, and whilst this is not entirely satisfactory for automobiles it works well up to a point. The difficulty he is up against, due to dirt collecting in the teeth is non-existant in properly designed machines, as the gearing is enclosed in the crankcase.

Mr. Peel mentions grinding valves, which is a very important subject. A small steam leak does not make a great deal of difference, but when it comes to internal combustion engines it is absolutely necessary that valves should be tight if the engine is to perform well. The usual thing is to smear the valve seating with coarse emery and oil and rotate the valve in it in a semi-rotatory manner, next using a medium grade and finishing off with fine. Personally, I find that the rough can be cut out unless the seating is very bad, and if the job is very particular, as in racing engines, the finishing can be done with crocus powder. The trouble usually experienced is that small pieces of

*Mr. Baxter sends a copy for the Library.

carbon get hammered into the seatings, a point which can be mitigated by fitting valves with a tungstan content as mentioned in my paper.

When valves have been ground a few times they sink into the seating and in order to remove the top ridge, which detracts from the area of opening, I turn up a valve out of tool steel and cut teeth in the seating, using it as a cutter. Mr. Peel also mentions the influence of tappet clearances upon the period of valve openings and he is quite right upon this point, this is why makers always stipulate the clearances in thousandths of an inch.

The trouble mentioned of sticking injection valves is a point which designers are up against for to get a valve to delicately function under high pressures is not easy, and when high temperatures are also involved the subject becomes more complex, involving the study of metallurgy. He also mentions the subject of lubrication which has always been a worry to me. Internal combustion engines are not lubricated with the same ease and certainty as steam engines, and no warning, or very little, is given before a seizure takes place which may result in serious damage. For this reason the only system is the completely forced installation which is now in extensive use.

He also speaks of gear pumps: I tested pumps of this type for an output of 10.000 horse-power per week, arranging them to pump oil against 45lbs. per square inch, obtained by closing a cock on the delivery side. These pumps are very reliable if kept primed by being situated below the oil level, and it was found that the clearances, both end and over the teeth, need not be very fine, for when they were increased from 0·005in. to 0·015in. no appreciable difference was noted in the quantity delivered.

Mr. Shanks asks a question re the cycle proposed by Mr. Durtnall. This cycle from a thermodynamical point of view is efficient as has already been pointed out by Captain Riall Sankey in one of the Society of Arts lectures I believe, but whether the amount gained would be more than counterbalanced by friction is a moot point. It also suffers from the same drawback as the six cycle engine mentioned in my paper.

In this engine the strokes are: induction of mixture, compression, explosion, exhaust, induction of air, exhaust of air; the object being, as explained, to get rid of the dead gas in the unswept portion of the cylinder. This gives an engine of higher theoretical efficiency, but as the power developed is proportional to the number of explosions it will be seen that a larger and heavier engine results. The remarks read by Mr. Shanks are quite true, but I can hardly agree with the view that the extra efficiency gained would be negatived by extra friction, whatever the size of engine produced.

Mr. Shanks: Would it be useless unless you went into very high powers?

Mr. Baxter: Yes, substantially the usefulness of this cycle, if any, would be best apparent in large sizes as the frictional loss is of course less, proportionally.

I think there is very little to say further, except perhaps in connection with the limit table given on page 481, Fig. 37, of my paper.

This is the standard table used and is said to be on a hole basis, which means that all holes drilled or bored are only allowed to depart from the size chosen to the extent of the limit given in portion A and B, A being, for very accurate work, and B for ordinary manufacture; a one inch B class hole, for instance, may be larger by 0·00075in. or smaller by 0·0005in., which is three quarters and half a thousandth respectively.

Shafts, etc., are machined to similar appropriate limits, for instance a shaft to be a running fit in the one-inch hole chosen above would be between 1in. minus 0·00125in. and 1in. minus 0·00275in., in other words between 0·99875 and 0·99725in. (an X class fit). It is quite easy to work to these fine limits by "go and not go" gauges, which are kept in stock for all the sizes used. Registers are push fits, etc., and a good designer with plenty of shop experience can cut out the quarter and half thousandths if the work is of fair proportions, for it is useless fixing limits to half thousandths of say a part 8in. diameter, as it is neither practical nor a commercial possibility and only hinders output.

There are many methods of writing limits on drawings, for instance, where gauges are stocked, a three inch B class hole would simply be dimensioned 3in. B, and the man would procure from the tool store a 3in. B gauge, one end of which will enter the hole and the other end will not. In odd sizes for which there is no gauge, say $3\frac{1}{16}$ in., a B class hole could be dimensioned $3\frac{1}{16}\,{}^{+1\frac{1}{2}}_{-\frac{3}{4}}$ in., the limit of course meaning $1\frac{1}{2}$ and $\frac{3}{4}$ thousandths, the man working to a micrometer in this case.

After much experience, however, upon designing work of all descriptions I have no hesitation in saying that I by far prefer the limit being written in the $3\frac{1}{16}\begin{smallmatrix} + \cdot 00150 \\ - \cdot 00075 \end{smallmatrix}$ form, a square being drawn round the limit portion so that the machinist can readily detect the important sizes, the other dimensions being assumed to be plus or minus ten thousandths, as the case may be, and a note to that effect put on the drawing.

I find it a great advantage to even further improve upon this, keeping any limited dimension in the complete decimal form and for that reason the practice in the office for which I am responsible is to write the limit as shown above, drawing a small square round it and putting the size over the top as a decimal. The works have instructions to work to the uppermost limit in the square and in the case of holes this the draughtsman makes the lower limit and in the case of shafts the higher limit, the percentage of scrap being greatly reduced by these means as if the machinist takes slightly more off than he intended, the work may still be within the limits set.

It is a great advantage to have a competent view room where work is inspected in different stages to prevent waste of time and money, finishing accurately, parts which are already scrapped by say one of the dimensions being below size.

In connection with cylinder sizes I would say that the difficulty experienced in designing large engines is purely one of arranging the metal round the cylinder so that internal strains are not set up in it, which cause distortion and breakages. There is no reason whatever why, with scientific design, engines should not be built of any size, more than equal to the largest size steam engines in fact, and with suitable arrangements, solid injection.

In conclusion, I would add that the question of cooling was dealt with in my paper, it being pointed out that the cooling of pistons and valves, etc., was now current practice, the question of get-at-ableness was also touched upon, the reason being given for the prevailing inaccessability.

Mr. David P. Peel: With regard to solid and blast injection there is much to be said in favour of both.

With solid injection, owing to the absence of the injection of air at a very low temperature with the fuel the difficulty of starting up in cold weather is greatly lessened. I have known a case where owing to this the entire supply of starting air was consumed in an effort to start, and then to fail in doing so. When starting a multi-cylinder engine many cylinders are on air, turning, and the remainder on fuel. The blast air is about 800 lbs. per sq. in., the compression about 400 lbs. per sq. in. Now in reducing air suddenly from 800 to 400 lbs. sq. in. there is a corresponding reduction of temperature, which in turn has a cooling effect, both on the heat of compression and the fuel, hence the difficulty of starting. Where blast injection has a real advantage is, in the superior possibilities of adjustment with regard to smoking.

The solid injection, with the exception of two stroke, has its air supply limited to the full opening of its induction valve and louvres. The blast injection can receive a further supply from the sprayer valve after the fuel has been injected.

Mr. Smith, in the discussion, claims an advantage in the blast system from a point of turbulence in the combustion space. I think this is easily evened up by the superior pulverising in the solid system from this point of view. I have found when a minute leak developed in the pressure side of the system the fuel escaping under a pressure of 3,000 lbs. per sq. in. and upwards came out in the form of vapour and was invariably detected first by sense of smell. This, together with the fact that in the Vicker's 100 h.p. unit, the sprayer nozzle was pierced with only 5—18/1,000 holes, proves the excellence of the pulverising.

Regarding the solid injection engine from a commercial point of view, I would like to mention a little about the class of engine at present being built by Messrs. Doxford, of Sunderland, to whose Chief Engineer I am indebted for the information. This engine is on the Junker principle of opposed pistons in the same cylinder, driving three cranks and using solid injection. The experimental engine on the test bed had a range of speed from a minimum of 30 r.p.m. to a maximum of 130 r.p.m., and in one cylinder developed 500 h.p. normal.

Considering the size of the engine this range is distinctly good, and the minimum creates a record I think. By throttling the exhaust, 750 h.p. can be obtained for an hour or more when urgently required.

Mr. Smith mentions about the piston speed of German submarines. In the British boats the average is about 990 ft. per min. at ordinary work, but this could be increased to about

1,140ft. per min. We maintained the latter once for fourteen hours until arrival in harbour, bringing home a seriously injured member of the crew.

I have read with interest the point raised about water and oil-cooled pistons. I have not had a great deal to do with these classes, but as far as I have had I can quite corroborate the statement with regard to the loss due to carbonisation.

There is another point against the oil system, that is the retention of a certain amount of heat by the oil due to imperfect cooling, and consequent dimunition of efficiency as a cooling agent. However, there is the advantage that in the event of a leak developing the oil merely falls to the crankpit and is not lost. On the other hand a similar leak from water cooling, unless precaution is taken, falls into the pit and is passed round with the bearing oil, and has a bad effect on the efficiency of the pump, if a geared pump, also causing marking of the crank and gudgeon pins if the brasses are inclined to be easy.

I would like to corroborate Mr. Smith's statement concerning the method of building the engine in, in the British submarines. The bed-plate consists of two channel girders laid on edge with the main bearings bolted between, the crankpit is formed in the structure of the hull.

Mr. Chaloner asks about fuel not being mentioned in my paper. I will give a little information on this subject with regard to submarines. Up to about November, 1915, Broxburne was used with, generally speaking, very good results, about the only trouble being the carbonising of the piston rings, the top two usually, but sometimes as far as the fourth were found to be solid with the piston.

About November, 1915, American distillate was introduced, my boat (*D*3) being the first to give it a trial. This fuel proved highly successful, an equivalent h.p. was obtained on a lower consumption. After running for a considerable time, a piston was withdrawn for examination, it was found to be coated with a thick heavy grease and the rings perfectly free. The only disadvantage was from the fumes of the cold oil, which in the confined space, and diving for 20 hours per day were particularly unpleasant, and resulted in sickness amongst the crew. In the steam boats the generator engine was fitted to use boiler fuel in the event of a shortage of distillate, but I have never known of an occasion arising necessitating the use of it.

When speaking of smoking I do not wish to infer this was a prolific source of trouble, but only in the sense of the numerous ways by which it could be caused. In the case of the propelling engines we were fairly clear. It was in the generator engines, as fitted in the steam boats, where we had most trouble. This was due to not being able to alter the fuel pressure, while running, as simply as in the propelling engine, where the simple turning of one handwheel regulated the pressure on the entire engine; in the other, each cylinder required to be handled separately, apart from the regulation done by the governor.

My remarks on grinding in valves, as spoken of by Mr. Baxter, were in reference to the sprayer valves only. Coarse emery must not be used on these, the fuel pump valves can also be ground in with smooth carborundum paste, although it is sometimes necessary to use flour emery first. When a fuel pump valve has been leaking it has the appearance of having had a sharp knife drawn radially across the seat.

Mr. Baxter mentions about the efficiency of the geared pump. My experience is briefly this: The geared pump when drowned and pumping new cold lubricating oil for cylinder lubrication through sight-feed lubricators, maintained 150lbs. per sq. in., and when pumping dirty bearing oil and lifting about 12 inches would give a pressure of 15lbs. per sq. inch with the oil cold. As soon as the engine and oil attained running heat we were pleased to get $1\frac{1}{2}$ lbs. per sq. inch.

I have to thank Mr. Baxter for his corroboration of my idea with regard to the effect of tappet clearances on smoking, and also the members for their interest in my paper.

Mr. F. A. Corns: I have much pleasure in proposing a vote of thanks to Mr. Baxter for the paper we have been discussing this evening. It is one of the most instructive papers on the subject that I have had the pleasure of listening to and treats the subject in a thoroughly practical way, and that is not what we always get. If the people interested in the Diesel engine were not so afraid of showing up the faults, the ordinary marine engineer would not be so scared of them. But everything seems to be a dead secret in connection with the Diesel engine. I am not acquainted with any standard book on the subject that treats it from a practical and commercial standpoint. There are any number that treat it in a thermodynamic way, but they do not interest the majority of sea-going men. If it were only advertised in such a way that the ordinary sea-going engineer would know what to expect, I do not think it would be quite so unpopular. This paper gives us some very practical information to work on, so to speak. In regard to the troubles with the piston, our chairman tells us that this is pretty well a thing of the past, since they have been able to cool the piston by water.

Mr. Harvey: It gives me great pleasure to second the vote of thanks proposed. Mr. Baxter has read a very interesting paper and I am sure, as marine engineers, we have lots to learn in regard to Diesel construction, and we want to learn it, because as the chairman says we waste a great deal of fuel, burning it under boilers when we might be burning it direct in a cylinder, with far better results.

———o———

The following articles are quoted from the *Motorship* for September, 1919, as they may be of service as supplementary to the discussion on the subject:—

EDITORIAL.

The question of solid injection.—Pioneers in modern engineering make advances so rapidly that the other manufacturers and users are occasionally confronted with situations that to them are problematical from a business point of view. The result is that the question of meeting these engineering advances is sometimes shirked as long as possible. This has been particularly so in the case of the heavy-oil engine and its construction and use aboard ship, and some vessel owners and ship builders are still endeavouring to avoid it. They may hold out until its certain and extensive adoption by others, threatens to jeopardize their trade. There is a limit to the time before them; as in this age of continuous progress, sound engineering developments which are practical commercial possibilities, will never be ignored for long.

In a similar way, a problem now confronts all builders of marine Diesel engines. This is the question of the solid-injection of fuel for high-compression oil-engines. Until recently it was the general concensus of opinion among oil-engine designers that this system was uneconomical and of little use for the heavier grades of fuel-oil. In fact, up to the commencement of the war this was known to be the case. But during the last few years important progress has been made abroad which demands closer investigation and experimenting on the part of our own engine builders. It has been thought that only one English concern was using solid-injection so it may be well to mention that for several years as many as twenty other engineering companies in Great Britain have been using this system under licenses. This, by the way, is the largest number of constructional licenses granted for any one make of Diesel engines. It indicates the technical opinion of these engineers familiar with the system.

According to our information a consumption of 0·28 lbs. per indicated horse-power (0·38 lbs. per b.h.p.) can regularly be maintained and an even lower consumption has been obtained on the test-bed. This, of course, is remarkable. The economy resulting from such achievements may be compared with the best marine steam-turbine practice; namely, 0·95 lbs. per indicated horse-power, or with 0·30 lbs. for the best air-injection Diesel practice.

With four 6,000 i.h.p. fast cargo ships of the same power fitted with coal-burning reciprocating steam-engines, oil-fired geared turbines, air-injection Diesel engines and the solid-injection Diesel engines respectively, we get the following daily fuel consumptions:—

Coal-Burning Ship	$96\frac{1}{2}$ tons
Oil-Fired Turbine Ship	61 ,,
Air-Injection Diesel Ship	19 ,,
Solid-Injection Diesel Ship	18 ,,

It will be seen from these figures that solid-injection widens the gulf between oil-fired, steam and internal-combustion engines, but that the actual difference in consumption between it and the air-injection system is not very much. Of course, it dispenses with the air-compressor and saves the power absorbed in that manner, and, on the basis of indicated horse-power there is a gain of about 5·2 per cent. efficiency per ton of fuel consumed over that attained in engines using air injection.

The figures would have been more effective had we quoted the consumptions per brake horse-power in each instance. Usually steamship owners carry in mind the consumption per indicated horse-power; so it may be best to use the more familiar term.

Perhaps it is well to make it clear that there is no desire on our part to suggest that builders abandon air-injection in favour of solid-injection at this stage. We simply intend to indicate the necessity for immediate investigation and experiment. Our own view is quite impartial, except that we naturally lean towards air-injection because we are acquainted with both its merits and weaknesses, whereas, we do not yet know the faults of solid-injection. While abroad we hope to have the opportunity of making further investigations.

PRACTICAL OPERATION OF MARINE DIESEL ENGINES.

By K. CARLSEN.

The popular objection to the Diesel engine for marine propulsion is that the men necessary for their reliable operation are of a high grade, and consequently, are difficult to obtain. It is acknowledged to be poor policy to place a steam engineer in charge of the machinery of a motorship without a preliminary shop course and some erecting and testing experience. To cover the ground briefly, the difficulty does not arise from the complications in the machinery, but from the necessity to have every detail of each working cylinder in proper adjustment. True, the adjustments must be finer and more exact than for steam, but there is considerable simplicity obtained by the fact that the pistons, rings, valves, valve gear and cams are all alike for each cylinder.

It is exceedingly simple to operate a Diesel engine when it is in correct adjustment, and almost every engineer prefers the Diesel engine to steam machinery after being able to make comparisons from personal experiences.

The dependability and cost of maintenance of a Diesel engine depends, as with steam machinery, on the care and "engineering sense" of the personnel. The engines should be kept in the best possible working condition and any defect remedied immediately.

[Before going further it may be remarked that the problems of ordinary engine room routine work whether on steam or Diesel engines are really those of diagnosis of symptoms which may come to the attention of the watch officer through his five senses. Troubles are nearly always noticed either from the feel or the sound of some part working improperly. Sometimes that so called sixth sense will detect trouble before it really arrives.—Editor]

STARTING.

If any repairs or adjustments have been made previous to the time of starting, the engine should be turned over by hand or by the turning engine. All moving parts should be clear of everything and all valve timing and manœuvering gear should be checked for correct operation. All lock nuts and split joints should be drawn up tight. Valve spindles should all work easily, but without leaks. The lubricating oil tanks and fuel oil settling tanks should be measured or otherwise tested. The condition of these tanks must be known, for clean lubricating oil and fuel is essential to reliable operation. The operator should give the inlet and exhaust valve stems a little kerosene. He should be sure that all overflow valves in the fuel line and also the indicator cocks are closed. To test the fuel line and to insure reliable fuel injection after starting on air, proceed as follows: Test the fuel line for leaks by opening it up to the high pressure air in the spray air bottles. Then close the fuel line to the injection air. Open the drain valves to let out all air pressure and immediately close them again. At least 800 lbs. pressure should show on the gauges for the spray air bottles and a good supply of starting air should be available.

Different designers use different pressure and amounts of starting air, but few engines of the full Diesel high-compression type will start when cold on much less than 150 lbs. of air.

All lubricating devices should be filled with oil and regulated for proper feeding. The oil pumps for forced lubrication should be started if separate from the main engine. If necessary, the cranks should be placed in the proper position for a positive start. The inlet valve, if any, on the low pressure side of the air compressor, should be opened wide, together with all drains from the inter-coolers.

[Evidently the writer means that the throttle valve in the first-stage suction of the air-compressor should be wide open—Editor]

If the temperature of the cooling water is very low, do not let it run through the cylinder in a full stream or for any length of time before starting. The cylinder might be cooled to such an extent that it will be difficult if not impossible to start the engine. All valves on the fuel supply line to the fuel pump should be opened wide. Adjust the fuel pumps to work by hand and pump oil into all fuel lines till it appears in a solid stream from the overflow valves. Then stop pumping, close all overflow valves and put the hand pumping gear out of action. Open the valve between the H.P. compressor and the air bottle and the engine is ready to start.

After the engine is started, open the cooling water discharge from the circulating pump to the running position and close all the drains from the inter-coolers. Fill all air tanks to the right pressure as soon as possible and examine the engine all over to be sure everything is working properly. [Of course, anything that has been adjusted since the last run will be carefully watched for a time—Editor]. If the pistons are water-cooled, inspect this system and ascertain the volume and temperature of the cooling water discharge. All cooling or circulating systems should be started before or at the same time as the engine. Everything proving all right, the engine may be stopped and it will be in readiness for immediate service.

If compressed air is not available, compressed carbonic acid may be used to fill up the bottles, but under no circumstances may oxygen, hydrogen or any other gasses be used. In filling a bottle with carbonic acid gas all valves should be closed, while the carbonic acid tank is connected to the air bottles. Open the valve between the two tanks. The pressure in a carbonic acid tank is usually about 750 lbs. per sq. in. and when the pressure has dropped to about 300 lbs. close the valve and slowly pour hot water on rags laying around the top of the carbonic acid tank. When the pressure has returned to about 750 lbs. open the valve to the air tank again. Repeat this until all the acid is evaporated or until the required pressure in the tank is obtained. After the engine is started immediately fill all tanks with air and drain out the rest of the carbonic acid. If the injection air tank has been filled in this way, the exhaust valves should be cleaned as soon as possible.

While Running.

The most important things to watch while running are the different gauges. These will often show where to look for trouble if there is anything wrong. The engine should run evenly without smoking or knocking. Care should be taken to see that the cooling water circulates properly through all parts requiring it. Small cocks are generally fitted in the cylinder heads to let air out of the cooling spaces and thus avoid air pockets which prevent proper cooling. Thermometers are furnished at different places where a constant check on the temperature is necessary. The temperature of the cooling water at the outlet should not be so hot that it cannot be felt by hand. 160° Fahr. is a maximum. The lubricating and fuel oil filters should be cleaned at frequent and regular intervals. The different stages of the air-compressor should each do an equal part of the work in compressing to the highest pressure. If the pressure in the forced lubrication system drops it is usually on account of dirt in the filter. The daily supply tank should be drained frequently because excess water in the fuel oil will stop the engine. There are generally two supply tanks. As soon as one is empty, the other may be connected to the pump suctions and the first filled up immediately. Any water in the fuel will thus have time to settle down, and be drained off. Air bottles should be drained of condensed water and there should be two drain valves; the one next to the bottle should be fully opened and the other just crancked open a little to let the water out.

Draining water through a valve opened very slightly and with two valves in the drain pipes, the first may be closed tight and the second taken off and ground when necessary.

Always be sure that the water or oil circulates properly if the pistons are cooled. If the oil circulation is not sufficient the oil will carbonize, resulting in the piston heating and the rings sticking. Press fingers on all valve rollers and if the clearances are correct, they can be prevented from revolving for the period during which the cam is not under the roller. [In some designs of valve gear the valve roller is intended to roll on the cam at all times.—Editor]

After the engine is stopped close all valves on the fuel supply line. The cooling water should be gradually reduced and not stopped until the engine has cooled down sufficiently to prevent the lubricating oil from drying on the cylinder walls. In a cold climate, if there is danger of the water freezing, all jackets and pipes should be drained. All lubricators should be turned off and the force feed lubricating pump stopped. All valves to the air injection and starting tanks should be closed tight, and the air blown out from the injection line and compressor. None of the gauges should show any pressure.

WILL NOT START.

If, when starting the engine, combustion does not take place it cannot be forced by prolonged operation on air. The only result will be loss of valuable starting air. The difficulty is generally due to one of the following reasons.

I. No fuel.

(*a*) The fuel valve from the daily supply tank may be closed.

(*b*) Daily service tank may be empty.

(*c*) There may be air pockets in the fuel supply line or in the fuel pump. This might happen if the supply tanks were not high enough above the suction valve of the fuel pump. In this case, take off plug above the pump's delivery valve, after closing the valve to the supply tanks, then open this slowly and let the oil run out until no air bubbles escape from the outlet. Then fill up the line to the fuel oil valves in the usual way.

(*d*) Fuel may be leaking past the fuel pump pistons.

(*e*) The line between the pump and the fuel valves may be empty, either on account of improper filling of the line, or from leakage if too long a time has elapsed before starting after the line is filled.

(*f*) The hand pump may be loose.

(*g*) Sometimes the engine will not start if the atmosphere is at a very low temperature. It may then be necessary to fill the water jacket with steam or heated water.

(*h*) At such low temperature the fuel oil may be too thick to run. Therefore, ships that have to go to cold climates should have arrangements provided for heating the fuel oil.

II. Low compression. The temperature may then be too low for ignition.

(*a*) The slots in the inlet pipes may be filled with dirt.

(*b*) Compression may leak past the valve housing and valve seats.

(*c*) The striking joint may be too big.

The various troubles that may develop in the running of the engine may be classified by their symptoms. In fact, the same result may be caused by totally different defects and it is the test of a good engineer to find the true cause promptly.

I. Motor knocks while running.

(*a*) A loose bearing. The knock may cease if the bearing is flooded with heavy oil.

(*b*) Too early injection. This may cause slight explosions instead of proper combustion and is to be remedied by the proper adjustment of the fuel gear.

(*c*) Too late injection.

(*d*) Too high or too low injection air pressure.

(*e*) The fuel valve may be leaking badly, and in that case the engine should be stopped immediately. Under this circumstance the fuel is getting in the cylinders too early and there may be ignition before the piston is at its top centre.

(*f*) Improper pulverising on account of dirt in pulveriser. Raising the pressure of injection air for a short time may remove the dirt.

(*g*) Improper distribution of fuel to the different cylinders.

II. If the engine is working correctly the exhaust gases will be nearly invisible. If the exhaust gases are smoky or black, this will be due to following causes:

(*a*) Too low injection air pressure.

(*b*) The fuel valve is not lifting high enough. This can be remedied by raising the injection air pressure. [Or reducing the clearances in the valve gear.—Editor]

(*c*) Leaking fuel valve. The valve may stick or need grinding. It may be on account of improper adjustment, which would prevent the valve from closing properly. In this case it is difficult to keep the injection pressure, because the air is continually leaking into the cylinder. This should be remedied immediately.

(*d*) If overloaded, the engine will smoke. This is not necessarily due to faulty operating. If the overloading of the engine will be necessary for some time, raising the pressure of the injection air, or a slightly earlier injection will lessen this trouble.

(*e*) The pulveriser may be dirty.

(*f*) A hot bearing will overload the engine and make it smoke; careful investigation may locate this trouble and increased lubrication overcome it.

(*g*) Resistance against the inlet air. The slots in the inlet pipes may be partly closed with dirt and must be cleaned.

(*h*) Resistance against the exhaust gases. The exhaust pipe is dirty or there is water in it.

(*i*) The compression is too low.

III. Uneven Running.

(*a*) The governor connections are not working freely; it should be re-adjusted.

(*b*) The air compressor pistons may be leaking, or the automatic valves are leaking, sticking, or not seating properly. In this case, the air injection pressure might vary.

(*c*) The fuel pump is working irregularly on account of dirt in valves or leaky stuffing boxes, or it may be working too fast on account of improper adjustment.

(*d*) Sometimes each cylinder is not doing an equal share of work. This will be easily found by taking indicator cards, and is usually on account of improper distribution of the fuel oil.

(*e*) If, when opening the test holes in the exhaust pipe, the exhaust is not uniform in colour and sound, the improperly working cylinder should be examined with regard to valves and their adjustment corrected.

(*f*) Water in the fuel will make uneven running, if it does not stop the engine.

IV. If the air pressure cannot be maintained, the engine is using too much or the compressor is not delivering enough.

(*a*) Count the r.p.m. for if the engine is running slowly it uses more air because the fuel valve is open a longer time.

(*b*) If the engine is running at the proper speed it might be using too much air because the play between the cam and roller is too small. The lifting of the valve would then be too great.

(*c*) The fuel valve may stick or leak. Stop immediately and fix it.

The compressor may not be delivering enough air for following reasons:

(*d*) The intake pipe, if any, on the compressor's low pressure side, is plugged up with dirt, or the valve is not fully open.

(*e*) The valves are leaking or sticking. This can be determined by laying the ear on the compressor close to the valve cages.

(*f*) The striking joint may be too big.

(*g*) Leaky or sticking piston rings.

(*h*) Leakage of air to cooling water.

(*i*) Leakage of air at the forced feed lubricator.

(*j*) Leaks in pipes, valves or connections. These last can be distinguished by a whistling sound.

If there is oil in the cylinder before starting it should be taken out. There can of course be no more oil burned than that which will use up the air in the cylinder and for that reason the pressure resulting from an overcharge of oil will hardly ever exceed 1500 lbs. per sq. in. This is usually a safe pressure for the working cylinders.

However, the ignition and consequent combustion may occur early in the compression stroke and further compression result in excessive pressures. Usually this results in blowing through the cylinder head gasket or down past the rings. This is only likely to occur on starting when the accelerating forces are high due to the starting air pressures and the extra heavy charges of fuel from the primed valves. Always close the valves in the fuel line to the injection valves upon stopping for a reasonable length of time.

The above seems to be just a long list of errors and rules, but on looking them over it will be seen that they embrace nearly the same remedies over and over again. These remedies are very simple and quickly applied, the principal source of trouble being the timing, adjustments, and tightness of the valves. The proper working of the fuel valve is most important.

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Circulation of Water in Cylindrical Marine Boilers.

REPLY TO DISCUSSION.

Mr. A. E. Jordan: I wish to thank the members present at the reading of my paper for the interest they showed in my system of boiler circulation, the discussion of which seems to have brought out several diverse opinions.

The straight tube of large diameter, from the bottom to the top of the combustion chamber was tried some long time ago and was found to leak badly, being altogether too rigid. The velocity of circulation in a small tube is relatively greater than in one of a larger diameter, and that, and the question of fitting tubes without having to cut too large a hole in the combustion chamber plates between the stays, determined the size of tube which was most suitable. A straight tube with a high velocity of circulation coming out at the top of the combustion chamber would tend to make the boiler prime, and for this reason the discharge orifice is kept down below the top of the chamber, which necessitates a bent tube.

In the Colven Express Boiler, of which a considerable number are used in this country (United States) the shape of the tubes in this boiler are almost identical with the shape of my circulating tubes and the diameter of the Colven tube is 1in. This type of boiler is very similar to the Thornycroft boiler, with the exception that the tubes in the Colven boiler are bent. The circulating tubes used are solid-drawn seamless steel. They have a safe working pressure of 1,200 lbs. per square inch. The 3in. plain tubes, in a multi-tubular boiler, are usually about ·150 thick, whereas the circulating tubes, of half that diameter, are ·1875 thick. These tubes have been working in a number of vessels for about two years, without giving any trouble, when made of proper material. In one case some ordinary black iron pipe was used and the tube gave out, but very little difficulty was experienced in plugging the holes; the water in the boiler had, of course, to be blown out and washers were fitted in the holes; but as previously stated, only when inferior material was used was any trouble experienced, and with the exception of a donkey boiler of a tramp steamer, which was fitted with these tubes, they have given no trouble by salting up. This donkey boiler must have been worked at an abnormal density as the tubes became partially choked with salt, so that the hole through the centre of the salt was only about half an inch in diameter.

Of course, no water tube is supposed to stand that sort of treatment, but a sample of the tube cut out and sent to me showed that the tube had not burned out.

American ships, as a rule, carry sufficient fresh water in their tanks for all boiler purposes and do not get salt water into their boilers excepting through a leaky condenser, and it is an easy matter to stop for an hour or so and make a condenser tight.

With regard to the Chairman's remark about working in the back end, I must say—from my own experience—that the three circulating tubes in the combustion chamber do not interfere with a man working inside the chamber; there is plenty of room to get at all the original tubes and stays and also to do any caulking, and there is no necessity to remove any of the circulating tubes to do any work in the back ends. The circulating tubes are not any more likely to be burned out than the tubes in any water tube boiler, and experience has proven this to be the case. I do not think there can be any doubt that these circulating tubes add materially to the efficiency of the boiler and that they produce positive circulation from the time the fires are lighted is unquestionable. I again tender to the members my best thanks for the way in which they received and discussed my paper.

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Lecture on the Antarctic Expeditions.

On Tuesday, February 16th, Commander Cope of the British Imperial Antarctic Expedition gave an interesting lecture on his former experiences in the Antarctic regions, illustrating these by means of lantern slides.

The well filled Lecture Hall of the Institute indicated the great interest which is felt in the subject and the good attendance of ladies among the audience showed their hearty appreciation of the work of the explorers, who have gone forth to brave the dangers and privations attendant upon such expeditions. The lecturer (who was accompanied by Mrs. Cope, Mr. and Mrs. Joyce and Mr. Larkman, M.I.Mar.E., who is going as chief engineer of the forthcoming expedition) described, by means of a map thrown on the screen, the course of the expedition, with the stopping places where huts are to be erected and parties left for exploration purposes, erection of communication stations, and of starting posts for aeroplane surveys, including attempts to reach the South Pole. It was pointed out that valuable information had already been gained by means of former expeditions to the advantage of the Empire, and it was hoped that further information would be added from some of which trade and commerce should gain a benefit, in respect to minerals, traces of which had been found and might be developed by commercial undertakings as to the mining of manganese, coal, granite, and marble; it was also stated that rubies had also been found. The vessel being prepared for the expedition is the *Terro Nova*, to be fitted with Beardmore internal combustion engines, an aeroplane will be carried and wireless installations. It is intended to start in June of the present year and to remain roaming around for five years, circumnavigating the Antarctic and sailing round to the Falkland Islands. In connection with the commercial side, it was stated that the climate is easier to live in than Klondyke or Siberia, where developments have been made in respect to trade ventures. The views were good and the information conveyed was instuctive, and the audience gave an appreciative accord with the vote of thanks proposed to Commander Cope accompanied the hope that public support would be given to him and his party in order to reduce as far as possible the privations which are more or less inseparable from such adventures. Mr. Joyce and Mr. Larkman expressed their confidence in Commander Cope as a leader.

The chair was occupied by Mr. J. Shanks. The vote of thanks was proposed by Mr. G. J. Wells and seconded by Mr. J. Clark. The lantern was manipulated by Mr. Wm. McLaren, assisted by Mr. Hargreaves.

Notes.

As several members have expressed the desire to record their appreciation of the services rendered by Mr. A. H. Mather during the period of 13 years when he held the position of Hon. Treasurer, it has been suggested to widen the opportunity to the whole membership and invite contributions so that a suitable presentation may be made at the re-opening of the Session in the autumn. It is desirable that the contributions be of a medium and uniform character so that everyone so inclined throughout the membership may have a voluntary share in the giving, on the basis of a percentage of his annual subscription, from Members to Graduates. Donations to be sent to the Hon. Treasurers.

Election of Members.

Members elected at a meeting of Council held on January 13th, 1920:—

Members.

William Bailey, 50, South Bank Road, Edge Lane, Liverpool.
Stanley Bickerton, Stransfield, Hook Road, Goole, Yorks.
Alexander Low Blackwood, 1, Endsleigh Gardens, Ilford, E.
Alexander Campbell, Alexander Place, Esplanade, Oban, Scotland.
Ernest E. Crouch, c/o Overseas Club, General Buildings, Aldwych, Strand.
Thomas Henry Clayton Dixcee, Hilton Villas, 45, Whitehill Road, Gravesend.
John Downs, 2, St. Cuthbert's Road, Brondesbury, N.W.6.
Fredk. Charles Duxon, Douglas Steamship Co., Hong Kong, China.
James Honey Hollingum, 61, Argent Street, Grays, Essex.
Thomas David Hindes, Pera House, Preston Road, North Shields.
James M. Imrie, Rosebank, Currie, Midlothian.
Robert George Inglis, 99, Second Avenue, Manor Park, E.12.
Alexander C. C. Kinning, R.D., Kingsley Bank, Formby, Liverpool.
William George Lean, Hartley, Higher Campfields, Truro.
Robt. Harold MacKillican, 60, Dartmouth Road, Hendon, N.W.4.
Alexander McNab, Brooklawn Park, Bridgeport, Conn., U.S.A.
Alexander Webster Matthew, Brooklyn, Moorland Road, Par., Cornwall.
Robert Henry Merrick, 3, Fernhurst Avenue, Cork.
Matthew Nairn, Sunnyside, Bridge of Weir.
Walter George Nicholas, 46, Cambridge Road, Seaforth, Liverpool.
Penrhyn Neville, 87, Southwark Street, S.E.1.
Wilfrid Lawson Patrick, The Crumyards, Kilcreggan, Scotland.
Joseph Charles Phillips, 21, Tours Road, Stoneycroft, Liverpool.
Ebenezer Redwood, 14, Lewis Road, Southall, Middlesex.
Maurice Rowland, c/o Lester & Perkins, Ltd., Royal Albert Docks, E.

Fredk. George Brooke Smith, Lloyd's Register, 25 de Mayo 158, Buenos Aires.

William Stevenson, 40, Gresford Avenue, Sefton Park, Liverpool.

Thomas David Symons, 3, Bishop Terrace, Brae, Rothesay, Scotland.

Associate-Members.

George Albany Crawford, 213 Albert Road, Jarrow-on-Tyne.

Chas. John Palmer Drewett, Box 513, Wellington, N.Z.

Reginald S. Williams, P.O. Box 513, Wellington, N.Z.

Associates.

Sidney Crossley, Fern Cottage, off Manchester Road, Denton, near M/e.

Thomas Percy Palmer, 17, Craven St., Newbury, Berks.

Graduates.

Alexander Allison, Ombersley, Boston Road, Hanwell, W.7.

James Winton Campbell, 37, Forest Drive East, Leytonstone, E.11.

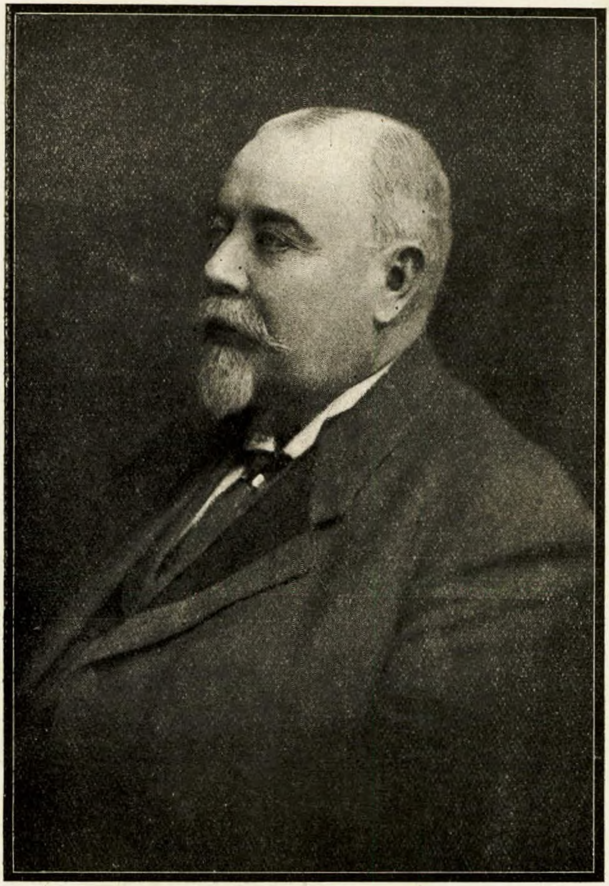
Transfers:—

From Associate-Member to Member.

David Brown, 15, George Street, Cellardyke, Fife.

From Associate to Associate-Member.

Fredk. W. Laverick, c/o United Kingdom Glass Co., Ltd., Hayes, Middlesex.



JOHN LOCKIE, Wh.Sc.

Our deep sympathy is extended to Mrs. Lockie and her family circle, mingled with great regret, on the death of John Lockie, proprietor of *The Steamship*. Mr. Lockie was well-known to a large circle of friends and associates by whom he will be much missed. He died on December 26th, 1919.

Born in Glasgow, John Lockie received his education at the Glasgow Training College and the West of Scotland Technical College. His engineering apprenticeship was served in the works of Messrs. Norman & Co., and he went to sea for experience in the engine room for nearly 12 months. By dint of study and keen attention to the science of engineering he gained a Whitworth Scholarship, and was appointed, in the intervals of the Glasgow University Course, as experimenting officer in the Industrial Museum, Edinburgh. He served also as an assistant to Lord Kelvin in the Laboratory, Glasgow University. Subsequently he served as an assistant to Prof. Archer, Edinburgh University, for about two years. He then opened a business in Leith as Consulting Engineer, and in 1880 started a Nautical Academy for Marine Engineers to study and make up for what they lacked in earlier educational facilities. Soon after settling in Leith he was appointed headmaster of the then recently formed Leith Science College, and for fourteen years he held the position of Principal. In 1889 he gave up the appointment, and started *The Steamship*, to the development of which he devoted himself with fervour. He also carried on his engineering academy with assistants, until about eight months ago when he parted with it in full action to his assistant. One of Mr. Lockie's sons was killed as the result of an explosion on board one of the monitors, and died in the Royal Naval Hospital, Chatham; the second son is on his way home from Australia; the third son is in Canada, and the youngest has now completed his engineering apprenticeship and served as a junior engineer at sea for some months.

Mr. Lockie was one of the early members of the Institute of Marine Engineers, and was a Vice-President for several Sessions, representing the East Coast of Scotland. He was also a member of the Institute of Journalists, and of the Royal Society's Club, St. James Street, London.