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Notes on the Upkeep and Management of Boilers on a Tramp Steamer.

BY MR. G. A. O'NEILL (Member).

READ

Monday, December 1, 1913.

CHAIRMAN:—MR. GEORGE ADAMS (Member of Council).

CHAIRMAN: In the unavoidable absence of the author, this paper will be read on his behalf by the Hon. Secretary.

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THE upkeep of a boiler depends a great deal on the management of it, and it is generally understood that the successful management of a boiler consists in getting the desired results with as low a cost as possible. To be able to do this it should be handled with proper care, and any defects showing should be remedied at once, or at the first opportunity, and their causes removed.

Internal Corrosion:—The greatest source of trouble with boilers is internally, through corrosion, and the depositing of scale on the heating surfaces. Internal corrosion may arise from various causes, viz., impurities brought into the boiler with the feed water, air in the feed water, mechanical straining, in many cases through galvanic action being set up between two classes of metal in the construction of the boiler.

If sufficient interest and care is taken, internal corrosion may be prevented to a greater extent than is often the case on tramp steamers, by the present means available for stopping or reducing it, such as the use of zinc plates, keeping the feed water as hot as possible for liberating the air, and adopting the use of alkalies (soda) in the proper manner.

Sufficient care is not always taken when fitting zinc plates into the boiler, by cleaning away the dirt and scale from around the necks of the studs, to which they are at some parts fitted, so as to ensure a proper metallic contact. If this is not done the dirt or scale acts as an insulator, and so destroys the object for which they are used, viz., in setting up galvanic action between the zinc and the boiler plates. It is a simple matter when fitting these plates to give the studs a touch up with a file.

The use of soda is an aid for the prevention of corrosion, or rather, in reducing the acidity of the water. This is very often used without any consideration as to the amount required. If an engineer knows his boilers were properly cleaned and a necessary amount of zinc plates fitted when leaving port, by the use of litmus papers, he can get an idea as to whether he is putting sufficient soda or otherwise into the boilers on the passage. A small quantity of water can be drawn off at the salinometer cock, and the litmus papers inserted; if the blue paper turns pink and the pink paper remains unchanged, the water contains acid; if the result is the opposite the water is alkaline in nature.

By careful treatment of corroded plates in a boiler they can often be prevented from further deterioration; for instance, the pitting that is frequently found going on, along and a little above the line of fire bars, on the water side of a furnace. These places, if thoroughly cleaned and the black scale removed, then coated with a mixture of metallic zinc powder and clean fresh water, will show good results, but it must be kept up and the same places done over again after every long passage.

Corrosion often sets up on the front end plates and the front end of the main stays in the steam space on the side of the boiler to which the uptake is fitted. Some engineers, to arrest this, suspend zinc plates from the stays by means of iron hangers. The presence of zinc no doubt is an advantage, but this method is not an advisable one, owing to the liability of the zinc plates to break, falling off the hangers, and landing on the top of the furnaces. A good method is to fix iron boxes on the stays and let the zinc plates rest in them. Good results have been obtained by filing the ends of the stays clean, and cleaning the front end plates as before stated on the furnaces, and painting them with zinc white, but this also must be kept up.

It is quite a general practice when scaling furnaces to only scale them down to the line of fire bars, leaving the entire bottoms untouched, and scale is allowed to form to a considerable thickness and left on for voyage after voyage. This I consider to be a very bad practice, as corrosion has been found going on badly under this scale on the furnace bottoms, which, had the furnaces been kept cleaned right round, might not have ever started; in any case, it would have been seen at the commencement, when steps could have been taken to remedy it.

The backs of combustion chambers and the necks of the stays at the combustion chamber end give another source of trouble due to corrosion, and require every attention and care. When corrosion has once started here it is hard to stop owing to its inaccessibility. Probably, the best means of stopping it is to clean the parts as well as possible and fasten zinc plates to the stays, midway between the boiler end plate and the combustion chamber back.

Internal Feed Pipes.—These pipes, when fitted, should be given every attention, as the position in which the feed water is discharged into a boiler has a material effect on the circulation, which leads to show that should they be allowed to remain in a bad state of repair it would mean loss of efficiency. They often give trouble by continually bursting, and in many cases, if not well secured by clamps, come off altogether. This may be said to be due to water hammering, caused by the internal pipe becoming partly filled with steam, and the feed pumps, every stroke, delivering comparatively cool water, producing a concussion by the sudden condensation of the steam, which forms a vacuum in the pipe and causes an inrush of boiler water. In Mr. Stromeyer's book on boilers it is stated that a small hole near the flange on the pipe or an uncemented joint entirely prevents this action. This has certainly been found to work well with the uncemented joint, but with copper internal pipes another trouble arises. Corrosion sets up badly on the boiler plate to which the brass flange of the pipe is jointed, also the studs when of iron or steel get corroded; this is undoubtedly due to galvanic action between the copper pipe or brass flange, and the boiler plate and studs. It is therefore necessary that this joint should be kept tight when copper pipes are fitted. Another advantage gained by internal feed pipes is that the feed water passing through them becomes heated before being discharged, and further loses any air it may contain.

In modern ships the foregoing troubles are somewhat eliminated by the fitting of independent feed pumps and the efficient feed heaters where the feed water is delivered into the boilers at over 200°F., being practically free from air. Impurities are further extracted by the use of modern feed water filters, and with a good evaporator the use of salt water feed is reduced to a minimum; but in the class of ship to which I am referring where the feed water is dealt with solely by the main feed pumps, the highest temperature at which the feed water can be pumped into the boilers is seldom over 150°F., and although evaporators and filters are fitted, it is, in many cases, found necessary to work the boilers at about 5ozs. density, to keep a protective scale on the plates, especially with new boilers.

Raising Steam.—When commencing to raise steam it is quite a common rule with many engineers to set the fire away in the centre low furnace of a three-furnace boiler four or five hours before the others, in the hope that the cold water which remains undisturbed at the bottom will get warm. This rule undoubtedly originated in old ships, where there were no appliances fitted for artificial circulation, such as hydrokineters, or a suction pipe from the boiler bottoms to a feed donkey pump. With these appliances I consider the above practice unnecessary, as it must set up an undue strain on the front end plate by the centre furnace becoming heated and expanding, and the two wing furnaces remaining cold and rigid, to which may be attributed the cause of leaky furnace mouth seams when happening under such circumstances. For this reason all fires should be lighted together, especially when there are means of promoting artificial circulation.

Too much care cannot be taken in attending to the circulation when raising steam. When the fires are set away the safety valves should be opened to allow the heated air in the steam space to escape. (Another plan is to ease the stop valves off the face and allow the heated air to pass through and warm up the engines, but this is not always convenient). If this is not done the air forms a pressure, and this air pressure on the surface of the water prevents the formation of steam bubbles when boiling point is reached, which would materially assist the circulation by carrying water with them as they rise. The safety valves should be left open until steam is blowing through them, and the hydrokineters or donkey pump, as the case may be, kept working, until the boiler bottoms have grown quite hot.

It is often the case that after steam has been raised it has not been wanted for some time, through delay, and with the boilers standing and no circulation going on the bottoms will become quite cold, even when the steam is at working pressure. If a donkey pump is the only means for circulating, difficulty will be found in getting it to work, if at all, with high pressure on the boilers. To guard against this drawback, it is always advisable to fill the boilers up full glass, and blow off the cold water from the bottoms at intervals. Should there be no delay, it is still an easy matter to blow the water off before starting. This method of blowing might be adopted when lying under banked fires, especially when fresh water is obtainable for making up the loss.

If the boilers are allowed to stand long with their bottoms cold, under pressure they are sometimes unable to bear the additional straining to which they are subjected, by the difference of temperature between practically the upper two-thirds and the lower one-third of their circumference, and if not causing a cracked shell plate it is invariably the cause of leaky circumferential seams, which, when once started, are a trouble to keep tight ever after. This difference of temperature can amount to considerably over 250°F., and as iron expands ·0012 and steel .0011 of their length between 32°F. and 212°F., it can thus be seen, that with a large boiler, a severe stress would be set up. Siemen's steel has now taken the place of iron in boiler making, and as it possesses a much higher tensile strength, together with greater elasticity, the danger of cracked shell plates is considerably reduced, but as the percentage of strength of the circumferental seams is comparatively low, the danger of sheared rivets and leaky seams have still to be guarded against.

External Corrosion.—In dealing with the external parts of a boiler, there are many things in the management to which sufficient care is not always given with a view to its preservation and upkeep. The bottoms of combustion chambers on the fire side for instance; here an incrustation of scale and dirt, if not watched, will form, and with the combustion chambers being frequently swept and scraped out, this scale obtains quite a smooth surface and appears like the plate itself. It can easily be detected by a tap with the round end of a hand hammer, when it will break off in flakes. If this is allowed to form, corrosion invariably goes on underneath it, and the thickness of the plate is sometimes seriously reduced before being noticed.

Salt from leaky tubes and joints, when mixed with wet ashes, causes corrosion, and as this often occurs in the combustion chambers, it is essential that any leaks noticeable should be stopped at the first opportunity.

The boiler front end plates at the bottom suffer a great deal by wet ashes coming in contact with them. This cause can be eliminated to some extent when at sea, if the ashes are removed from the furnace fronts immediately after the fires are cleaned, and not allowed to remain there until the end of the watch, as is often the case.

Great care should always be taken when putting on bottom manhole doors, to ensure a good joint. These doors, when leaking constantly, cause the flanges of the plate to get corroded away, which, in time, renders it impossible to make a proper joint. This trouble is further influenced by the presence of wet ashes, when the manholes are in the stokehold. More often than not, ashes accumulate on the manhole flanging, between the " dogs " of the door, and any salt leaking from the joint forms a solid mass with the ashes on the door, and might remain this way when on a long passage for weeks, corrosion going on all the time. This leads to show that they should be looked at daily at sea, and any signs of accumulation of dirt at once removed.

Furnace Doors.—These being in constant use soon get out of order, and as they are an important item regarding economy, it is necessary that they should be kept in proper repair. If not kept properly fitted with baffle plates, they soon become warped with the intense heat to which they are subjected. The difficulty then arises in getting them to shut closely, and cold air is allowed to be admitted into the furnaces to excess, and so reduces the efficiency of the boiler.

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CHAIRMAN: The paper before us to-night is evidently drawn from the practical experience of the writer with boilers under natural draught, and even although the experience of some of us present may not be of the tramp steamer class, the various points raised should enable us to have a fairly good discussion.

Mr. Jas. S. Gander: I have been very much interested in listening to the reading of this paper. It is a paper on a subject which is of the utmost importance to the marine engineer, because, whatever type of machinery the vessel is propelled by, the fact remains that there are always boilers of some kind or other on board. With reference to the author's remarks on internal and external corrosion and the causes, I think the matter is one which does not always get the fullest consideration on the average vessel. In these days of feed heaters, air extractors, and filters, we may safely assume that the feed water which enters the boilers at sea is fairly clean. In my opinion damage is done when in port or when proceeding up a fresh water river. Too frequently the water from the river is pumped directly into the boilers instead of being allowed to settle in tanks first. Even when such water is pumped it is usually the case that the suctions are too far from the bottom of the tank to deal with any sediment. Such tanks should be provided with high and low suction—the high suction for boiler use and the low suction for draining purposes. Many fresh water rivers, such as the Euphrates and the Yang-tze-Kiang, contain many vegetable organisms which do not deposit, but, on entering into contact with the water in the boiler, form a very objectionable scum on the surface, which may cause valve trouble and priming, in the event of heavy weather. This can only be got rid of by the intelligent use of the scum valves in calm weather. The sediment is best removed by slow pumping out with little or no steam on the boiler. The author's remarks as to the necessity for fixing the zinc plates in a careful manner appear to me to fit the case exactly. It appears to me that when fitting these in position, we are making an electrical joint, as it were, for a current of extremely low potential. It is therefore unreasonable to expect that a dirty joint will be effective. The exact cause of the pitting or corrosion at the fire bar level seems difficult to arrive at. Authorities, so far as I have been able to observe, agree that the temperature difference is the chief cause. Is the cause the sudden liberation of gases in a nascent state at this particular point, or is it a pure galvanic action due to the unequal heating of the parts of the same metal?

This furnace corrosion, so far as I have observed, does not occur when the boilers are fitted for burning oil fuel, as usually the whole circle of the furnace is used as a heating surface. External corrosion on the fire side is also absent with oil fuel, as the heating surface can be kept so much cleaner.

The author appears to have covered the ground with reference to corrosion in a very practical manner. There is one item, however, which he has not mentioned. I refer to the external corrosion of the shell plate under the boiler covering. This very frequently occurs where valves have been allowed to leak for some time and the escaping water gets under the lagging and the result may not be observed till the covering is removed. Referring to the author's note on the difference in metals supplied, I think, as a general rule, this is not the fault of the makers. Tubes are often renewed with others of a material differing from the original, with the result that the expansion varies, the tube plate is always in a state of varying tension, and the tubes necessarily give further trouble.

In his remarks *re* circulation in the boilers, the author touches on one of the most important duties of the marine engineer with relation to the boilers under his charge. The old idea of lighting one furnace at a time seems to be exploded nowadays. In my opinion the use of the hydrokineter should be attended to with care, as too great an injection tends to stir up and circulate sediment, and the vibration attendant on the injudicious handling cannot but be harmful to the boiler. To engineers trading between ports where a plentiful supply of pure water is available, this injunction may seem superfluous, but to those in Eastern waters, where the supply has often to be taken from the rivers, the fact is a very important one. Every engineer realises the fact that boilers should be well circulated when raising steam. Why should we not circulate also when cooling down? With regard to the use of zinc plates, I think these are being less used than formerly. The Company with which I am connected has not used them for several years. Although zinc plates and soda are used for two different purposes in a boiler, it is found that the constant use of soda effects a double purpose, viz., it neutralises the acidity and deposits the scale-forming constituents of feed water. For reducing the weight and bulk, the soda is often calcined, that is to say, that the water of crystallisation is driven out by heat, otherwise the formula is the same as that of common washing soda. If the water of the boiler be examined twice a day by the phenolphthaleine test, and sufficient soda be added to the feed water to keep the boilers slightly alkaline, scale will not form. The nitrate of silver test is a very delicate one for the salinity of feed water, and by its use a leak from the condenser can be detected long before it is apparent to the taste.

With reference to the advantage obtained from the careful use of calcinated soda, I have been obliged on one occasion to run a donkey boiler for a week on sea water, not even having the benefit of the condensed feed, which was put into the main boilers. On opening up, the heaviest scale found was less than one-sixteenth of an inch thick on the crown of the furnaces—other parts were practically clean. On the same vessel, the main boilers ran from February of this year to the end of September without the water being changed. On opening up, practically no scale was found. The feed during this period was principally made from fresh water rivers and from evaporators. I attributed this to the constant use of soda and paying due attention to the scumming and drawing off of sediment. I ought to mention also that the condenser gave trouble and about 18 tubes were plugged or renewed. I think a very common cause of the heavy scale found in some boilers is due to pumping out (unless for cleaning) when the scum settles on the heating surfaces. I think all members will agree that the life of the boiler tubes and plates would be much prolonged by the introduction of an efficient apparatus for scaling tubes, and that boiler tubes are never cleaned properly, to say little about other parts difficult of access. Perhaps the best scaling obtainable is in the Chinese ports, where the operators are often small enough to sit on the combustion chamber stays.

Mr. F. M. Timpson: The author emphasises the necessity of circulation, which is certainly most important during the process of raising steam. In large vessels I think the system of circulation should be as much as possible automatic so as to require no special attention on the part of the engineer. During the last few years there have been a number of circulating devices fitted to large steamers, and the results, I believe, have been very good in consequence. Of course, it is true that accidents have happened with a number of boilers, but we are all liable to make mistakes, and circulation is of such vital importance in maintaining the boilers in good condition, and in avoiding the leaky seams, that I think automatic circulation would be the right thing to adopt. With regard to boiler scale it came to my notice recently that a method of scaling boilers has been tried in this country by an injection of certain ingredients into a boiler at a temperature of, I think, 70 deg., and the scale all dropped from the tubes and came off perfectly clean. I believe experiments have recently been made with marine boilers, and the same results have been obtained.

Mr. Jas. Shanks: The subject of the paper to-night is one in which all marine engineers must be interested, and as one who has been trained in tramp steamers, and who has had the superintendence of both tramp steamers and liners, I can claim to know something about the management of boilers in this class of vessel. If I went back a few years I could tell you great and wonderful tales of internal corrosion of boilers; but those days are past, the days of internal corrosion in boilers are nearly over, and at present, even in tramp steamers, it is hardly known. The engineer of the tramp steamer, as a rule, is entirely responsible for the upkeep and management of the boilers of his ship. He is not under the wing of a superintendent and shore staff to look after the boilers during his stay in port. He has to look after the arranging of these matters himself, and, as a rule, it is excellently done. The ordinary sea-going engineer is conversant with most of the things mentioned in the paper. It is the first duty of every engineer taking charge of a new ship to take precautions to prevent corrosion, and by the use of zinc plates as described in the paper, and the judicious use of soda, I can say without hesitation you will find internal corrosion in scarcely any boilers. These are actually facts which have come under my observation in a great number of tramp steamers. But it sometimes arises that there is a difficulty in getting fresh water to fill the boilers, or in getting zinc plates properly fitted or even in getting them fitted at all, or perhaps there is no soda obtainable, and thus at times corrosion starts, and when once it starts it is difficult to arrest. I perfectly agree with the author's methods of attempting to arrest it. It is what I have experienced myself and the steps I have taken to arrest corrosion in boilers. There is not much said in the paper about the density of water in boilers, but I think the author mentions that, for some reason, he finds it necessary to keep the density at five ounces per gallon to get a protective scale on the heating surface. I do not agree with that at all. Keep the boilers fresh, prevent scale forming in the boilers, and you will get the best results.

With regard to the method of fitting internal feed pipes, in some boilers they are carried into the steam space and in others they are often fitted near the furnace crown level, and the author is quite correct in saying that these pipes sometimes break away due to shocks; it is a common practice. I do not believe in having an unjointed flange against the boiler shell. The proper method is to have a small hole in the top of the pipe near the flange; that reduces the shock, and there is no trouble whatever. But I still believe in carrying the feed pipes into the steam space; you get a better circulation, and it is better for the boiler. It is most important that efficient circulation should be maintained in the boiler while raising steam, and the most efficient method is the use of the boiler feed pump. As long as the pressure is not too high it can be done with a degree of safety. As Mr. Timpson has said, serious accidents have been known to occur in connection with the circulating of water, and very great care should be observed when circulating the water with steam pressure on the boilers. A number of superintendent engineers have been attempting to get some automatic system of circulation, both for raising steam and under banked fires; but as far as I know there are none which are quite efficient. Some do excellent work while lying under banked fires, and that is important in tramp steamers, and I think they should be fitted into every ship, as any engineer would hesitate in using the donkey or feed pump for circulation with a pressure of 220 lbs. on the boilers. There is always a danger, and we need some automatic system of circulating water under banked fires. The author's remarks are quite right about allowing the heated air in the steam space to escape when raising steam. The ordinary practice, I think, is, not to open the safety valves, but to open the gauge cock. It is quite sufficient for the purpose. The stop valves are, as a rule, eased off the face. With a well-managed boiler, and with the almost perfect system of manufacturing boilers nowadays, there is really very little trouble with external corrosion, even on the bottoms of shells in large boilers. I have had experience of boilers 20 ft. long and working for a great number of years without any indication of leakage on the circumferential seams. The author remarks about the shearing of rivets on the circumferential seams on account of the low strength of the circumferential as compared with the longitudinal; is an experience unknown to me. In former days it was very common to see very bad leakage in those seams. As the author says, leakage, wet ashes, and salt lead to very detrimental corrosion on the fronts at times, and if allowed to go on it becomes serious, but, nowadays, the average sea-going engineer is fully alive to difficulties of this description, and takes every precaution to prevent anything arising from such a source. As the Chairman remarked, the author does not refer to forced draught boilers. Of course the management of forced draught is more important than many of the subjects touched upon, and we could have an entirely new discussion on that alone.

CHAIRMAN: The author speaks of a feed temperature of 150 deg.; it is evident that in such a case a feed heater is not used. It should now be realised that every 10 deg. increase in the feed temperature by exhaust steam means a saving of one per cent. in the coal used can be effected. These results are being constantly obtained.

Mr. D. HULME: In my experience with the management of boilers, to open the safety valves when once they are tight is a thing I would not care to do. In a number of boilers, if one is set a little weaker, it would save the others. I am afraid the writer would lose a little of his economy if he opened the safety valves and could not get them tight again. Reference has been made to the good effect of scale forming in the seams; but if the evaporator is used and you are getting nothing but pure water in the boilers I do not see how it is possible to get this with which to fill up the crevices in the seams.

Mr. G. U. MORGAN: The question of internal corrosion seems to be one of the chief points in this paper, and Mr. O'Neill mentions that, in fitting zinc plates, the bolts should be well cleaned before being bolted on. Later on, with regard to the combustion chamber main stays corroding, he says that, instead of hanging the zinc plates from the stay, it is better to fit them in a box. If they were fitted in the box they would have no direct action with the stay, and I have found that the best way is to clean the stay itself and put zinc powder on it. He also refers to corrosion at the backs of the combustion chambers, and the necks of the stay, and there again I have also found it much better to clean the plate thoroughly and apply the zinc powder. By keeping constantly at it. I have arrested several very bad pitting cases in that way, but I have not any great faith in the zinc plate itself. It is all right when you can get a clear action. With regard to external corrosion, this is sometimes caused by the fumes from the bilges, and I think attention ought to be paid to the bottoms of the boilers. The bottoms of the boilers, when they are affected in this way, should be scraped and covered over with zinc. Mr. O'Neill refers to the practice of setting away the centre fire first. It is, of course, a thing which is very commonly done, and I know of a rather bad accident which I attributed to this action in causing unequal expansion. Mention has been made of fluid scalers for getting scale off the boilers. In tramp steamers it is very often found better to let a slight scale form, and if a fluid scaler is used it would get the scale out of the seam also, and the seam would leak badly. That is the only thing I see against it. Of course it might act when at sea. Some of this fluid may stay in the boiler and bring the scale down on the top of the furnace. You get that result even with fresh water, say when in the river under banked fires for three weeks as we were on one occasion. With the constant pumping up, the fresh water had a scaling effect, and in time the scale came off and settled round the furnaces and the result was the furnace came down. The same thing might happen with the use of this fluid, and it will require a great deal of testing before it can be used satisfactorily.

Mr. D. Hulme: I had a good deal of trouble with pitting in the bottom of the drum of a water-tube boiler, and I met the difficulty in the following manner. I drilled a hole through the corroded part, and put a collar stud on. I then attached a zinc plate, and got a metallic contact. By doing this in each instance I filled up all the holes and made the shell good again. I had 14 of these in the one drum. I have had the boiler under my charge for 21 years, and it is still carrying 210 lbs. of steam. My difficulties arise due to the steam being taken from the boiler, passed through copper tubes, condensed and sent back to the boiler, also additional water on the outside of the copper tubes, so that electrolysis ensues, which sets up pitting. The plates are $6'' \times 12'' \times 1''$, and in three weeks or a month they are all eaten away. I have to renew them once a month. Many years ago a method was introduced to stop corrosion by attaching zinc balls with copper wire; electrogens, they were called, but I think they were not successful.

Mr. F. M. Timpson: In view of some of the remarks which have been made on the use of fluids for scaling, I most strongly agree that they should not be used in a haphazard manner. Boiling out with fluids is, however, a practice very commonly adopted, especially when the boiler is new, and it is extremely good in such cases because it gives a perfectly clean boiler to start with. After the trial trips the boilers are boiled out thoroughly clean before the vessel is handed over. I did not refer exactly to the use of a fluid in the case of scale, but to the use of a certain amount of fluid and other ingredients, which

I have seen used with good results. Of course we should be very cautious about introducing fluids of any kind into a boiler.

Mr. B. P. FIELDEN: It seems to me that we are considering the question of scale in boilers at the wrong end. The troubles with boilers depend upon the capital value of the plant put into the vessel. Some ships are not fitted with feed heaters, filters, evaporators, or anything but the barest machinery necessary; they are built to carry the cargo at the lowest possible initial cost, and that is the beginning of the trouble. With regard to circulation I think the common practice is to start the pump when the fires are lighted until steam is showing and the circulators take care of the rest, and as long as the fire is alight the circulation proceeds. That is our practice, and I think it is fairly general. What is the use of circulating the water? The only advantage, it seems to me of fitting circulators is that it stops corrosion from forming around the combustion chambers. There is not much advantage gained by circulation in the bottom of the boilers. We find that circulators reduce the amount of zinc used, and the combustion chambers are kept in a much healthier condition. I think a paper like this might be left over for a week for further discussion. I am sure there are a good many points which might be considered further.

Mr. D. HULME: Mr. Fielden asked what was the use of circulation. I can give you an instance, not in connection with boilers, but one which will show the use of circulation. We are now running evaporators with glass discs and electric lights inside, and where we are getting a ton of water for $1\frac{1}{2}$ sq. ft., if we get the water in the evaporator just to the height the circulators take effect, immediately we get one ton per sq. ft. We are very frequently running them on trials, and we can see the action taking place. We have to make the water now absolutely pure, and with the circulators we get the high efficiency I have mentioned. I have no doubt they will do equally well with the boilers as with the evaporators.

The HON. SECRETARY: One point that has not been touched upon is the action of mill scale, and I daresay many of us have had experience of the harm done by mill scale left on the boiler shell as I have had one or two bad examples under my notice. Another point to discuss is the best way of treating a boiler when it is left out of use for two or three weeks. Should it be filled with water or left empty with a free circulation of air? In tramp steamers it is not uncommon for them to be fitted with feed pumps working from the main engines only. I have examined boilers where this has caused great harm, and when an independent feed pump has been installed the cause of deterioration has been eliminated. The liquid scaler referred to, I believe, is one which has come out quite recently. It is put in in very small quantities, and it has not that objectionable feature which some may have had experience of. Ten or twelve years ago there was a liquid of that kind brought before notice, and we arranged a visit one Saturday afternoon to see it tried and tested. Then we lost sight of it altogether, and I do not know if this is the same idea revived, it seems from what I hear, to have the effect of removing the scale. The element of danger referred to in connection with misshapen or collapsed furnaces, is another point to discuss. The fire box stays sometimes give trouble, and I do not think we can be too emphatic in pointing out the necessity of seeing that the stays are put in true and a good fit. In some cases they are in at bad angles, and slack, with resulting leakage. Mr. Hulme referred to evaporators, and those who deal with emigration work know that the tendency is for the Board of Trade to advise that the evaporator should supply steam to the distillers instead of it being supplied by the donkey boiler. We had discussions about 20 years ago with regard to the use of zinc in boilers, and the question arose as to whether that zinc passed over along with the steam into the distiller. The result of experiments showed that the zinc did get through to the distiller, and it led to the zinc in donkey boilers being removed when distilling. Electrogens are good for the purpose intended if the attachments are good, they require to be carefully made, and carefully fitted to be effective. This also applies to the use of zinc plates, as, unless there is a proper contact between the zinc and the boiler plate with a good clean stud you do not get the full value and benefit. That was established by the tests of the boiler commission of 30 to 40 years ago; some experiments were also conducted in connection with the Institute some 24 years ago.

On the proposal of the CHAIRMAN, seconded by Mr. J. CLARK, a hearty vote of thanks was accorded to Mr. O'Neill for his paper, and the discussion was adjourned.

ADJOURNED DISCUSSION.

Monday, December 8, 1913.

CHAIRMAN:—MR. GEO. ADAMS (Member of Council).

MR. B. P. FIELDEN: I have read the paper over since last meeting and it is evident that the author is dealing, not with the highest class modern steamer, but with a steamer fitted with the least machinery that it is possible to put into a ship. The first thing to do would be to fit independent feed pumps and stop the corrosion. It seems to me the want of these is the greatest cause of corrosion, but in modern vessels corrosion is not a serious thing. Boilers last 20 to 25 years, and I think that is what we might call a good average result. He also speaks about blowing the boilers down, filling the boilers to full-glass then blowing down to heat up the bottoms. It is questionable whether that is good practice. It is good in the first place by warming the bottom of the boiler, but unless that action is continuous I do not see that any good result is accomplished. If you start off by raising steam the water is hot on top and cold at the bottom. If you blow the boiler down it will become hot at the bottom, but it will cool down again and more harm than good is done unless the action is continuous. At the last meeting I said the question of scale was considered at the wrong end, it should be considered before the water got into the boiler, and in my experience the greatest trouble with scale in the boilers is from condensers. The condenser of to-day is not a perfect machine, and in modern twin-screw steamers with winch condensers, refrigerators, etc., there are many places where salt water finds its way into the boilers.

When you consider the way cargo is worked in the modern ship, a donkey boiler is out of the question, and the usual plan is to fit auxiliary boilers, that is, boilers which are worked at sea as well as in port. In port, the auxiliary feed is made up from tanks, and the boiler is in charge of a donkeyman; if the boiler is short of water he will have no hesitation in putting the pump on to the dock or sea, and I think a good deal of the dirt gets into boilers in port. The tank water itself becomes dirty, and contains a sediment; I have found it better not to pump direct from a tank, but to go to the expense of providing an additional pump to feed the tank water through a filter before it goes into the main feed pump. I think the water should be filtered before it goes to the pump and also after, so as to have a double filtration. With these means I do not think the scale trouble can be a serious one. The author does not mention about the time that ought to be taken in heating up the boilers. The way ships run nowadays it is a difficult matter to get sufficient time to light a boiler properly, but I think 24 hours is a limit which should be worked to for lighting up and every care should be taken of the boiler during that time, not to force it. Then again there is the question of cooling down. Owing to working the auxiliary boilers in port for working cargo, very often all the boilers are led to one funnel, and I think a good many leakages happen when the boilers are cooling, more so than when lighting up, as there is more care taken with the lighting up than with the cooling down. The difficulty is the want of time when a ship arrives in port. The tubes have to be swept and the back ends cleared out, and one boiler has to be kept on for working cargo. The men open the smoke-box doors and start sweeping the tubes while one boiler has steam kept on it, with the result that the contraction of the boilers that are off is excessive. I think that is a cause of a good deal of leakages. The cleaning of fires is another very important matter. A great deal of harm is done by carelessness and want of attention in cleaning the fires at sea. It is rather hard usage on boilers to have two furnaces on each side of a combustion chamber, one heating the combustion chamber while the other is cooling down. I referred last week to the question of circulation, and my remarks were criticised. One member said that by using circulators a good deal more water could be evaporated. I am quite aware that by circulating water you get more evaporation. I believe it is so, that if you keep stirring the water in a kettle over the fire it will boil in less time than by leaving it alone. On the other hand, I am not convinced that the ordinary marine boiler is a bad circulating boiler, and I think the advantage you gain in one way is lost in another, by circulating on to the cooling surface at the bottom of the boiler, and it is questionable whether it is an advantage or not. The author speaks of cracked shell plates. I should be very sorry for any engineer to have cracked shell plates at sea for want of circulators, and if circulators are going to remedy it there should be more adopted than there are now. The leakages owing to differences in expansion are not excessive. I know of boilers 20 to 30 years old which do not cause trouble from leaky seams. Generally speaking, I think the whole question of the management of the boilers depends upon what the man has to start with. If the ship is not sufficiently provided with means for the engineer to keep things right, it is hardly his fault if things are not right; it is the fault of the people who supplied the ship in the first place. I referred last week to the fact that a ship is often contracted for and built to carry as much cargo as possible for the least capital value. I think that is one of the principal hard things the engineer has to contend against, and I sympathize with such a man in having to keep his ship in good condition with the outfit insufficient. The view from the commercial side of engineering and the technical side are often totally different. One man wants to earn as much as possible with the least possible expenditure, and the other has to see that the work is done as well as possible.

Mr. G. U. Morgan: This paper deals entirely with the tramp steamer, and as the tramp steamer is not fitted in the same manner as a first-class liner, the engineer has to put up with a lot of disadvantages that the engineer on a first-class ship does not meet with. Pitting does occur very often in the boilers of tramp steamers. It may be caused sometimes by oil and dirty water getting into the boiler, and sometimes through the galvanic action set up by two classes of metal being used in the construction of the boiler. In two ships I know of, corrosion set in very badly in the combustion chamber dogs in the donkey boiler. It only occurred in the donkey boiler, and only in the two ships, both ships being built by the same firm and my opinion is that the corrosion was set up by two different metals being used in the combustion chamber. On the tramp steamer usually there are no feed heaters and no feed filters, and the usual practice to heat the water when you want hot feed is to have small pipes led from the steam chest into the hotwell. You may then get a feed temperature of 180 deg., but on most ships it is not more than 160 or 170 deg., otherwise the pumps would overflow. With the drains running from the cylinder, especially if you have a h.p. D slide valve and have to use a lubricator, the tendency is for the oil to do its work in the h.p. steam chest, pass through the heater, and get into the hotwell and pass from there into the boiler. I have seen cases where there has been oil in the boiler and one cannot expect anything else but trouble if proper appliances are not fitted; and the engineer on a tramp steamer cannot otherwise keep things always in good condition. It is strange that the owners of tramp steamers do not go to the little extra cost of supplying feed heaters and filters, which would effect a great saving as compared with the initial expense and which would give the engineer a chance of carrying out his work to the best advantage. They do not give them in the class of ship the author refers to. All sorts of remedies have been tried to arrest pitting in the boilers. The chief thing to do is to purify the water—" prevention is better than cure." One speaker stated that pitting is practically unknown in boilers to-day. I beg to differ. My experience in all tramp steamers has been that there is a great deal of pitting going on, and it is only to be expected when oil and dirty water get into the boilers. More might have been said on the subject of management, such as working fires, cleaning fires, and the different ways of working boilers for economy. The old Scotch marine boiler is not really a satisfactory boiler. It is not so efficient as we should expect in these days, when we have to compete with the oil engine, and if we wish to keep the boiler ahead we must have some better means of obtaining work from the coal. In a lb. of coal we get 14,000 B.T.U.'s, with oil there is about 19,000 B.T.U.'s, and comparing results we find there is something radically wrong somewhere. The engineers of some tramp steamers do not seem to realise that they are losing heat through not having the boilers covered well. In spite of all these difficulties, however, they do get some good results. I have seen the consumption work out at 1.6 lb. per i.h.p. per hour, which is not bad for any class of steamer. In fact, in some of these papers which give comparative results I have seen stated the average steamer consumes 1.7 lbs., which is rather absurd, because an old tramp steamer of which I was chief used to turn out with a consumption of 1.6.

Engineers know that winch condensers, evaporators, feed heaters, filters, and many other parts of the equipment are actually saving devices. Take the winch condenser, for instance, the first and main saving effected is the expensive item of buying fresh water in a port to supplement losses.

The Hon. Secretary: The author refers to the boiler as being a machine from which it is desired to get the best results possible, but he has omitted to refer to the cleansing of the heating surfaces, yet that is a very important element. I should like one of our members who is present to-night to give us a dissertation on that subject, as I know he has had experience of testing the results from clean surfaces and from surfaces on which carbon was allowed to be retained. We know the difficulties that beset the engineer of a tramp steamer and we also know how difficult it is to persuade owners of tramp steamers that such things as Mr. Fielden has referred to are absolutely necessary in order to get the best results. I was reading over one of the Board of Trade reports recently in which the owner had some very sharp things said to him in connection with an accident where the third engineer was killed and also two firemen, such comments will help to emphasize what has been said to-night, that the owner of even a tramp steamer ought to be fully alive to the necessity of providing both time and appliances so that the best results may be obtained from engines and boilers. The heating surfaces, tubes, furnaces, and fire boxes should be thoroughly scrubbed; when this is done the results in that voyage will be better than on previous voyages, when time and opportunity did not allow of them being cleaned as thoroughly as they should have been. I apprehend that the author is not referring to a forced draught boiler, otherwise the speed of the fan and the blast or pressure at the fan and at the fires would be given, and also the necessity of keeping the smokebox doors perfectly tight would have been mentioned. We know the difficulty that arises from time to time when using a certain class of coal. The smokebox doors become badly buckled and the leakage interferes with the draught and consumption. There is a tank filter adopted in some steamers, which seems to give good results. The feed water enters one compartment, passes through a layer of coke, thence to the pump. It may tend to heat up the engine-room, due to the surface exposed, and the vapour pipe, two disadvantages which may be minimised by insulating the sides of the tank and carrying the vapour pipe well up the skylight. With regard to the question of scale below the bars, the impression given is that the scale below the bars does not materially affect the coal consumption, and perhaps preserves the lower part of the furnace from pitting.

Mr. J. S. Gander: There is one point in connection with tramp steamers that I think we are inclined to overlook at times. I believe that many of these boiler troubles arise from lack of attention to the elementary rules of boiler management. The vessel I referred to previously, was running from February to September last in Eastern ports, very hard running all the time, with cargoes that were discharged in about 40 hours. The vessel had to evaporate all water for engine purposes, and often for the drinking water tanks. The engine fresh water tanks only held 30 tons. The ship was fitted with an H.P. slide valve, and had neither feed heaters, filters, nor auxiliary condenser. To efficiently lubricate the slide valve, cylinder oil was used internally. Besides evaporating sufficient water to make up for usual engine losses, an extra 7½ tons per day were consumed in supplying the burners with atomising steam. The vessel was fitted on the old steam with oil system which has been superseded by the direct pressure systems. These conditions I consider as unfavourable as those of any tramp steamer, and yet, on opening up the main boilers only a very slight scale was found on parts of the furnaces and practically nothing on the tubes. When dealing with floating impurities the best plan is to scum very easily and not to blow-down. Where the blow-down is resorted to in the presence of a surface scum the impurities will deposit on the heating surfaces as the water level falls and form a very injurious scale.

I maintain that the consistent and judicious use of soda will keep a boiler in good condition in spite of the most adverse circumstances. Phenolphthaleine or a similar indicating medium, with test tubes, should be placed in a convenient rack and the boiler water tested at least once a day. The point to guard against in connection with the use of soda is that, if the water be made too alkaline there is a tendency towards priming. The use of the silver nitrate test every watch will indicate the existence of a leaky condenser tube long before it is apparent to the taste. A good deal of trouble is caused often by the staff not taking the necessary precautions with regard to river water, and when in port. Where a donkeyman is carried too much is frequently left in his hands. Where an engineer is on watch the boiler duties in port ought to be under his personal observation.

Mr. J. Clark: In connection with the electrical process referred to, I should like to ask is it to prevent scale being formed or is it to overcome the voltaic action that takes place?

Chairman: I have had no experience of it, and have only seen it fitted in connection with condenser tubes.

Mr. Clark: It seems to me that it would be very difficult to prevent scale if the scale-forming properties are in the water. Mr. Gander referred to soda causing priming, but I do not think soda alone will cause priming. You can have a very alkaline water without priming taking place; but in conjunction with certain oils which saponify with soda, priming will take place. There is, however, another action in connection with soda; gunmetal mountings and fittings in the boiler will be affected by the soda if it is in excess, because it will raise the density as it is soluble in water, it is not merely foreign matter in suspension. Mr. Adamson remarked about the effect of dirt. I think nearly every paper we get at the Institute bears in some degree on this question of dirt. There is a little motto that we used to hear: "Dirt is the prophet of the breakdown." It is a motto that ought to be emblazoned on a good many stokeholds as well as in engine-rooms.

Mr. Gander: A serious steam pipe explosion occurred about four years ago, and the surveyor, in making his report, stated that the explosion was due to the fact that brazing on the steam pipe was partially eaten away by the soda. This coincides with the remarks on the same subject by Mr. Clark. It is obvious, however, that soda has no business beyond the boilers, and the soda in this instance must have been carried over by priming in the presence of excessively alkaline boiler water.

Chairman: I think it only requires some judgment on the part of the engineer to see that the soda is not used to excess.

The meeting closed with a vote of thanks to the Chairman on the proposal of Mr. Clark.

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Mr. O'Neill's reply to discussion:

In reference to the Chairman's opening remarks, I wish to state that I refer to natural draught boilers only. Mr. Gander speaks of the damage done to boilers in port, when pumping them up from fresh water rivers. With his opinion on this point I think there is little doubt, but I think it is a general practice now with engineers to fill a ballast tank and let the sediment settle, both for main and donkey boiler use. I was junior engineer in a ship which had a by-pass connection so that the water could be pumped through the main feed filter by the donkey pump. This was a good arrangement. Referring to his remarks on the use of the hydrokineters with care, this should be especially borne in mind when raising steam the second time after the boilers have run a long passage, and there has been no time to open up the boilers due to quick despatch, as there is always a certain amount of sediment, more or less, in the bottom of a boiler after, say about 25 to 30 days steaming, no matter how careful an engineer may be. With a donkey pump the water can be pumped on the deck for inspection before delivering it through the check valves.

In regard to my remarks in the paper, referred to by Mr. Shanks, about it being in some instances found necessary to keep the density at 5ozs. to the gallon to get a protective scale on the plates. This practice I have never adopted myself, but I have met quite a number of engineers who have told me of their doing this with new boilers. I have never had the experience of taking charge of new boilers at sea so cannot give my own version of this, but I know of it being done by chief engineers in tramp steamers with many years' experience.

Mr. Hulme refers to the opening of the safety valves when raising steam, for the escape of the heated air, causing them to leak. I may state that I have been doing this for four years with the easing gear, and have never experienced any trouble from leaky valves.

The Chairman remarks about the oil in the boiler question. This, undoubtedly, is one of the greatest dangers at present to contend with, and I much regret that I did not deal on it in my paper. With an h.p. D. slide valve the use of oil cannot be done away with, apart from swabbing the rods, but a piston valve certainly reduces internal lubrication considerably, and whatever advantages are gained by a D valve, are lost by the damage which is so often done to the boilers by the use of the extra oil.

I agree with Mr. Morgan in his method of cleansing combustion chamber stays and coating them with zinc powder for preserving them from corrosion. I have obtained good results in this way myself, but there are some of the stays too awkward to get at to clean sufficiently for the application of the zinc powder, and it is with these that I have resorted to the zinc plates.

The Hon. Secretary expresses his surprise that I omitted to refer to the cleansing of the heating surfaces. I quite agree that I have overlooked a most important element, and am pleased to see that it has been brought forward extensively in the discussion. There is one point I should like to mention, that is, the damage done to heating surfaces in the process of scaling, by the spilling of colza oil from the lamps used by the men. This is, without doubt, done time after time, and scalers knowing how it is resented by the engineer, will try to hide any oil they may upset by rubbing dust over it. It is always advisable, if time permits, to wash the furnaces at least, with strong soda water to guard against this deception.

In further reference to the Hon. Secretary's remarks on the scaling of furnaces below the fire bars, the impression he gathered is what I meant—that it did not materially effect the coal consumption; but the scale that forms here I have always found to be soft and loose, and when taken off, I have found a black corrosive scale on the furnace.

There is not the least doubt, as I mentioned in the paper, that most of these troubles have been overcome by fitting modern appliances, but there are still a number of ships afloat without them, and will be for some time to come, and as a great number of junior engineers commence their sea career in this class of ship it has been my intention to point out and bring forward a discussion on the things that have to be contended with, so as to endeavour to obtain, for their benefit the manner in which the best results can be derived under the circumstances, always remembering a mechanic or tradesman who makes a good job with bad tools or no tools, will have no difficulty in doing so with the best of tools.

Report on the Circumstances attending an Explosion which occurred at an Electricity Generating Station

(Cd. 6964 Complete, Price—FIVEPENCE)

BY MR. G. S. TAYLOR, H.M. INSPECTOR OF FACTORIES.

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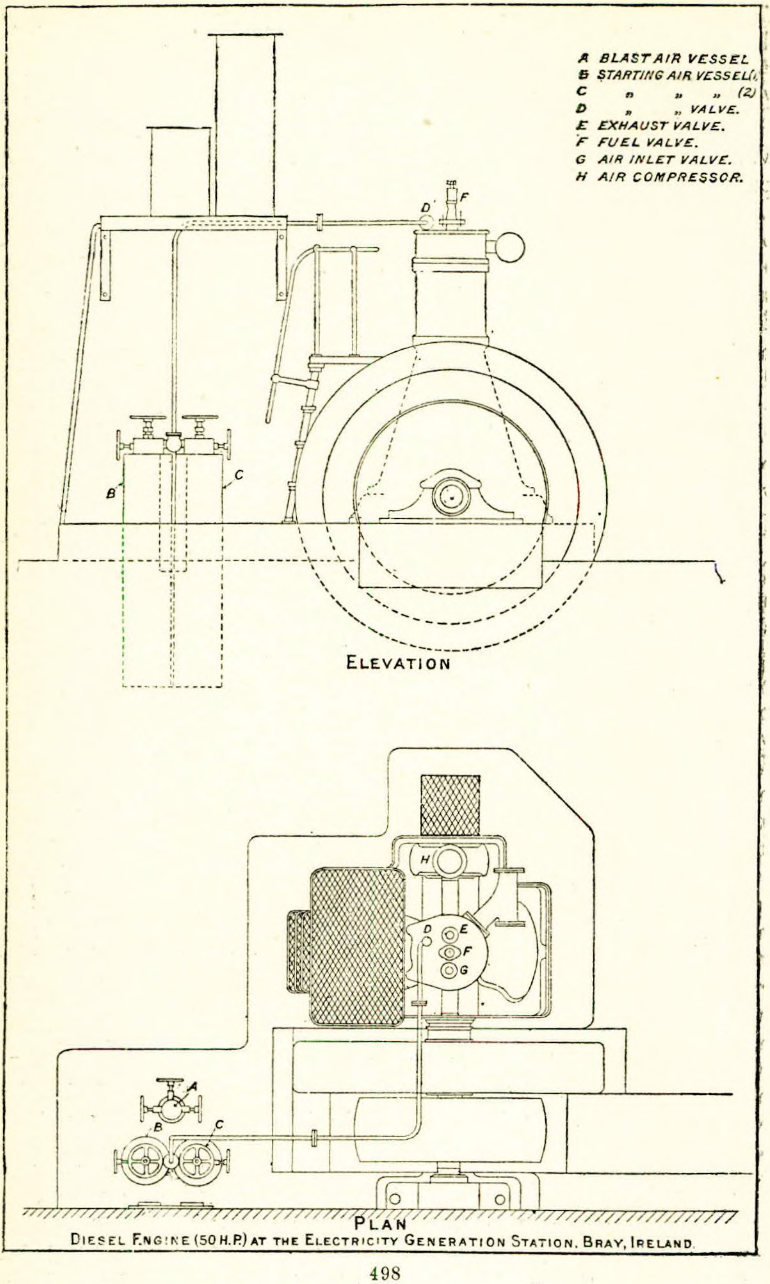
THIS explosion caused the destruction of a steel storage vessel for compressed air used in connection with a Diesel oil engine, resulted in the death of Christopher Coates, the head fitter at the station, and caused such injuries to Mr. W. J. Sowter, the chief engineer, that both legs had to be amputated. Mr. McDonnell, the assistant engineer, also sustained extensive burns and other injuries to his face.

The Diesel oil engine is so named after its inventor, Dr. Rudolph Diesel, of Munich, who produced his first experimental engine in 1893. The first practical engine on the Diesel principle was constructed by the Maschinenfabrik

Augsburg-Nurnberg A. G. in 1897, and in the same year the first British engine was constructed by Messrs. Mirrlees, Watson and Yaryan, Ltd., at Glasgow. The principal British patents in connection with the Diesel engine expired in 1906 and 1909, and during the past few years an increasing number of British firms have undertaken the manufacture of Diesel engines for land purposes. Certain patent rights in connection with marine types of Diesel engines are still held by various firms of continental engineers, but a number of British engineers are now constructing marine Diesel engines under licenses from the patent holders, and one firm have successfully evolved their own type of marine engine. Diesel engines have already been installed in a large number of electrical stations and various classes of factories, whilst several ocean-going vessels have also been fitted with sets of these engines for propulsion purposes. In an ordinary gas engine or oil engine, on the outward stroke of the piston, the gas or vapourised oil is drawn into the engine cylinder mixed with a volume of air sufficient to ensure its complete combustion; on the return stroke the piston compresses this mixture to a pressure not exceeding 130 lbs. per square inch in a gas engine, and not exceeding 80 lbs. per square inch in an oil engine. After compression, the mixture is exploded by a heated tube, electric spark, or other ignition arrangement, and the explosion gives the working impulse to the piston. In the Diesel engine, however, only atmospheric air is drawn into the cylinder. which is subsequently compressed by the piston on its inward stroke to a pressure of about 500 lbs. per square inch. This high compression under approximately adiabatic conditions raises the temperature of the air to over 1,000° F. (dull red heat), and just before the piston commences its next return stroke, a spray of finely atomised fuel oil is injected into the cylinder by means of air at a pressure which varies from 650 to 900 lbs. per square inch. The temperature of the compressed air in the cylinder is sufficient to cause the immediate ignition of this spray, and no special ignition device is required. It is often contended that this auto-ignition of the fuel is the essential feature of the Diesel principle, and that the extent of the compression was decided by this factor. But, in a paper read by Dr. Diesel, in Berlin, in 1912, he states that this view is incorrect, and that in order to obtain the highest heat efficiency from the fuel, the air was heated by compression considerably above the ignition temperature of the fuel. Full descriptions of the various types of Diesel engines have been



DIESEL ENGINE (50 H.P.) AT THE ELECTRICITY GENERATION STATION, BRAY, IRELAND.

published in the Proceedings of the Institution of Mechanical Engineers,* The Transactions of the Institute of Marine Engineers,† and also in the Engineering Journals.

DESCRIPTION OF DIESEL ENGINE AT BRAY.—The Diesel engine at Bray electrical generating station was constructed by Messrs. Mirrlees, Bickerton and Day, Ltd., Hazel Grove, near Stockport. It had a single cylinder 12 ins. diameter (*see* page 498), worked on a four-stroke cycle, developed about 50 H.P., and was first started in March, 1910. Compressed air for fuel ignition and starting purposes was obtained from a two-stage air compressor (H) driven directly from the main engine shaft. An inter-cooler was provided for cooling the air between the two stages of compression, and the air passed through another cooler after the final compression. From this after-cooler the compressed air, at a pressure approaching 900 lbs. per square inch, passed through a $\frac{1}{2}$-in. copper pipe into the blast air vessel (A). Compressed air from the blast vessel was conveyed to the fuel valve (F) by a blast injection pipe of solid drawn copper $\frac{1}{2}$-in. diameter, $\frac{1}{4}$-in. bore, and about 16 feet in length. The air pressure in the blast vessel was regulated according to the load on the engine, a higher injection pressure being necessary for a heavy load. The blast air vessel (A) consisted of a lap welded mild steel cylinder 3 feet in length, 8 inches external diameter, and $\frac{13}{32}$ inch in thickness; circular plugs of $1\frac{3}{8}$ inches in thickness were welded into the ends, the upper plug having a hole communicating with the entrances to the valves in the steel "head." The latter was secured to the top plug by means of studs and nuts, and contained three valves which respectively controlled the compressed air supply—(1) from the air compresser (H), (2) to the fuel valve (F) on the engine and the pressure gauge, and (3) to the starting air vessels (B and C). The "head" was also fitted with a spring loaded safety valve $\frac{3}{16}$ inch diameter set to blow off a pressure of 1,050 lbs. per square inch. A $\frac{3}{8}$-inch copper pipe with an open and bevelled end extended almost to the bottom of the blast vessel; this pipe acted as a drain for any condensed water, and also conveyed the compressed air to the starting air

* "Diesel Engines," by H. Ade Clark. Proc. I. Mech. Engrs. 1903. Part 3, p. 395.

"Modern Diesel Oil-Engines," by J. F. Schubeler. Proc. I. Mech. Engrs. 1911. Part 3, p. 519.

"The Diesel Oil-Engine and its industrial importance," by Dr. R. Diesel. Proc. I. Mech. Engrs. 1912. Part 1. p. 179.

† "Modern Developments in British and Continental Oil-Engine Practice," by E. Shackleton. Trans. I. Marine Engrs. Vol. XXIII., p. 157.

vessels. There were two such vessels (B and C) of mild steel with a longitudinal lap-weld and welded ends, of the following dimensions: length 6 feet, external diameter $14\frac{3}{4}$ inches, thickness $\frac{3}{4}$ inch. They were fitted with steel "heads" connected by a T-piece, the vertical branch of which communicated with the starting valve on the engine cylinder. Each "head" was fitted with a valve which admitted compressed air to the engine cylinder, and also with a valve which connected the vessel to the pressure gauge. The two vessels were also fitted with drain valves connected to internal drain pipes which were carried to the bottom. The three air vessels were rigidly tied together by means of wrought-iron straps ($\frac{5}{8}$ in. $\times$ $2\frac{1}{2}$ ins.) and bolts; they were placed in a vertical position with their tops in the same plane, and the lower ends of the vessels below the floor level. The interiors of these three air vessels had been coated with a bituminous composition to prevent corrosion.

The cover of the engine cylinder was fitted with four valves, viz., the air inlet valve (G), fuel valve (F), exhaust valve (E), and compressed air starting valve (D), held on their seatings by means of strong springs, and opened at the proper times by means of levers in conjunction with cams on a revolving cam shaft. The levers which operated the fuel and starting valves were pivoted eccentrically upon the same rocking shaft in such a manner that when the starting valve was being operated the roller end of the fuel valve lever was held clear of its cam, and the fuel valve remained closed. By means of a starting hand lever attached to the rocking shaft the conditions could be reversed, and the fuel valve put into operation when the starting valve was closed. This starting lever could be held with a catch in three positions, viz., starting, neutral, and running. The fuel valve casing consisted of a thick cast-iron tube with a nozzle-piece attached to the lower end; the interior at this end was tapered to form a seating for the needle fuel valve which was surrounded by a cast-iron sleeve concentric with the outer casing. At the upper end of the casing, connections were made to fuel pump delivery pipe and to the blast vessel The fuel oil passed from the fuel pipe through a small vertical hole in the walls of the casing, and entered the interior of the casing through a small horizontal hole just above the atomiser. The latter consisted of a series of washers round the bottom of the needle valve sleeve; the washers were drilled with a number of small holes, the holes of adjoining washers being staggered. When the needle fuel valve was lifted, the compressed air from the blast vessel injected the fuel oil through the holes in the washers into the engine cylinder in the form of a fine spray. The needle fuel valve passed through a suitable stuffing box and gland carried in a cover forming one casting with the spring box. This cover was secured to the cylinder head by two studs, one inch diameter, and held the fuel valve casing in position in the head. The fuel oil was pumped to the fuel valve by means of a pump driven off the cam shaft, and this pump was supplied with oil from an overhead tank.

The sequence of operations in starting up and running the engine are as follows:—The blast and starting air vessels when received from the makers are already charged with air at a pressure of 900 lbs. per square inch, and should be kept charged by the compressor whilst the engine is in operation. Before starting, the respective pressures in the air vessels should be ascertained by connecting them to the gauges. The starting lever should then be placed in the "starting" position, and the crank barred round until just over the top centre (piston on the downward stroke). After examination of the various lubricators and opening all the valves on the water circulating system, the requisite valves on the fuel supply system should be opened and the fuel pumps and pipes tested to ensure that they are charged with oil. The air suction inlet on the compressor, the valves between the compressor and blast vessel, and that between the blast vessel and the fuel valve should then be opened. As soon as the valve on either starting air vessel is opened, compressed air will be admitted to the engine cylinder and the engine set in motion. After the engine has made from four to six revolutions the starting lever should be put in the "running" position, and the valve on the starting air vessel immediately closed.

Circumstances and Result of Explosion.—On Sunday morning, July 7th, the Diesel engine was stopped by the engine attendant, and about 6 p.m. on the same day, when the station was visited by Mr. McDonnell, the assistant engineer, the attendant drew his attention to the loss of air from the three air vessels. At this time, the gauges indicated a zero pressure in the reserve starting air vessel, and pressures of 350 lbs. per square inch in the other starting vessel and in the blast vessel. Owing to sickness, Mr. W. J. Sowter, the chief engineer, had not paid his usual visit to the station on this date. Hence neither of the engineers had any personal knowledge of the pressures in the air vessels when the engine was stopped. The valves on the reserve starting vessel were provided with a chain and lock, but the reserve air in this vessel appears to have been used by the engine attendant in attempting to start the engine during the Sunday afternoon. On Monday, July 8th, the Diesel engine was overhauled, the fuel, exhaust and air valves were taken out, reground, and replaced; the atomiser was cleaned, and the clearances on the valves were set by Mr. McDonnell. It was impossible to start the engine with an air pressure of only 350 lbs. per square inch in the blast vessel, as this would be insufficient to inject the fuel oil into the cylinder. The Diesel engine was used for driving an alternator by means of a belt; and although the plant included three other alternators driven by two steam engines and a water turbine, it was impracticable to use the Diesel alternator as a motor, and thus drive the engine and compressor until the necessary air pressure had been obtained in the blast vessel. In the absence of an auxiliary compressor, the pressure in the blast vessel had to be raised by other external means. A printed copy of instructions supplied by the makers of the engine, contained the following statement:—

> "If by any mishap the air is lost and no compressor is available, or if the engine cannot be run by external means so as to charge the receivers by its own air compressor, then these may be charged with carbonic acid gas or oxygen from the cylinders containing these gases, as used for many purposes."

As compressed oxygen had been so used without accident when the air pressure was lost in the previous February, a cylinder of compressed oxygen was ordered by Mr. Sowter from a firm of Dublin chemists, which was delivered at the factory on the morning of Wednesday, July 10th. Oxygen cylinders are usually charged with gas at a pressure of 1,800 lbs. per square inch. Shortly after its arrival the oxygen cylinder was coupled to the compressor connection of the blast vessel and the pressure was raised to 800 lbs. per square inch. The supply of oxygen was temporarily stopped and the valve opened between the blast vessel and the starting vessel; compressed air and oxygen thus passed over into the latter vessel, but the pressure in this was only slightly raised above 350 lbs. per square inch, as the pressure in the blast vessel fell from 800 lbs. to 750 lbs. per square inch. The volume of the starting vessel was about nine times the volume of the blast vessel. The valve between the vessels was closed, and the oxygen again turned on to the blast vessel until the pressure within was raised to 800 lbs. per square inch; the oxygen cylinder was then removed and the high pressure air delivery pipe from the compressor re-connected to the blast vessel.

The ordinary fuel (crude oil) was then emptied from the fuel pump, and from the engine fuel supply pipe which was temporarily disconnected from the fuel valve. The fuel pump and pipe were then charged with ordinary lamp oil (kerosene), and when the fuel valve connection had been made, several strokes by hand were made with the pump, so that the atomiser in the fuel valve casing was charged with kerosene. The crude oil was then turned on from the supply tank, and the starting lever on the engine placed in the "starting" position. Mr. McDonnell stated that he then opened the valves in the following order:—(1) valve from blast vessel to fuel valve; (2) valve from compressor to blast vessel; (3) valve between blast vessel and pressure gauge; and (4) starting valve on starting air vessel. The engine began to move, and after the starting valve was fully opened, seemed to run quite satisfactorily. Mr. McDonnell therefore went to the engine platform and put the starting lever over from the "starting" to the "running" position. No firing stroke occurred, but air could be heard escaping from one of the valves with a hissing noise. The fitter Coates was at this moment standing on the far side of the engine with his hand on the air intake pipe, which is connected to the air valve on the engine cylinder. Coates made some remark apparently about the escape of air, but Mr. McDonnell did not hear this distinctly; Coates then moved to the other side of the engine, and at this instant an explosion occurred at the fuel valve on the cylinder, a blue flame was seen to travel along the blast pipe to the blast vessel, and the latter exploded with great violence. Mr. Sowter was standing on a concrete platform about 1 ft. 6 ins. above the floor level close to the blast vessel which exploded, and was struck on the legs by flying metal. Probably the same fragment struck Coates, who was on the floor level, in the abdomen, causing his death within a few minutes. Mr. McDonnell was standing on the engine platform and sustained burns to his hands and face as a result of the fuel valve explosion. In addition to these personal injuries, the explosion and flying portions of the blast vessel caused considerable damage to the building and plant.

Particulars have been obtained as to the condition and position of the exploded parts of the engine and blast vessel. Through the kindness of Mr. Edward Hiller, M.I.M.E., Chief

Engineer of the National Boiler and General Insurance Co., Ltd., the portions of the fractured blast vessel, fuel valve and connecting pipes have been examined personally at their offices. By the courtesy of Messrs. Mirrlees, Bickerton and Day, Ltd., the two starting air vessels were seen at their works.

The upper part of the fuel valve cover was found on the platform near the engine cylinder; it showed no signs of having been violently projected, but was fractured across the webs below the spring box. The lower part of the cover was fractured on one side close to the gland and inside a stud hole. The top of the fuel valve casing which was outside the cylinder cover had a piece broken out on the same side as the fracture in the lower part of the casing cover. The fuel valve needle was in position in the casing and only slightly bent. The perforated washers forming the atomiser were in position around the needle, and had a slight carbonaceous deposit on them. The air inlet and exhaust valves in the cylinder cover were both found to be leaky, and apparently at least one of these was in this condition prior to the explosion. Neither of the valves had been damaged, and the exhaust passage was coated with the usual sooty deposit. The air starting valve was found in order, but it is not clear whether the hand lever was left in the "starting" or in the "running" position. Mr. McDonnell is certain that he put the lever into the "running" position, and thinks that he probably pulled it back involuntarily at the moment of the explosion in the fuel valve casing when he jumped from the engine platform. The engine cylinder cover was quite intact and the bolts showed no signs of injury. The blast injection pipe was burst in three places; the pipe had been opened up and flattened over lengths from eight to 10 inches, and the metal at the edges of these fractures was reduced to the thickness of a piece of paper. The interior of the pipe was coated with a more or less oily deposit. The blast vessel was blown into eight fragments, and both the top and bottom plugs were completely separated from the cylindrical body of the vessel. The steel head with the valves remained attached to the top plug, and the holding down studs had not been injured. The welding between the top plug and vessel was defective for about three-fourths of the circumference. The welding of the bottom plug was good and the metal had been torn from the weld near the inside edge of the plug. The fragments of the body are of various shapes, and showed that the material at the longitudinal weld was practically as strong as the other parts. The fragments show signs of stretching, and as part of one piece had been bent double without indications of cracking, the steel appears to have been of good average quality and ductility. The interior surfaces of the fragments forming the centre of the vessel were blued, showing subjection to a high temperature, but the action of heat was less marked towards the ends of the vessel and on the plugs. No evidence of corrosion, either external or internal, was noticed, but the whole of the internal coating of anti-corrosive paint, with the exception of a slight trace, had been removed, probably by the explosion. The brass relief valve was broken off, apparently when the top of the blast vessel struck some object in its flight. The spring and other parts of the valve were in order, and there were indications that the valve had operated during the explosion, but a valve $\frac{3}{16}$ in. diameter would offer little relief for an explosive pressure. The wrought iron strap encircling the blast vessel was broken into several pieces, and one piece had been blown with such violence against one of the starting air vessels that a considerable indentation was made in the metal. This air vessel was slightly displaced from its vertical position, and the cast-iron T-piece between the two starting vessels was fractured. These vessels have since been tested hydraulically to a pressure of 1,500 lbs. per square inch and found to be sound. The internal pipe of the blast vessel had been burst in two pieces in a somewhat similar manner to the blast pipe. The copper pipe, connecting the high pressure air cooler to the blast vessel, was broken off near the latter, but showed no signs of bulging or overheating. The air compressor and air coolers were uninjured and in order.

Cause of the Explosion.—Tests have not been made upon the material of the blast vessel, as there was no reason to doubt its suitability. Assuming this mild steel had an ultimate tensile stress of 30 tons per square inch, and allowing 30 per cent. reduction in strength for the welding, a pressure of at least 5,320 lbs. per square inch would be necessary to rupture the blast vessel. Such pressure might be produced in a vessel containing a gaseous mixture: (1) by rise of temperature due to addition of heat from some external source; (2) by rise of temperature due to injection of a mass of highly heated gas; (3) by transmission of an explosive pressure wave from some connected vessel; or (4) by rise of temperature and increase in the gaseous contents due to ignition of some combustible material within. Previous to the explosion, the blast vessel contained a mixture of pure oxygen and air in the proportion of about 3 vols. of oxygen to 2 vols. of air, equivalent to about 68 per cent. of oxygen. The gaseous mixture was at a pressure of 800 lbs. per square inch, and at a temperature of about 70° F. (the temperature of the engine house). In order to produce a pressure of over 5,000 lbs. per square inch, the gaseous mixture would have to be raised to a temperature approaching white heat. There is, however, no evidence of the proximity of any external source of heat which would produce such a temperature. The second cause appears to be equally unlikely; though the temperature of combustion in a Diesel engine cylinder may approach white heat, the total mass of gas in the cylinder would be inadequate to raise the temperature of the gaseous mixture in the blast vessel to that corresponding with the bursting pressure. Dealing with the third possible cause, the blast vessel was connected to two sources from which an explosive wave might be propagated, viz., (1) the high pressure air delivery pipe from the air compressor, and (2) the blast pipe from the fuel valve casing. Except for a fracture near its junction with the head of the blast vessel, the air delivery pipe was undamaged by the explosion. The air compressor apparently was working satisfactorily. An explosion originating in the pipe or in the compressor, which could produce sufficient pressure to burst the blast vessel, would have caused fractures in these parts. The absence of damage indicates that the explosion did not originate in them. On the contrary, evidence of damage was found in the condition of the blast pipe and the fuel valve casing. The former was burst open and the cover of the latter was fractured. Moreover, Mr. McDonnell stated that an explosion first occurred in the fuel valve, and then a flame appeared to travel along the blast pipe. This suggests that an explosion took place, and the ignition wave passed along the blast pipe to the blast vessel. An ignition wave, however, cannot be transmitted as such through a gaseous mixture unless that mixture contains some combustible constituents. Under normal conditions the blast vessel and pipe should only contain compressed air, though at the time of the explosion this air was enriched with oxygen, but this mixture would not be combustible.

A pressure wave arising from an explosion either in the engine cylinder or fuel valve casing, however, might have been transmitted to the blast vessel. When a Diesel engine is running on normal load, the ignition of the fuel oil does not take place so rapidly as to cause an explosion, but the finely sprayed oil burns more or less quietly in the compressed and heated air. It is, however, well known that on starting these engines the initial strokes are often accompanied by explosions of considerable violence, which are usually attributed to an excess of fuel oil in the engine cylinder. The question therefore arises, did such an explosion take place in the cylinder of the engine, and, if so, did it produce a pressure wave of sufficient intensity to be transmitted to the blast vessel and cause its rupture? Mr. Sowter is unable to say whether a firing stroke occurred in the engine cylinder before the explosion in the blast vessel, and Mr. McDonnell neither heard nor felt the usual thud of a firing stroke; he did not think that one took place, unless it was simultaneous with the explosion of the fuel valve casing. The engine was started by means of compressed air from the starting vessel, and made between 6 and 9 revolutions before the starting lever was put into the "running" position. The air in the starting vessel had been enriched with oxygen from the blast vessel, but the amount of added oxygen appears to have been very small, as the pressure in the starting vessel was only raised a few pounds. It is estimated that the added oxygen did not exceed $\frac{1}{90}$th of the total volume of the vessel, so that the enriched air contained between 22 and 23 per cent. of oxygen instead of 21 per cent. in normal air. The starting air at a pressure of 350 lbs. per square inch expanded and set the piston in motion on the downward stroke; on the upward stroke almost all of this air would escape through the exhaust valve, and normal air from the engine house would be drawn into the cylinder previous to the compression stroke. Hence, when the fuel valve was put into operation, the fuel oil (in this case kerosene) would be injected as a spray into the compressed and heated air which contained very little more than the normal amount of oxygen. The compressed air which injected the kerosene was certainly rich in oxygen, and some of this would enter the cylinder, but whether in sufficient quantity to cause an excessive explosion in the cylinder seems doubtful. Under ordinary conditions of working the amount of fuel oil admitted is very small, and the fuel valve is open only whilst the piston travels about $\frac{1}{10}$th of its stroke—less than two inches in this engine. Hence, the amount of air rich in oxygen which would enter with the charge of fuel would be insufficient to increase the rapidity of combustion to such an extent as to cause a very violent explosion in the cylinder. Moreover, as the amount of air present in the cylinder is always in excess of that required for complete combustion of the fuel, unless an excessive charge of fuel was admitted through a defect in the fuel valve, or a deposit of carbonaceous matter, either on the cylinder cover or on the top of the piston, was present, there would be no combustible material with which the excess of oxygen could combine. There is the possibility of both an excessive charge of fuel and carbonaceous deposits, and it is said that some of the latter remained in the cylinder after the explosion. In the present case, the conditions are further complicated by leaky air-inlet and exhaust valves before the explosion, which would tend to reduce both pressure and temperature of the compressed air in the cylinder, and also reduce the amount of oxygen available for combination with the fuel oil. Any explosion in the engine cylinder which could transmit a wave of sufficient pressure to burst the blast vessel would in all probability have caused more damage to the cylinder and attached parts than was actually found. The cylinder cover and cover bolts, the air, exhaust, and starting valves were uninjured, and the damage to the fuel valve casing and cover were indicative rather of an explosion within the casing than of excessive pressure in the engine cylinder. Hence it appears that the explosion was not due to a pressure wave (without flame) transmitted from the cylinder to the blast vessel. The fragments of the blast vessel, especially those from near its central section, bore signs of local heating, and the bituminous lining appeared to have been burnt off. The fragments were not much reduced near the edges of the fractures, though there were indications that the material was sufficiently ductile to have shown, under a steadily increasing pressure, considerable thinning before fracture. It may therefore be concluded that an explosion occurred within the vessel and developed with such rapidity that an instantaneous pressure was produced causing a stress in the walls beyond the ultimate strength of the material. The explosion appeared to have been localised near the central portion of the vessel, which showed signs of exposure to a higher temperature than the ends, and there was absence of any stretching or damage to the four bolts securing the steel head to the blast vessel. The fractures in the blast pipe and the internal drain pipe indicated violent, but localised, explosions. There is evidence that these were preceded by an explosion which was more or less localised in the fuel valve casing. Under ordinary conditions of working, the blast vessel contains an oily emulsion in addition to compressed air. This emulsion is a mixture of water, from the moisture in atmospheric air, and traces of lubricating oil from the air compressor cylinder. Though much of the water and oil is removed by drains on the air coolers of the compressing plant, appreciable quantities of these pass over as vapours into the blast vessel and are there condensed. In the case of the engine at Bray, the oily emulsion was blown periodically from the blast vessel into the starting vessel from which it was drained at intervals. In course of time the interior of the vessels becomes coated with oily matter. There is definite proof of oily deposits within blast vessels and similar compressed air cylinders. Since the explosion at Bray, an explosion of a blast vessel occurred on the *Vulcanus*, a ship fitted with Diesel engines, whilst lying in port. I am informed by two engineering experts who examined this exploded vessel, that the interior had an appreciable coating of oily matter. The blast vessel of the *Vulcanus* had been in use about a year, whilst the blast vessel at Bray had been in use over two years, and the interior had never been scraped or otherwise cleaned. Many explosions and failures of air receivers, used in connection with compressed air plant for mines, factories and other works, have been traced to ignition of lubricating oil or vapour carried over into the receivers.* The interior of the Bray blast vessel had been coated with bituminous composition which would also provide some amount of combustible matter. Moreover, since the engine had been standing for a few days previous to the explosion, it is improbable that any vapour of lubricating oil was present in the blast vessel, especially as the lubricating oil had a flash point between 425° and 450° F.

The Departmental Committee on Compressed Gas Cylinders appointed in 1895, reported†

> "That there is no direct proof of the possibility of the spontaneous ignition of oil in the presence of compressed oxygen, at ordinary temperature in contact as it would be with metal surfaces. If, however, ignition occurred the explosion might be violent."

In view of this statement, it seems unlikely that the spontaneous ignition of the oily deposit on the blast vessel occurred

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* "Explosions and Ignitions in Air Compressors and Receivers," by A. G. White. Proc. I.C.E. 1899, vol. cxxxiv.

"Notes on Accidents due to Combustion within Air Compressors," by A. R. Ledoux. Trans. Am. Instn. Min. Engrs. February, 1903.

"Ignitions and Explosions in the Discharge Pipes and Receivers of Air Compressors," by A. M. Gow M.E. "Engineering News," 2nd March, 1905.

† Report of the Committee appointed to inquire into the causes of explosion and the precautions required to ensure the safety of cylinders of compressed gas (p. 8). London, 1903 (C. 7952). Price 1s. 4½d.

in the presence of a mixture of compressed gases containing 68 per cent. of oxygen at the ordinary temperature of the engine house. Some of the oily deposit probably was vapourised and ignited by injection of heated air or vapour into the blast vessel. As the engine had only made a few strokes, it is doubtful if this heated air or vapour travelled from the compressor, though explosions have been known to occur in this way; an explosion attended with fatal results, at Barrow in 1911, was attributed to ignition of oil vapour in a compressed air receiver pipe used in connection with an experimental engine on the Diesel principle. Heated gas or vapour could, however, enter the blast vessel by means of the blast or air injection pipe. Before the engine was started, this blast pipe would be filled by the blast vessel with a rich oxygen mixture which would be in contact with the kerosene in the fuel valve casing. The flash point of ordinary kerosene is between 70° and 90° F., and it is conceivable that kerosene vapour might have diffused into the oxygen mixture in the casing and blast pipe. The kerosene or its vapour might have been ignited in several ways, but it is difficult to say what actually occurred. When the fuel valve was opened, the kerosene in the casing may have been ignited by a flash back from the cylinder; a case is known in which this occurred with ordinary air injection, owing to the fuel valve sticking up, and a considerable length of the blast pipe was burst open. Again, kerosene would ignite at a lower temperature in compressed oxygen than in air, and it is possible that it might have been detonated in the oxygen mixture by the fuel valve coming down on to its seat. Further, Sir Boverton Redwood has demonstrated that kerosene (F.P. 79° F.), if finely sprayed by pressure through a leaky rivet hole, formed a mist which readily ignited at a temperature of 50° F.‡ Therefore, if any obstruction was present in the fuel oil orifice in the valve casing, the mere spraying of kerosene into the oxygen mixture might have produced ignition.

Whatever the cause of ignition, and whether it originated from the cylinder or the fuel valve casing, the evidence is clear that an explosion occurred in the casing. After the accident, the blast pipe showed on its interior surface traces of oil, possibly carried over from the blast vessel, or due to creep-

‡ "Petroleum and its Products," by Sir Boverton Redwood, Vol. I., p. 506.

Annual Report of Chief Inspector of Explosives for 1886, report on the explosion on petroleum oil tank steamer *Petriani*, 1886.

ing of fuel oil along the pipe, or accidental injection in operating the fuel pump by hand. The explosion in the valve casing probably vapourised some kerosene which would propagate an ignition along the blast pipe and set up violent local explosions which burst the pipe, producing the effect observed of a flame travelling along the pipe. The flame would travel to the blast vessel, raise the temperature sufficiently to vapourise and ignite the oily deposit and the bituminous lining, which in the presence of excess of oxygen produced a violent explosion. The blast vessel probably contained some condensed water, and as water vapour would be present both in the vessel and piping, this may have accelerated the velocity of explosion and even added to its intensity. Dixon* has shown that gaseous mixtures which cannot be exploded when perfectly dry, will do so readily when a trace of water vapour is introduced, and that the velocity of the explosion is enormously increased by the presence of water vapour. The fact that the oxygen mixture in the blast vessel and blast pipe was at a pressure of 800 lbs. per square inch would not affect the propagation of an explosion from the valve casing, for Berthelot† has shown that the velocity of transmission of explosions is independent of the pressure, the diameter of the tubes containing the explosive gaseous mixture, and also of the material composing the tubes.

There is no doubt that the presence of more than three times the normal amount of oxygen in the blast vessel added greatly to the violence of the explosion, and also facilitated the transmission of the explosion from the fuel valve, if it did not actually cause the initial explosion in the fuel valve casing. But it seems also clear that an explosion of the blast vessel would not have occurred if the walls of the vessel had been free from oily deposit. How far the anti-corrosive lining added to the effect it is impossible to say.

Loss of Air Pressure from Blast and Starting Vessels and Means of Re-charging these Vessels.—Shortly after starting a Diesel engine, the starting air vessels are charged to a pressure of 850 to 900 lbs. per square inch, which pressure should be maintained. The pressure in the blast vessel varies with the load, but should not be allowed to fall below 520 lbs. per square inch. Whilst an engine may be set in motion with a starting air pressure as low as 350 lbs. per square inch, it is

* Journal of the Chemical Society; Vol. 49 94, 384 (1896).

† "Theoretical Chemistry," W. Nernst; translated by G. S. Palmer, p. 577. Macmillan & Co. 1895.

generally impossible to obtain a firing stroke unless the blast air pressure exceeds the compression pressure (500 lbs. per square inch) in the engine cylinder. It sometimes happens, in attempting to start an engine, that the starting air is lost through some temporary defect, and the pressures are so reduced that it is impossible to start without re-charging the air vessels. Several makers of Diesel engines are of opinion that this loss of starting air rarely occurs, but the general experience of many users of these engines is the reverse, especially with first installations where the engine attendant has not had time to gain much experience with this type of engine. The air pressure had been lost on only three occasions at Bray during the $2\frac{1}{4}$ years the Diesel engine had been running, but this engine was under the supervision of experienced engineers. In some plants, the air pressures have been lost as often as six times in twelve months with a single set; one instance is known where the air pressures were lost from the six air vessels comprising two sets, due to the carelessness of an engine man in failing to turn on the fuel oil when starting an engine.

There are several methods by which the air vessels can be re-charged, viz.:—

(1) The engine and compressor may be driven by some other source of energy.

(2) An auxiliary air compressor may be installed.

(3) One or more of the air vessels may be taken out and re-charged either by the engine makers or by some firm with a Diesel engine or suitable air compressing plant.

(4) Cylinders of compressed air or of other compressed gases may be obtained.

The method of re-charging adopted in any particular case will depend upon the local circumstances. Where two or more sets of Diesel engines are installed, loss of air from all the sets of vessels should be a rare occurrence, as these are usually connected by piping so that an engine can be started from any air vessel. Where a Diesel engine is used to drive a direct current dynamo, this may be run as a motor by means of current from a storage battery or from another generator set. If other prime movers are used on the premises, it may be possible to drive a Diesel engine by means of shafting and belting connected to these. Auxiliary air compressors driven by a small petrol engine, oil engine or electric motor, are sometimes installed with large sets of Diesel engines; and such auxiliary engines and compressors are invariably fitted with marine Diesel sets, as large storage vessels are used and the engines are generally driven by compressed air when manœuvring. Owing to additional expense, power driven auxiliary compressors are rarely provided with ordinary Diesel plants, but several engine makers supply hand pumps for re-charging purposes; these, however, are extremely slow and need relays of men to work them. The removal of the air vessels is often troublesome, and considerable delay is involved if they have to be sent a distance by rail or steamer for re-charging. Nevertheless, this procedure has been adopted in several instances. Cylinders of compressed air (pressure 1,800 lbs. per square inch) can be obtained from the gas compressing firms in London and some of the large provincial cities. Such cylinders have been utilised on several occasions for the purpose of re-charging the air vessels of Diesel engines. But these facilities do not appear to be generally known, and so far as can be ascertained this method of re-charging is not specifically mentioned in the instructions issued by any of the British or continental makers of Diesel engines. Cylinders of other compressed gases, such as carbon dioxide, nitrogen, hydrogen, ammonia, and oxygen can also be obtained in most towns, whilst cylinders of compressed carbon dioxide and ammonia are often carried on ships for use in refrigerating plants. Carbon dioxide and nitrogen are inert gases, and will not form any explosive mixture either with air, oil, or oil vapour; and though they will modify the combustion of oil fuel, they may be considered as suitable for re-charging purposes. Cylinders of liquid carbon dioxide are cheap and easily obtainable; this gas is therefore generally suggested in the instructions issued by Diesel engine makers, and often used by their clients. Still, there are some disadvantages attaching to the use of carbon dioxide, as considerable care has to be exercised in charging the vessels, and the gas cylinder must be kept in warm water. Moreover, if the blast vessel requires charging with carbon dioxide in addition to the starting vessel, the exhaust gases will contain quantities of unburnt carbon when the engine is first started, and the exhaust valve should be taken out and cleaned at the first opportunity. Use of compressed nitrogen for re-charging air vessels is prohibitive on account of the cost of cylinders of this gas.

Danger of Using Oxygen or Combustible Gases for Re-charging.—Hydrogen and ammonia are combustible gases, and for this reason they are not suitable for re-charging purposes. At ordinary temperatures ammonia liquifies at a pressure of about 120 lbs. per square inch, which is inadequate for re-charging the air vessels. Compressed hydrogen is easily obtainable, but when mixed with air in certain proportions the mixture is highly explosive and the temperature of ignition decreases as the pressure of the mixture is increased. One case was found where an engineer had obtained a cylinder of compressed hydrogen for re-charging the blast vessels of a Diesel engine, and its use for this purpose might have been attended with disastrous results, but, fortunately, the engine was connected to a dynamo, and this was used as a motor to drive the engine and compressor until the necessary pressure had been obtained. Under normal conditions pure oxygen is a very active supporter of combustion, but when compressed, this activity is considerably increased, and the ignition-temperature of any combustible vapour would be lower in compressed oxygen than in the gas at atmospheric pressure. Hence the danger, recognised by gas compressing firms, of allowing compressed oxygen to come into contact with oil or grease. These firms issue instructions to their customers warning them not to use oil or grease for lubricating valves, gauges, or other fittings on oxygen cylinders. This recommendation was also made by the Departmental Committee on compressed gas cylinders in their report.* Under these circumstances, compressed oxygen is not only unsuitable for re-charging the air vessels of Diesel engines, but its use is obviously dangerous. Nevertheless, some firms of Diesel engine makers have issued instructions that compressed oxygen may be used for re-charging purposes, as cylinders of this gas are easily obtainable. Oxygen, however, does not appear to have been used to any extent for these purposes, and in addition to the two occasions at Bray in February and July, 1912, only one other case of its use in Great Britain has been noted. In this latter case the engine was started without accident, but the amount of oxygen added to the blast vessel appears to have been less than that used at Bray in July last. On both occasions at Bray the amount of oxygen was practically the same, and there is some difficulty in suggesting why no trouble occurred on the first occasion, and yet such disastrous results on the second. It is possible that the higher atmospheric temperature prevailing in July may have had some effect tending

* Report of the Committee appointed to inquire into the causes of explosion and the precautions required to ensure the safety of the cylinders of compressed gas, p. 24. London, 1903. (C. 7952.) Price 1s. 4½d.

to produce the explosion. The higher temperature would cause (1) vapourisation of more kerosene in the fuel valve casing; (2) the kerosene vapour would be more readily ignited by detonation or otherwise; (3) the compressed air delivery to the blast vessel would be at a higher temperature and therefore contain more oil vapour with a greater deposit in the blast vessel and blast pipe. On the other hand the fuel valve possibly stuck up on the second occasion, or there might have been some obstruction in the fuel orifice which caused the kerosene to be finely sprayed into the richly oxygenated air and so ignited at a comparatively low temperature.

Other Explosions with Compressed Oxygen.—As the result of inquiry it has been ascertained that at least two explosions of the blast vessels of Diesel engines have occurred on the Continent, owing to the use of compressed oxygen for recharging. Through the kindness of the London representative of the M. A. N. (Maschinenfabrik Augsburg-Nurnberg A. G.) a report has been obtained of one case which occurred at a tube works in Bavaria in December, 1910, resulting in the deaths of two workmen and injuries to others who were enagaged in starting a 50-h.p. Diesel engine constructed by a rival Augsburg firm, now in liquidation. The foreman had obtained a cylinder of compressed oxygen from the welding department, and charged the blast vessel and one starting vessel with the gas. When the starting lever was put into the "running" position, the blast vessel exploded with great violence, and the fragments struck the unfortunate men. The cause of the ignition in this case has not been satisfactorily explained, but was supposed to be due to presence of lubricating oil, carried over from the compressor into the blast vessel. Only a single stage compressor appears to have been fitted on this engine: the air supply for the compressor was taken from the air compressed in the engine cylinder on the upward stroke of the piston.

Explosions in the Air Compressing Plant of Diesel Engines.—Many explosions and failures of air receivers connected with air compressing plant, have been recorded in the past, which have been traced to the presence of lubricating oil in these receivers. As the result of inquiry, it has also been found that similar explosions have occurred in the pipes and air vessels of Diesel engines. At Barrow in 1911, an engineer was killed by the explosion of a compressed air receiver pipe of an experimental oil engine on the Diesel principle. The pipe was cooled by a water-jacket, but at the inquest, the works chemist attributed the explosion to ignition of lubricating oil vapour, which had been carried over from the compressor and formed an explosive mixture with the compressed air. In several cases explosions have occurred in the high pressure air delivery pipe near the compressor. Generally, the pipe had been subjected to a high temperature, and contained carbonaceous deposits, showing that carbonisation and ignition of the oil vapour had occurred. In some instances these deposits appeared to have choked the pipe sufficiently to cause an explosion by rise of pressure. In one case* an explosion which occurred in the blast vessel, blew the safety valve across the engine room and fractured the blast pipe near its connection with the steel head on the blast vessel. Whether ignition in this case originated in the high pressure air pipe, or in the fuel valve casing and extended along the blast pipe cannot be definitely determined. It is, however, evident that owing to presence of oil in the blast vessels of Diesel engines there is the same possibility of ignition and explosion in these vessels as in the air receivers of ordinary air compressing plants. Moreover, the ignition-temperature of the oil vapour is lowered at the high pressures employed with Diesel engines. Mineral lubricating oils with high flash points should always be used in the cylinders of air compressors. Since any defects in the cooling arrangements, or in the discharge valve of a compressor may result in a considerable rise in temperature of the compressed air, the amount of lubricating oil vapourised may be increased, and the ignition-temperature easily reached if the defect is not discovered. Temperatures above 130° F. have been taken on the outside of a blast vessel, with an engine running under normal conditions. There is also the possibility of ignition of the oily deposit in the blast vessel of a Diesel engine, by a "back fire" from the engine cylinder into the fuel valve casing and blast pipe. Such a case is known to have occurred in connection with a marine Diesel engine; the blast pipe was burst for a length of 20 feet.

In addition to explosions from ignition of oil vapour, explosions of the high pressure air cooler casings have occurred, and some of these have caused personal injuries. Cooler casings are usually made of cast iron, and contain the high pressure air pipes around which cold water is circulated to reduce the temperature of the compressed air before it is delivered to the blast vessel. The compressed air, and possibly also the

* "The Electrical Review." August 16th, 1912, p. 248.

particles of solid matter which it contains, appear to exercise a scouring action on the interior of the pipes, especially in the neighbourhood of bends. After a time the pipes may be reduced in thickness to such an extent that they are unable to withstand the pressure of 650 to 900 lbs. per square inch to which they are subjected, and therefore burst. If this should occur within the cooler casing, the cast iron is unable to withstand the stress suddenly imposed by the high pressure, and usually the end of the casing is projected violently across the room. An ordinary spring loaded safety valve is quite inadequate to relieve the sudden pressure exerted, and other safeguards should be provided, *e.g.*, thin diaphragms of metal or other material which readily rupture with excessive pressure.

Prevention of Explosions in connection with Diesel Engines.—Though a few Diesel engines have been working for over 10 years, and a considerable number have been in use over three years apparently without any serious accident or breakdown, it must be admitted that certain latent possibilities of accident exist, even when the plant is under the direct supervision of skilled engineers. It is not suggested that there is no risk of accident with other types of engines driven by steam, gas, oil or spirit. Though many makers of Diesel engines are of the contrary opinion, the average user of these engines considers that, owing to the high pressures employed and the accurate fitting required in the working parts, they should be entrusted only to skilled attendants or at least to attendants under the direct supervision of an experienced engineer. Whilst it is natural that Diesel engine makers do not wish to advertise cases of breakdowns or accident in connection with these engines, as the result of inquiry several cases of accident due to failures of the air compressing plant have been brought to light and others have occurred with engine parts not relevant to this inquiry. One is, therefore, forced to the conclusion, previously expressed in the technical press*, that the experiences of various makers and users with regard to failures and accidents, if published, would be advantageous to the engineering public.

Dealing with the prevention of those classes of accidents previously mentioned:—

(1) The blast and starting air vessels are usually made of mild steel of suitable quality. In some cases the whole vessel is solid drawn, in others the body is solid drawn and the ends

* "The Engineer," 15th November, 1912, and 3rd January, 1913.

welded, or the body lap-welded and the ends welded. These vessels are made to specification, and their construction is generally supervised by engineering inspectors of Lloyds or similar authorities. The thickness of the material is such as to allow an ample margin of safety for working stresses, and the finished vessels are tested hydraulically to about twice the working pressure, but stretch tests of the vessels, as recommended by the Committee on Compressed Gas Cylinders†, do not seem to be generally carried out.

(2) Some firms have the vessels coated internally with anti-corrosive paint, but other firms consider that this is liable to scale off and cause trouble by entering the pipes and valves, whilst it may provide combustible material in the blast vessel. Some engineers are of opinion, that if corrosion occurs in the vessels, small holes will be formed through which the compressed air will escape without explosion. It may be mentioned, that one firm of continental engineers are now said to be shrinking wrought iron bands or sleeves on the lower ends of their air vessels to prevent the fragments flying in the event of an explosion. There can be no doubt that corrosion is liable to occur in the air vessels, owing to the quantity of water vapour condensed in them, and if the air supply for the compressor is drawn from a source which contains acid fumes (such as the neighbourhood of a battery room), then the condensed water may contain appreciable quantities of acid, and the corrosion may be rapid. The large starting air vessels fitted with some marine Diesel engines are constructed like small boilers, and fitted with manholes giving access to the interior; but ordinary air vessels have no provision which will allow internal examination, except the small hole in the top plug. If such provision is made, the cost of manufacture of the vessels would be increased, more joints will be necessary, which are difficult to keep tight with pressures of 900 lbs. per square inch. So far, Lloyds have not issued any rules with regard to examination of the air vessels of Diesel engines, but according to an article in a technical journal* rules have been issued by the Germanischer Lloyd.

(3) Compressed gases other than air, carbon dioxide, or nitrogen should be absolutely prohibited for the purpose of re-charging the air vessels of Diesel engines, and a statement to

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† Report of the Committee appointed to inquire into the causes of explosion and the precautions required to ensure the safety of compressed gas (pp. 14 & 22). London, 1903. (C. 7952). Price 1s. 4½d.

* "The Motor Ship and Motor Boat," 12th December, 1912, p. 473.

this effect should be printed in the instructions issued by engine makers. Some of these do not appear to issue any instructions on the subject of re-charging air vessels, but it is desirable, if accidents are to be avoided, that some guidance should be given both to the engine user and his employees. Since the fatality at Bray, many Diesel engine makers have issued notices warning their clients not to use compressed oxygen for re-charging purposes.

(4) Various means have been adopted to minimise the amount of lubricating oil which passes over into the blast vessel from the air compressor. Only mineral oil with a high flash point, and the smallest practicable quantity, should be used for lubricating the air compressor cylinder. In some plants it may be practicable and advisable to provide special oil separators between the air compressor and blast vessel, as considerable difficulty is experienced in removing the last traces of oil from the compressed air.

(5) Adequate arrangements should be made for cooling the high pressure air, and the cooling pipes should be fitted with drains through which condensed water and oil can be periodically removed. Incidentally, cooler casings should either be made with sufficient material to withstand the maximum air pressure in the cooling pipes, or adequate means of relieving the pressure should be fitted on the casing.

(6) Only in a few instances have attempts been made to clean or examine the interiors of Diesel air vessels after a period of use. It is contended by some engineers that the coating of oil on the interior of an air vessel is an advantage, as it acts as an anti-corrosive and so preserves the metal. On the other hand this oil is regarded as a source of danger by many experts, and it prevents any examination of the metallic surfaces. Much of the oil coating can be removed by scraping, or by suitable solvents, but these methods are probably not so satisfactory as the use of steam. This could be applied in some instances without removing the air vessels from their place. Steam is always used to remove the oil from the tanks and other parts of oil tank ships before they are entered for repairs. The frequency with which air vessels should be cleaned and examined must depend to some extent on the number of hours an engine is in use, and on the opportunities afforded for such work when the engine is standing. At one works it was ascertained that the blast vessel of the Diesel engine was cleaned every six months, but in many works the

air vessels had not been opened up for two or three years. Very little additional expense or trouble would be involved if Diesel engine users had the air vessels cleaned and examined periodically, say every twelve months or oftener.

(7) It might also be advantageous to test the air vessels hydraulically to twice their working pressure about once in four years; the expansion of the vessel should be gauged whilst under test. As Diesel air vessels are not subjected to shock or rough usage under normal conditions of working, there is less necessity for periodical annealing than in the case of compressed gas cylinders, although annealing before the quadrennial test would improve the ductility of the material.

(8) Various suggestions have been made with regard to provision of some device to prevent transmission of an explosion from the fuel valve along the blast pipe to the blast vessel. The interposition of a non-return valve in the blast pipe is not considered practical by the majority of engineers, as such a valve is liable to stick owing to the presence of oily matter, and even if this did not happen, it is probable that an explosion would travel with such rapidity as to pass the valve before it closed. One firm are now fitting relief valves on the blast pipes of their engines close to the fuel valve casing. It is considered that in the event of a "back fire" or explosion in the fuel valve casing, the relief valve would operate and prevent progress of the explosion along the blast pipe.

(9) Another firm (Messrs. John Thorneycroft & Co., Ltd., Basingstoke) have devised a flame interceptor which they have fitted in both the blast and starting air pipes of a Diesel engine. This consists of a cylindrical steel chamber 6 ins. diameter, 4 ins. long, $\frac{3}{8}$ in. in thickness; the interior of the chamber is packed with a series of thin perforated metal plates, soldered together near their edges, and held in place by distance pieces which come into contact with the steel covers of the chamber. The covers are $\frac{3}{4}$ in. thick, recessed on the inner side to form a joint with the end of the chamber, the whole being held together by six $\frac{3}{4}$ in. bolts between the covers. The holes in adjoining perforated plates are staggered. Suitable unions are screwed into the centres of the covers so that the interceptor can be placed in a line of piping. If an explosion travels along a pipe and reaches an interceptor, the temperature of the gases will be reduced below the ignition point of any oil vapour by contact with the metal in the perforated plates. The large diameter of the intercepting chamber will also reduce the velocity

of the gases passing through. The interceptor is of simple construction, and can be readily removed and cleaned when necessary.

Conclusions.

The inquiry leads to the following conclusions:—

(1) The explosion of the blast vessel was caused by the ignition of an oily deposit on its interior.

(2) Ignition was transmitted by a flame explosion from the fuel valve casing passing along the blast pipe, but there is no evidence to show whether this ignition originated in the fuel valve casing or was transmitted from the engine cylinder.

(3) Ignition was facilitated, and the resultant explosions were intensified, by the large volume of compressed oxygen contained in the blast vessel and blast pipe.

(4) This compressed oxygen had been used in the blast vessel in order to raise the pressure sufficiently to start the engine, and was so used in accordance with the printed instructions issued by the makers of the engines.

(5) Owing to the presence of deposits of lubricating oil carried over from the compressors, the same danger of ignition and explosion exists in blast vessels of Diesel engines as in the air receivers of air compressing plants.

(6) There are considerable practical difficulties which prevent the removal of all the lubricating oil vapour from compressed air before it enters the blast vessels, although entire removal is very desirable.

(7) "Back fires" or explosions are sometimes transmitted from the cylinders of Diesel engines to the fuel valve casings and blast pipes; and ignitions, sometimes accompanied by explosions, occur in the high-pressure air delivery pipes of the compressors.

(8) Loss of air pressure from the blast and starting air vessels of Diesel engines occurs more frequently than the engine makers admit. This loss is often due to carelessness, but sometimes due to the inexperience of the engine attendant.

Recommendations.

It is suggested that the observance of the following recommendations would tend to reduce the risk of explosions and accidents in connection with the running of Diesel oil-engines:—

(1) Compressed oxygen, on account of its intense chemical affinity, and combustible gases like hydrogen, should not be used for the purpose of re-charging air vessels, and a warning to this effect should be issued by the makers of Diesel engines.

(2) Definite instructions should be issued by the makers with regard to the adoption of safe methods for re-charging air vessels.

(3) Only competent engineers, or experienced men under the direct supervision of a qualified engineer, should be employed as engine attendants on Diesel plants.

(4) Traces of oil or oil vapours should be removed as far as practicable from the compressed air before it passes into the blast vessel.

(5) Air vessels, especially blast vessels, should be cleaned and examined internally as far as practicable once every 12 months; they should also be tested hydraulically once in every four years, and the amount of expansion of the vessel under the test pressure should be carefully gauged.

(6) Some device should be fitted for preventing the transmission of flame explosions along the compressed air pipes.

G. STEVENSON TAYLOR.

APPENDIX.

Explosions in connection with Diesel Oil Engines, compiled from information obtained from Technical Papers and other sources.

Dates of explosions. (1)	Parts of engine which exploded or burst. (2)	Probable cause of explosion. (3)	Persons killed or injured. (4)
Dec. 1910	*Blast injection vessel	Ignition of mixture of oil vapour and compressed oxygen	2 killed, 1 seriously and several slightly injured.
Aug. 1911	Safety valve on blast vessel and blast injection pipe	Defect in air compressor	—
July 1912	Blast injection vessel, blast injection pipe, and fuel valve casing	Ignition of mixture of oil vapour and compressed oxygen	1 killed, 1 seriously, 1 slightly injured
Oct. 1912	*Top part of blast vessel	Defective internal drain pipe and bad weld in blast vessel	1 loss of arm
,, 1904	Blast injection pipe	Back fire from cylinder	—
,, 1911	Blast injection pipe	Back fire from cylinder	—
,, 1909	Fuel valve casing	Excess of fuel oil in cylinder	—
Feb. 1912	*Scavenge air pipe	Fracture of cam lever operating scavenge valve and consequent ignition of oil vapour	12 killed or died from burns, and several injured
Nov. 1912	Cylinder cover	Excess of fuel oil in cylinder due to leaky fuel valve	—
Jan. 1909	Compressed air pipe and inter-cooler casing	Safety valve screwed down on blast vessel	1 injured
,, 1910	Compressed air cooler pipe	Thinning of pipe at bend	—
,, 1911	Compressed air receiver pipe	Ignition of mixture of oil vapour and compressed air	1 killed
June 1910	Compressed air cooler pipe	Thinning of pipe	—
July 1911	Compressed air cooler pipe	Thinning of pipe	—
Sept. 1911	Compressed air discharge pipe for compressor	Thinning of pipe	—
,, 1903	Compressed air delivery pipe from compressor	Thinning of pipe	—
,, 1912	Compressed air delivery pipe from compressor	Thinning of pipe	—
Mar. 1912	Compressed air cooler pipe and cooler casing	Thinning of cooler pipe	—
Sept. 1912	Fly wheel	Excess of fuel oil in cylinder caused racing	1 slightly injured

In addition to the above-mentioned cases, several Diesel engines have been completely wrecked owing to the pistons seizing in the cylinders, in other cases considerable damage has been caused by fractures of the crank shafts, whilst cracked pistons and cracked cylinder covers are not uncommon.

* These accidents occurred on the Continent.

Abstract of Paper and Discussion from the Transactions of the American Institute of Mining Engineers.
Volume XXXIV. 1904.

Notes on Accidents Due to Combustion within Air Compressors.

By ALBERT R. LEDOUX (New York City).

READ
February, 1903.

In this paper an account is given of an accident in a mine, the compressor in question being for a three-drill machine of standard make. At the time of the accident it was supplying air to a single drill working in an upraise from a well-ventilated tunnel, and also giving ventilation to a winze below the tunnel where two men were hand-drilling. The drills were located about 1,200 ft. from the compressor. The engineer testified that he had never been short of air, that there had been no complaints of the machine being inefficient, and that the water used in cooling the air-cylinder had never become greatly heated. He had used a mixture of good cylinder oil and of a lighter grade known as "Atlantic Red." The valve of the compressor was set to blow off at 80 lbs. He was in the boiler-room when he heard a "crack like a pistol" and, going into the engine-room, he found water spurting out of the jacket about two feet from the end of the compressor; he tightened the jacket and stopped the leak, and found that the jacket was perfectly cool. He next noticed that "grease began to fry on the pipe and receiver"; then that the air-pipe had become red-hot. The intake of the compressor was in the engine-room, the temperature of which was 115 deg. Fahr. The men in the upraise, finding the air getting bad, opened the valve full. The engineer, observing that the pressure suddenly went down, stopped the engine, but, getting the signal for more air from the men in the winze, started it again. Two men were killed and four others barely escaped with their lives as a result of the bad air caused by the combustion of the oil, deposited carbon and organic dust accumulated in the compressor, receiver and pipe.

Explosions of air-compressors due to this cause have been frequent, and lives have been lost thereby. What is known as "flaming" of compressors or cylinders is an every-day experience, and in some cases the rupture of the air-pipes, but, so far as the author could ascertain, without the serious consequences described above.

To prevent such catastrophes he suggested taking in the air from a point where the temperature was as low as possible, the introduction of auxiliary coolers, the use of as heavy oil as possible—yet never to excess—the cleaning out of cylinders, receivers and pipes, and especially a warning to the engineer to be very sure, when he receives a signal for more air, that the actual shutting down of the compressor may not be more essential.

ABSTRACT OF DISCUSSION.

Mr. E. Hill, South Norwalk, Conn., sent a communication in which he said the common formula for the adiabatic compression of dry air did not account for heat sufficient to flash ordinarily decent cylinder oils, nor did the text-books give due consideration to the effect of leaks.

In presenting a formula to supply this lack, he pointed out that at the beginning of the stroke, the air in the cylinder came from three sources, namely: that which was left in the cylinder clearance spaces on the previous stroke, that which had leaked in from the discharge valves and past the piston, and that drawn in from the atmosphere. The air which was left in the clearance might be disregarded for purposes of calculation, as, on expansion, it performed work, falling in temperature to that just previous to compression. The air coming from the leaks expanded from the high pressure of discharge to the low intake pressure of the cylinder without performing work except in creating velocity in its own mass; but as it came to rest in the cylinder its temperature became that of the discharge.

In some cases the incoming air was greatly heated in consequence of being drawn over the heated surfaces of piston rod and piston for the purpose of cooling those parts, and through the partial vacuum created by restricted inlet openings; but he assumed a well-designed compressor with dry air and adiabatic compression.

Taking the formula for the adiabatic compression of a gas as a basis, he submitted the following:—

$$T^1 = \frac{t\,(P_1^{\,0.29} - LP_1^{\,0.29})}{1 - LP_1^{\,0.29}}$$

T^1 being the absolute temperature of the discharge; t the absolute temperature of the atmosphere from which the supply is drawn; P_1 the pressure of the discharge, and L the amount (in percentage of cylinder capacity) of the leakage; the figure 0·29 being the air constant.

Applying this formula to a single stage compressor at sea level, compressing to 88 lbs. or seven atmospheres, the atmospheric air being at 62 deg. Fahr., the following would be the temperatures of discharge, when the leaks of piston and discharge-valves are as stated:—

Leak.	Temperature.	Leak.	Temperature.
0	459 deg. Fahr.	0·08	524 deg. Fahr.
0·01	466 ,, ,,	0·10	544 ,, ,,
0·02	475 ,, ,,	0·12	566 ,, ,,
0·04	489 ,, ,,	0·14	589 ,, ,,
0·06	506 ,, ,,	0·16	615 ,, ,,

He pointed out that there was thus a possibility of a temperature fully sufficient to produce gas from the oil lubricant and to cause it to burn, creating further excessive heat and an increased development of gas, quickly followed by explosion.

It would be noticed that there was a rapid increase in heat as the leak increased. A leak was constant, and it followed that it was proportionately higher when the revolution speed decreased. The oil feed, when adjusted for the maximum speed, would be in excess for the slow speed. This combination of a larger proportional leak and a liberal supply of oil was dangerous. This was quite in accord with experience as in several cases of violent explosions the compressor was running slowly at the time.

To avoid these dangerous conditions the compressor should be made with compound air-cylinders. Such compressors, when compressing to eight atmospheres or 103 lbs. gauge, would develop, under normal conditions, 245 deg. Fahr. in each cylinder. There was less liability to leakage in these compressors, because there was less difference between the discharge and the intake side of the piston.

In two and three stage compressors, the greatest temperature due to any percentage of leak, no matter where located, was within safe limits. In the best modern compressors, the air leaking past the pistons was passed through an inter-cooler, and by this means pressures of from 3,000 to 5,000 were obtained without inconvenience or anxiety.

Combustion was more vigorous under higher pressures and no doubt there was likewise an easier oxidation and a lower flashpoint for oil under pressure in the cylinder than under ordinary conditions outside. In many cases a noisome gas was generated long before the explosion.

Mr. W. L. Saunders also advocated compound compressors and compressing the air in stages. The oil, which should not be used in excess, should be of a high grade, with a high flashpoint, and should be of a non-coking nature. Any deposit in the cylinder should be removed at least once a week, and the discharge valves, air receiver, and other places where deposits were likely to accumulate should be kept clean. The intake air should be taken from outside the engine-room and inter-coolers should be used.

N. S. S.

INSTITUTE OF MARINE ENGINEERS.

The following were elected at a meeting of the Council held Thursday, January 22nd, 1914:—

As Members.

A. J. Adamson, Colonial House, Water Street, Liverpool.
Wm. Bartlett, 39, Kingscourt Road, Streatham, S.W.
A. J. Blake, 100, Embleton Road, Lewisham, S.E.
W. G. Brettell, Colonial House, Water Street, Liverpool.
J. Bruce Duff, B.Sc., B.E., 194, Park Road North, Birkenhead.
Peter Duff, Messrs. J. Gordon Alison and Co., Ltd., Birkenhead.

Charles H. Fowling, 101, Lewisham High Road, New Cross, S.E.
James Hogg, 41, Winstanley Road, Waterloo, Liverpool.
Thomas Kimpton, 9A, Grenade Street, Limehouse, E.
William Kimpton, 9A, Grenade Street, Limehouse, E.
Thomas Kinghorn, Bureau Veritas, 155, Fenchurch Street, E.C.
William MacPherson, "Palmyra," Obelisk Road, Woolston, Southampton.
Duncan A. Malcolm, 104, Hermon Hill, South Woodford, Essex. ,,
Gerald Mavor, Messrs. Jardine Matheson and Co., Hong-Kong.
George D. Melville, Association of Engineers, Singapore.
William E. Plummer, Cambridge House, Bradford, Yorks.
William A. Reynolds, 36, Herongate Road, South Wanstead, Essex.
Joseph R. Scott, "E," Milburn House, Newcastle-on-Tyne.
Keith S. M. Scott, B.Sc., "E," Milburn House, Newcastle-on-Tyne.
Robt. Thompson, 155, Fenchurch Street, E.C.
Frank L. Warren, 3, Earlsthorpe Road, Sydenham, S.E.
Walter H. Webb, Messrs. the Liverpool Refrigeration Co., Ltd., Colonial House, Liverpool.

As Companions.

Harold A. Ross, 1, Glengall Road, Old Kent Road, S.E.
Sidney V. Selley, 3, Billiter Avenue, E.C.

As Associate Member.

Michael Vaughan, "Lynwood," Whalebone Lane, Beacontree Heath, Essex.

As Associates.

Edward M. Sellex, 28, Argyle Road, Ilford, Essex.
William R. Thompson, 45, Lewisham Hill, S.E.

As Graduates.

Thomas M. Candy, 143, Portswood Road, Southampton.
Nicholas G. Rutherford, 55, Warren Road, Leyton, Essex.
Allan F. C. Timpson, 4, Coventry Road, Ilford.

Transferred from Associate Member to Member.

Duncan S. Pollock, Albany Road, Manor Park, E.