INSTITUTE OF MARINE ENGINEERS

INCORPORATED

SESSION 1911–1912

President: The Most Hon. The MARQUIS OF GRAHAM, C.B., C.V.O.

VOLUME XXIII.

PAPER OF TRANSACTIONS NO. CLXXVIII.

Notes on 2-Cycle Oil Engines

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READ

Monday, November 6, 1911.

CHAIRMAN: MR. JOHN McLAREN (VICE-PRESIDENT).

CHAIRMAN: The paper before us to-night is called "Notes on Two-Cycle Oil Engines," by Mr. F. Duncanson. As Mr. Duncanson is unable to be present, Mr. Adamson has kindly consented to read it on his behalf. I might mention that two years ago Mr. Duncanson gained the Lloyd's Register Scholarship given under the auspices of the Institute. This is the first paper he has given to the Institute, and I am sure we all take an interest in his career.

MR. CHAIRMAN AND GENTLEMEN,—If the internal combustion engine is to displace the steam engine for marine propulsion, it must answer to the following requirements:—It must have a large shaft horse power at a reasonably low speed (in order to get propeller efficiency), its weight per B.H.P. must be low, the space taken up must be small, and most important of all, the fuel consumption must be low.

In comparing the advantages of 2-cycle internal combustion engines with those of 4-cycle engines, we have these important factors to consider.

A 2-cycle engine theoretically should give twice as much power at a given speed as a 4-cycle engine having the same piston displacement. Hence for a given power and speed we should need only half the piston displacement in a 2-cycle engine and consequently should get a lighter and more compact machine. In order to get these ideals realized the mean effective pressure in the cylinders must be the same in a 2-cycle as in a 4-cycle engine, and the mechanical efficiency must be the same in both cases.

The difficulties which must be overcome in the design of a successful 2-cycle engine are :—

1. Due to imperfect scavenging, the fresh charge is diluted with inert exhaust gases, and hence combustion is imperfect, consequently the mean effective pressure is low.

2. Due to the same cause, weak mixtures, which would otherwise effect an economy in fuel, will not ignite at all, and therefore cannot be used.

3. If the exhaust valve or port is still open when the fresh charge is pumped in, some of the fuel will inevitably escape with the exhaust, and thus the fuel consumption will be high. This applies also to engines which have a " buffer " of scavenging air blown in between the exhaust and the mixture, because it is impossible to avoid diffusion, and mixing of the gases due to eddies.

4. The mechanical efficiency of the 2-cycle engine will be less than that of the 4-cycle engine on account of the auxiliary machinery which must be used in scavenging the cylinder and pumping in the fresh charge.

All these disadvantages will naturally combine in giving an engine which compares unfavourably with the 4-cycle in fuel consumption, weight and bulk. The conditions to be aimed at in the design of a 2-cycle engine are :—1st. At the end of the power stroke we must get rid of the exhaust gases, then the cylinder must be scavenged, i.e., the residual gas now at about atmospheric pressure must be swept out of the cylinder, and the cylinder left full of fresh air at or above atmospheric pressure. While this air is being compressed on the return stroke of the piston and the exhaust ports are closed, a small quantity of fuel must be sprayed into or otherwise intimately mixed with the air to form an explosive mixture which may be ignited towards the end of the compression stroke or at the commencement of the power stroke. It would be an advantage if the fuel were not injected until the compression stroke is completed, thus the danger of pre-ignition would be entirely avoided, the extra work in pumping in the small quantity of fuel at compression pressure instead of at slightly above atmospheric pressure being quite negligible. Another advantage of pumping in the fuel at the end of the compression stroke is that the space is much smaller, and therefore the mixing can be more easily effected.

The advantages which we have given to us straight away on the adoption of the 2-cycle principle are :—

1. The absence of valve pockets and big valves in the cylinder head renders the design of this very simple, moreover the combustion chamber or clearance space is much more compact, thus giving ideal conditions for the ignition of the charge, because, as is well known, the flame originating at the ignition plug takes an appreciable time to travel to the more remote parts of the combustion chamber, and the more compact the combustion chamber can be made the more rapid the ignition, and hence the better the thermal efficiency of the engine.

2. If scavenging is perfect, then the total volume of the cylinder, i.e. the piston displacement, together with the clearance volume is filled with fresh air which can be usefully employed in the power stroke, whereas in the ordinary 4-cycle engine the combustion chamber is always left full of exhaust gases, at about atmospheric pressure, which mix up with the fresh charge and dilute it, thus lowering both the capacity and the thermal efficiency of the engine.

3. Much weaker mixtures could be used in well scavenged 2-cycle engines, thus increasing the thermal efficiency to even more than that of a 4-cycle engine.

4. A more uniform torque can be obtained with a 2-cycle engine because work is done on every downward stroke of the piston. This uniformity of torque, besides enabling a fly-wheel to be dispensed with, also conduces to better propeller efficiency.

5. The dimensions of the engine would be much less than those of a 4-cycle engine of the same power, and this would compensate for the space taken up by the auxiliaries.

By careful design and understanding of the conditions to be aimed at, there is no reason why the all-round efficiency of the 2-cycle engine should not be as good as, or even better than, that of the 4-cycle engine.

Considering now the pumping operations, the suction stroke of the 2-cycle engine differs from that of the 4-cycle only in that it is carried out in a separate pump which is designed for this purpose only. The pump cylinder is not heated up, and the cylinder walls and valves, since they are subject to small pressures only, can be made of proper proportions, and hence they will be light in weight. All these things combine to raise the efficiency of the pumping actions ; the volumetric efficiency,—i.e. the capacity of the engine—increases, due to the fact that for the same piston displacement the power cylinder receives a greater quantity of colder air than if the suction stroke had been carried out in the cylinder itself. The frictional losses and volumetric efficiency of the pump-cylinder should not be far different from those attainable in all good air pumps, say a suction pressure of 14·1 to 14·4 lb. absolute, and a volumetric efficiency of from ·95 to ·97. Since the most favourable pressure of the scavenging air is from 1 lb. to 3 lb. by gauge, the rise of temperature due to compression is negligible, and in any case it disappears during the transfer of the air to the reservoir or the power cylinder.

It is, of course, assumed that the scavenging air and charge is furnished by a separate pump independent of the power cylinder. The conditions are much worse when, as is sometimes done, the front end of the cylinder is used as a pump, in which case the efficiency is lowered by the strong heat transfer from the power cylinder to the pump cylinder. The conditions are still more unfavourable when the enclosed crank case is made to serve as a pump, but this design is used only in very small powers and need not concern the question of the marine engine at all.

The conclusion to be arrived at is, that to utilize to the fullest extent the advantages of the two-stroke cycle, only independent pumps, which may be designed as such without restriction, should be used.

Turning now to the question of scavenging, it is of the utmost importance that all the burned gases should be driven out of the cylinder, for on this depends the efficiency, reliability, and capacity of the engine.

Assuming that the cylinder volume is to be cleared out with air, the introduction of some air in excess is indispensable, hence there must be available a volume of scavenging air greater than the cylinder volume, because during the scavenging period some air is certain to be lost through the exhaust ports, and unless some excess air is at hand, some of the burned gases are certain to remain. If independent pumps are used, the supply of air may be made as much as is desired, but when the front end of the cylinder or crank case is used to compress the air, an excess is not obtainable.

It is found that as long as the scavenging air is led from the pump directly to the main cylinder, its proper action is seriously hampered. With the pump and main cylinder cranks at 180° apart, it is possible to scavenge only at the dead centre ; where the pump crank leads the main crank, the scavenging air must have comparatively high pressure on account of the short time available for transfer. It seems necessary, therefore, to interpose between pump and power cylinder a receiver of such size that, during the entire scavenging period, the air pressure can be maintained without much drop. This pressure should be as low as is consistent with sweeping out the exhaust gases. An abnormally high scavenging pressure not only increases the lost pump work, but, what is worse still, interferes with a thorough driving out of the burned gases. If the air is highly compressed it enters the cylinder with great velocity, and rebounding from the inner walls, causes eddy currents of such magnitude that, from the outset of the scavenging period, burned gases mix with the incoming air, and thus a part of them is retained in the remaining air or the new charge. The perfect scavenging action on the other hand shows very different characteristics. The air should enter the cylinder slowly, avoiding all counter or eddy currents, and should, if possible, in the form of a solid column drive the exhaust gases ahead of itself out through the ports. This action, however, can only be obtained with low pressures and sufficiently large ports.

By carefully timing the introduction of the scavenging air, a great saving in the pumping-work might be effected, for the following reason. During the exhaust the velocity of the outflowing gases is very high, in the neighbourhood of 2,600 to 3,000 feet per second, and is independent of port area, so that if the exhaust line is made as straight and as long as possible the kinetic energy of the exhaust gas column may be sufficient to overcome all frictional resistances in the line, so that the pressure in the cylinder, owing to the over-expansion of the gas, may drop to less than atmospheric. This phenomenon can be easily seen by taking a weak spring indicator diagram from an engine. Figs. I and II show this for a 4-cycle

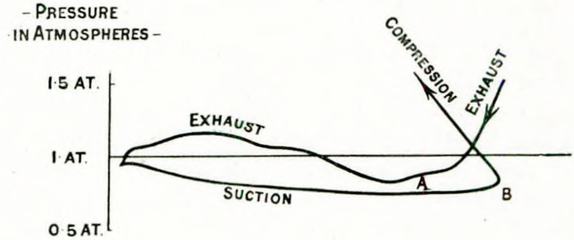


FIG. I.

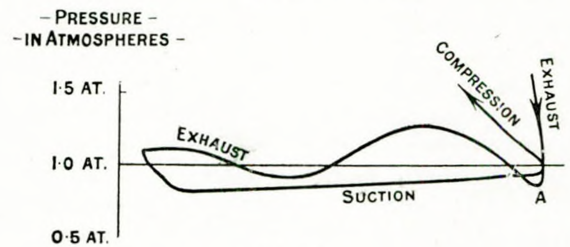


FIG. II.

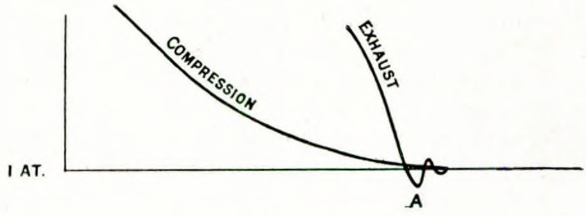


FIG. III.

engine, and Fig. III shows it for a 2-cycle engine. It will be seen that at a certain point A in the exhaust, the pressure falls well below atmospheric. Now if the introduction of the scavenging air is so timed that it occurs just at the point when the pressure in the cylinder is below atmospheric, then there will be less exhaust gas to be swept out, and the scavenging will be much more perfect. The attainment of these ideal conditions depends a great deal upon the size and form of the inlet and exhaust passages, and a consideration of these points should have a marked effect on their design. The allowable minimum pressure of the scavenging air depends mainly upon the size and frictional resistance of the ports and passages and upon the time available for scavenging.

If ρ lb. per sq. in. is the pressure in the receiver or pump, and T is its temperature, and if ρ_0 is the pressure in the cylinder, then the velocity of the air will, in general, be

$$v = 58\ C\ \sqrt{T\ (1 - \frac{\rho_0}{\rho})}\ \text{ft. per sec.}$$

where C represents a velocity coefficient.

If the time allowed for scavenging is $t = \frac{1}{x}^{\text{th}}$ of the time taken for one complete stroke, then the volume of air delivered into the cylinder will be

$$V = a.\,V.t.f.\ \text{cubic feet};$$

where f = area of ports

a = the coefficient of contraction.

In practice it is found that C varies from ·85 to ·95 and a is approximately equal to from ·6 to ·65, but varies with the shape of the ports.

From the above relations it would be quite easy to arrive at the pressure of the scavenging air which would give the best results.

When the piston controls the exhaust ports the time taken for exhausting and scavenging should be from 10 to 12 per cent. of the time taken for one stroke, and if the ports are made in a ring round the cylinder a large area is available for the

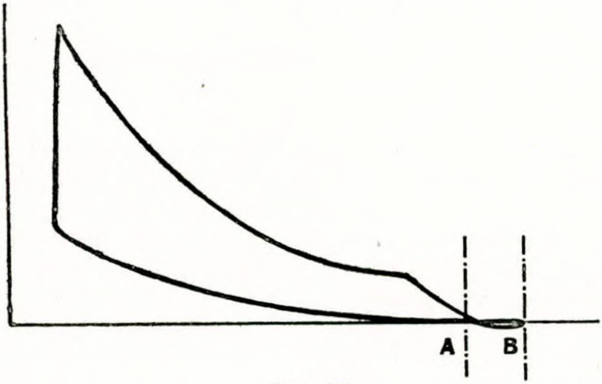
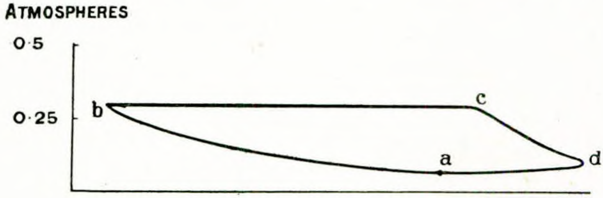


FIG. IV.

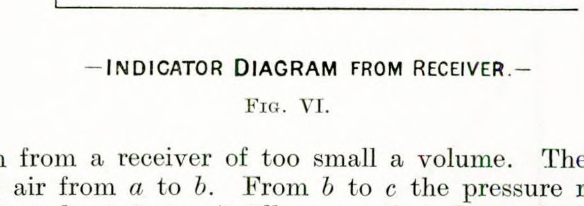
exhaust to get away. The idle part of the stroke, as it were, when the piston is uncovering these ports, A to B, Fig. IV, is not detrimental, since, as compared with 4-cycle engines, the beginning of the compression occurs with full, or above atmospheric, pressure instead of the suction pressure as at B, Fig. I.

It is desirable to have the pressure drop in the air receiver as small as possible in order that the scavenging may continue with undiminished force to the end of the period. To attain this end the receiver should be made as large as possible. The two diagrams, Figs. V and VI, make this point clear. The first



—INDICATOR DIAGRAM FROM RECEIVER.—

FIG. V.



—INDICATOR DIAGRAM FROM RECEIVER.—

FIG. VI.

is taken from a receiver of too small a volume. The pump delivers air from a to b. From b to c the pressure remains constant at about ·3 atm. (4·2 lb. per sq. in.) above atmosphere. Scavenging commences at C, but at the outer dead centre, d, the pressure has already dropped to ·1 atm. (1·4 lb. per sq. in.), and beyond this point the drop is very slow. It is evident that the transfer of air had already ceased before the inlet valve closed at a; that is, part of the time available for scavenging had not been used. After an increase in the size of the receiver, diagram Fig. VI resulted. The maximum scavenging pressure is now a little less than before, the transfer commences a little later, but continues at about the same rate until the closure of the inlet valve, since in this case the receiver pressure does not drop below ·2 atm. (2·8 lb. per sq. in.) above atmosphere. The pressure at the beginning of compression in the power cylinder is correspondingly higher, and since on account of somewhat later introduction of the air it is less highly preheated, there will be a greater charge volume in the cylinder, which finally means greater engine capacity.

By a careful consideration of the facts upon which these notes are based and with greater improvements in the design of 2-cycle engines, there can be no doubt that a 2-cycle engine can be made just as efficient as a 4-cycle engine, and there are even grounds for hope that in the future, instead of saying "a 2-cycle engine can never be made as efficient as a 4-cycle engine," the tables will be turned and we will say "a 4-cycle engine can never be made as efficient as a 2-cycle engine."

Chairman: We will now be pleased to hear any remarks members may have to make on this interesting subject. There are some oil engine experts with us to-night, and I hope there will be a good discussion.

Mr. F. M. Timpson: I have listened with great pleasure to Mr. Duncanson's paper, and think he states the case for the 2-cycle oil engine very clearly. In fact, as far as my experience goes, and it is mainly in connexion with the 2-cycle engine, there seems to be a gradual tendency to its further adoption. He mentions a point with regard to the exhaust: "If the exhaust valve or port is still open when the fresh charge is pumped in, some of the fuel will inevitably escape." In the engine I am associated with we do not seem to have that trouble; but a later production of the same type of engine is on a system he describes later on, that is, the injection of the fuel at the highest point of compression. That is, I consider, a great improvement, because it completely does away with the pre-ignition trouble. Mr. Duncanson apparently believes that a separate pump is necessary for the scavenging air. That system is not adopted by us. We still use the front portion of the trunk as the air chamber, but use a separate air pump for getting the pressure of the fuel, and when the consumption is compared with that of the full Diesel engine it comes out very near the average. Mr. Duncanson goes on to say : " By careful design and understanding of the conditions to be aimed at, there is no reason why the all-round efficiency of the 2-cycle engine should not be as good as, or even better than, that of the 4-cycle engine." I cannot speak from experience of very large size engines, but as regards 40, 60 or 95 horse-power engines, the 2-cycle oil engines are more economical than any make of 4-cycle in my experience. This is not based on test results, but on periods of running of from one to three years, and when compared with the engines on other boats. Another feature is that it is a simple engine, and seems to lend itself to being run by fairly unskilled labour, a point in its favour to the small owner in a class of trade which does not pay high wages. I would like to congratulate Mr. Duncanson on writing such a comprehensive paper on this subject, which covers many points known to those in constant practice with the 2-cycle engine.

Mr. E. Shackleton : I think we may all congratulate Mr. Duncanson on giving us a very clear paper. He has gone pretty well into the details and laid a good deal of emphasis on the scavenging, which, of course, in a 2-cycle engine is very essential. It may be of interest to mention that although the 2-cycle engine has made such progress in the oil engine world, it makes very moderate progress as a gas engine. That is due to a fact not so well known in connexion with the two classes of gases. The gaseous products of combustion from town or producer gas give more trouble to get out of an engine than the products of oil fuel, and, moreover, a little of the products of combustion left behind in an oil engine have not such an injurious effect as have the products of town or producer gas. Of course I do not for a moment say that it is desirable to leave any products of combustion behind in either, but of the two the products are less detrimental with the oil fuel than with the producer or town gas.

It is taken for granted that the 2-cycle engine must, of necessity, have a somewhat shorter life than the 4-cycle. It is pretty obvious that, if you are getting an explosion or power stroke at each stroke of the piston, you must have relatively higher wear and tear, but even then that does not mean that the life of a 2-cycle engine must of necessity be short. I think the 2-stroke engine has made such progress in marine work due to the fact that it is less complicated and more easily reversed than the 4-stroke, although it would not be well to draw too hard and fast lines. The author goes on to say something that is quite to the point : " A more uniform torque can be obtained with a 2-cycle engine, because work is done on every downward stroke of the piston." That, of course, is an advantage where there are large fluctuations in power. On the other hand, regarding Mr. Timpson's remarks on the scavenging pump, if there is not a separate pump I say so much the worse for the engine if of a higher power. Mr. Duncanson says : " It is, of course, assumed that the scavenging air and charge are furnished by a separate pump independent of the power cylinder. The conditions are much worse when, as is sometimes done, the front end of the cylinder is used as a pump, in which case the efficiency is lowered by the strong heat transfer from the power cylinder to the pump cylinder. The conditions are still more unfavourable when the enclosed crank case is made to serve as a pump, but this design is used only in very small powers and need not concern the question of the marine engine at all." I think the engine Mr. Timpson has referred to is not exactly a small engine, and the huge amount of experience of large builders proves that it is unwise to dispense with the pump. After all, there are escapes, and it has been found very desirable to have positive scavenging. Positive scavenging is a practice which may be traced to Mr. Hamilton of the Premier Gas Engine Co. Messrs. Crossley Brothers tried a system in which the scavenging gas travelled along a long exhaust pipe and induced a vacuum, but it was a doubtful success. Mr. Hamilton, in the early '90's, introduced a positive scavenging system which has been adopted, although in a different way, by most of the builders of large 2-stroke engines, oil and gas, that is, a positive pump, the sweeping out of the combustion space and clearing the exhaust gases out by force. Where a separate pump is used, it is a separate job, and you know it is being done properly, but where the pressure is on cylinder areas of large diameter you must have forced scavenging, because in those cylinders the time is so short that if you depend to an extent on the crank you get a sluggish scavenging. I can quite appreciate, where the combustion pumps are used on the Diesel, for instance, the scavenging air rushes in, the unburnt products are pushed out and the velocity of the air which comes along is cool and is the base of the new working charge. You cannot afford, in large engines, to be doubtful as to whether you are getting a perfect scavenge, and I therefore endorse the author's notes on the necessity of an independent scavenging pump. Mr. Duncanson's paper is very well thought out, and everybody with a knowledge of the internal combustion engine will welcome such research work. This is theory based on practice, not practice based on theory, and I think the average engineer will appreciate a paper of this kind.

Mr. W. McLaren: At a previous meeting in connexion with Mr. Shackleton's paper, I said it was desirable for the flexibility of an explosion engine that it should have as few strokes as possible, and it is that consideration, among others, which gives us the 2-cycle engine. Evidently the scavenging is a difficulty. I should like to ask the author, in reference to that, at what end of the cylinder he would be prepared to admit the scavenging air. The question has been raised as to the combustion end of the cylinder, the clearing of that end, although the author says something about allowing the air to enter slowly. I do not see how he is going to attain his object with a slow velocity. In my opinion it must be done with a fairly high pressure, and that is the usual practice, to take from 12 to 20 lb., I should say 20 lb. I take it that the air pump would work automatically with the receiver, it would adjust itself as the pressure was taken from the receiver, and that whatever the capacity of the receiver the pressure would not be diminished. Mr. Shackleton referred to the turning moment or torque. That would depend on the number of cranks, whether two, three or four, resultant upon the number of cylinders, and certainly the flexibility must be superior to that of the 4-cycle engine. I have not had the practice one would like in order to compare the 4-cycle and 2-cycle engines, but it seems to me, looking at the question from a marine point of view, that for the manipulating of the engine under docking or manœuvring conditions, the cylinder should be in the best possible position for applying the compressed air. I had the pleasure of visiting the Motor Show a short time ago, and in going round I was struck with the fact that there is a good deal of marine engineering design in these engines. I also noticed that they are departing from the poppet system of valve and are coming back to some of our own work, that is the sleeve, and I must say as gas engineers they are doing the wrong thing. They should adhere to the poppet valve, as they cannot get the same amount of control on each end with a sleeve. I have to thank the author for giving us this further information on the internal combustion engine.

Mr. TIMPSON: Mr. McLaren referred to the question of scavenging in 2-cycle practice. The scavenging air goes into the lower end of the cylinder, the exhaust port being higher than the admission port. The air is about 4 lb. pressure and sweeps out the gases.

Mr. MCLAREN: There is no question of the heat. The cold air is bound to absorb some of the heat left.

Mr. TIMPSON: We only admit air at about 4 lb. pressure. They put gauges on, but they are rarely of any value. It is found that a very low pressure is quite sufficient to drive everything out.

Mr. THOS. JONES: Mr. Duncanson is to be congratulated upon his paper; not only is it practical but theoretical. In his notes on the difficulties to be overcome, Mr. Duncanson has given us a correct statement with regard to the inert gases in the combustion chamber. It is practically impossible to design an efficient engine with these gases remaining; therefore it is necessary to have scavenging arrangements and, preferably, they should be away from the charge, and should not depend on any of the fuel. Concerning the running of the engine on a weak charge, I might mention that this will help towards the adoption of the graduated governing gear. It has the best effects on oil engines, as it keeps the cylinder under continual heat, and also prevents any condensation of the fuel taking place on the cylinder wall and there acting as a lubricant. With regard to auxiliaries, I do not see, if auxiliary machinery is simply designed, why it should be less efficient than the ordinary methods of valve gearing. The 2-cycle engine is clear of gear wheels, springs and anything of that kind. It also takes less time to put it together, as the timing and setting of the valves in a 4-stroke engine require considerable attention. In the matter of the combustion chamber, the 2-stroke engine has a minimum surface, therefore there is a minimum loss of heat from the working charge, that is to say, there is a minimum of heat loss in the water jacket, which minimum loss of heat may be said to be a defect of the internal combustion engine. Another thing is that the combustion chamber of the 4-stroke engine has to be a little larger in surface owing to the valve pockets. It is most difficult to design the combustion chamber of the 4-stroke engine to give efficient results without cramming the valves; even putting them in the cylinder head causes them to be too close together, resulting in the small amount of metal between the valve seats tending to distort the seats during a long running on heavy loads. In the combustion chamber of some 4-stroke engines the valve pockets occupy about one-sixth of the cylinder capacity and are not scavenged, so that with every fresh charge you are putting in one-sixth of the cylinder capacity of exhaust gases. As Mr. Duncanson remarks, the simpler the combustion chamber, the better provision there is for the quick firing of the charge. The efficiency of quick firing of the charge has been proved with petrol engines where two sparking plugs are inserted. In high speeds power was gained, and in an engine of 1,600 revolutions per minute the indicated horse-power was increased from 6·5 to 7·3. Concerning the starting of the 2-stroke and 4-stroke engines, the ease of starting simply depends on how the engine was left previously to the starting. I have found it good practice to turn off the lubricating oil from the cylinder a short period before the engine stops. This prevents the gumming of the piston, and an easy start is effected. Where paraffin oil is injected into the combustion chamber or cylinder of the engine after the engine has finished running, a slight treatment with paraffin by injection while the engine is still warm is of advantage. The paraffin is vaporized and condensed on the cylinder walls and helps to lessen the gumming-up of the piston in the cylinder. In connexion with Mr. Duncanson's remarks referring to the 4-cycle engine not being made as efficient as a 2-cycle engine, I am of the same opinion, especially when we get double-acting 2-cycle engines, because in a double-acting 2-cycle engine the inertia forces and weights of the respective parts will be cushioned on each stroke, as in the steam engine. In the ordinary single-acting 4-cycle engine, three of the four strokes remain uncushioned, and the forces are passed though the connecting rod and bearings to the foundations, whereas in the

2-stroke double-acting they are absorbed in the compression of the charge and the accumulated power given out in the next working stroke. The double-acting 2-stroke engine, therefore, would be still more mechanically efficient than the ordinary 4-cycle engine. I think Mr. Duncanson has set before us an extremely good paper, and one well worthy of study. I shall read it over several times, and I believe we have all learnt something from it.

Mr. E. SHACKLETON : I might mention a method of using the unburnt gases to govern the speed of the engine. When they want the engine to run slower, instead of using the throttle they have an arrangement whereby the lift of the exhaust valve is decreased, the new gas cannot get in, and the engine therefore runs slow. That system depends entirely on the unburnt gases preventing the new gas entering the cylinder. In connexion with the ordinary stationary oil engine having a variable load, there was trouble about keeping warm. If there was a governor on the exhaust and the engine was on a light load it choked the exhaust. Choking the exhaust means keeping it warm. It was thought better to have had no exhaust and keep it going than to have it so light as not to keep it going and thus fail to utilize the charge.

Mr. TIMPSON : It may add a little to the information with regard to the cost of upkeep of the 2-cycle engine to say that in a 40-horse-power engine the cost of upkeep was £4 for the year. In one case an engine had been running for over six months and had never been touched.

Mr. SHACKLETON : Mr. Timpson will appreciate the difference between engines of 40 and 500 horse-power. When the large 2-cycle engine was introduced one firm had the strange experience of seeing the end of the piston visibly disappearing day by day.

Mr. W. WALKER : Was the moulder to blame ? Perhaps the castings were wrong.

Mr. SHACKLETON : No, it was a case of modification. The 2-cycle engine got very warm, and such difficulties were only overcome by a better knowledge of the composition of the metal and its action under the new conditions.

Mr. Timpson : It is evident that such troubles are due simply to a lack of experience, and as the experience grows the difficulties disappear.

Chairman : I think we will agree with Mr. Duncanson that this engine is arousing a great deal of interest. As the members are aware, we started on the subject of the oil engine last March, and have since had some heated discussions upon it. Personally, I have not had much experience with oil engines, but from what I can gather the 2-cycle engine seems to be managed by unskilled labour more easily than the 4-cycle, and with small powers the wear and tear and upkeep are very much less. The wear and tear are almost equal in large powers in the 2-cycle and 4-cycle engines. It may interest the members to know that in this month's issue of *The Marine Engineer and Naval Architect* there is a description of the 2-cycle engine fitted to the yacht of the Marquis of Graham, our President. I think it will be gratifying to our President to know that our members have given so much time to the discussion of this type of engine. Undoubtedly it will claim the close attention of all engineers in the near future. A question was raised at a previous discussion as to who was to build the oil engines. I think the men to deal with the matter are marine engineers. Marine engineers are never slow in taking advantage of every good thing placed on the market. When a new engine is introduced they immediately set their brains to work to see if it can be adapted for marine purposes. Marine work is very different to land work ; there must be many modifications before engines can be put on board ship, and several of those who are making experiments on this new type of engine to my knowledge are marine engineers who are making a speciality of it. With all due respect to gas and oil engineers, one has to help another in this matter, and the best results are being obtained when this is done. We hear a lot of the large powers on board ship, but I do not think we have had much experience yet. We had a gentleman here a week or two ago who told us about a coal gas engine on board ship, but I do not think that so reliable. I think the oil engine is a step in the right direction, but, as already remarked, the difficulty is to get the oil. The carriage and stowage of oil is a very big item. It has been said that one can get it for almost nothing in India and America, but it is a very different thing to bring it to this country and store it. Not long ago there was a fire at the American Oil Co.'s wharf—people do not want dangerous fuel stowed on valuable docks where there are all kinds of cargo, and if oil fuel is universally adopted the Dock authorities will want an extra high tariff and insurance, and all this must be reckoned in the cost. You cannot stow oil where you can stow coal. Another question has been raised with regard to carrying oil in the double bottoms. Personally, I do not think this is possible. I think there must be separate bunkers apart from the ship's structure. Supposing the ship ran ashore and started a leak in the bottom, there would not be much hope of getting her off if all the fuel ran away. You would be carrying a valuable quantity of oil fuel with the risk of losing it at the very time you wanted it most. I think we are all indebted to Mr. Duncanson for his very able paper. He is a young man who has forged ahead, and we are very proud indeed to have him set forth a paper of this kind before the Institute, and hope it will not be the last.

Mr. Timpson : I have pleasure in moving a very hearty vote of thanks and congratulation to Mr. Duncanson on the paper he has put before us, and I support Mr. McLaren's remarks expressing the hope that we may hear from him again.

Mr. Ross seconded the resolution, which was carried with applause.

The meeting closed with a vote of thanks to the Chairman.

REPLY BY MR. DUNCANSON.

In replying to the discussion I must first take this opportunity of thanking the members for the kind way in which they have received my paper.

With regard to the point brought forward by Mr. Timpson, it has been found that with most 2-cycle engines in which the exhaust is still open while the fresh charge is being pumped in, part of the charge escapes, to a greater or less degree. Of course the escape is minimised when there is a cushion of scavenging air between the exhaust gases and the fresh charge, but even then some of the charge diffuses into the exhaust. Fuel economy, of course, may be only a secondary consideration in determining the choice of an engine, because if we have the interest and depreciation, and repair bill of a 2-cycle engine very much lower than with a 4-cycle engine of the same power, then the consumption of fuel is a matter of small importance if it is only slightly greater.

I agree with Mr. Shackleton with regard to engines running on producer gas, as this already contains a large proportion of inert gases, and the presence of the products of combustion from the previous charge would still further retard combustion. In connexion with Mr. Shackleton's remarks on the scavenging pumps, I should prefer to drive them from ordinary pump levers driven from the crosshead of the engine. The total displacement of the pumps would be about 1·5 times the total piston displacement of the engine. This arrangement would give the engine something of the appearance of an ordinary marine steam engine, and the whole design would, I think, appeal to marine engineers.

With regard to the question of the long exhaust pipe acting as a scavenging agent, it may have failed to effect this properly by itself, but my contention is that this could be used in conjunction with the scavenging pumps and thus put as little work as possible on to the auxiliaries. In one case a ship has been fitted with Diesel engines which exhaust through one of the steel masts, thus dispensing with a funnel and getting the advantage of a long exhaust pipe. In answer to Mr. McLaren's question as to the best end of the cylinder at which to admit the scavenging air, I think the best system is for the exhaust to be controlled by the piston uncovering a ring of ports in the cylinder at the bottom of the stroke, and the scavenging air to be admitted by one or more valves in the cylinder head. By this means a very large opening to exhaust could be obtained and a "straight run through" of the scavenging air would be an additional advantage. With a long exhaust pipe the pressure in the cylinder might drop to something like ·5 lb. per sq. in. below atmosphere and a pressure of about 4 lb. per sq. in. would be quite sufficient for the scavenging air to sweep out the remaining gases.

With reference to Mr. Thos. Jones' remarks on the double-acting 2-cycle engine, I may say that this arrangement would be the ideal one, but I am afraid it would be impossible, on account of practical considerations, because of the difficulty of cooling the piston rod, and the complication of valves in the bottom of the cylinder. Of course, if these difficulties were overcome, the double-acting 2-cycle engine would be lighter for its power, and would give a more uniform torque, than the single-acting engine.

With regard to the practical considerations governing the design of oil engines, it was only within comparatively recent times that an efficient internal combustion engine was possible, on account of the high quality of the material and the exact workmanship necessary in making engines which have to stand up continually to a pressure of 500 to 700 lb. per sq. in. The quality of material necessary in making a good steam engine, say 50 years ago, would not nearly come up to the requirements of an oil engine of the present day, and it is only with the improvements which have come about in materials and workshop methods that a good mechanical job can be made of an oil engine. There is still room for improvement, however, and if only we could get the material to stand up to it even more progress could be made in modern internal combustion engines.