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Corrosion of Iron and Steel.

(With special reference to Marine Boilers.)

BY MESSRS. W. B. LEWIS AND G. S. IRVING, A.M.I.Chem.E., F.C.S.

READ ON

Tuesday, February 14, at 6.30 p.m.

CHAIRMAN: ENGR.-CAPT. W. ONYON, M.V.O., R.N. (RET.)
(Past President).

The CHAIRMAN: I do not think I need introduce Messrs. Lewis and Irving, because you have had the opportunity of hearing them lecture at this Institute about three years ago on the question of scale in boilers. Since then a great deal has been done with regard to research on corrosion, and the authors will no doubt give us an interesting paper on the subject.

IN the space of one paper and with the time at our disposal, it is not possible to deal fully with the corrosion of metals—even when limited to the metals iron and steel. We shall treat briefly the theoretical side of the subject, and the practical outcome of such knowledge.

Historical Notes.—Since the commencement of the Iron Age, it can be assumed that mankind has been interested in iron. The Pyramids of Egypt, in the construction of which granite blocks have been used, indicate the use of iron tools. Inside the Great Pyramid, a wrought iron tool was found, of an age approximately 3,000 years B.C.

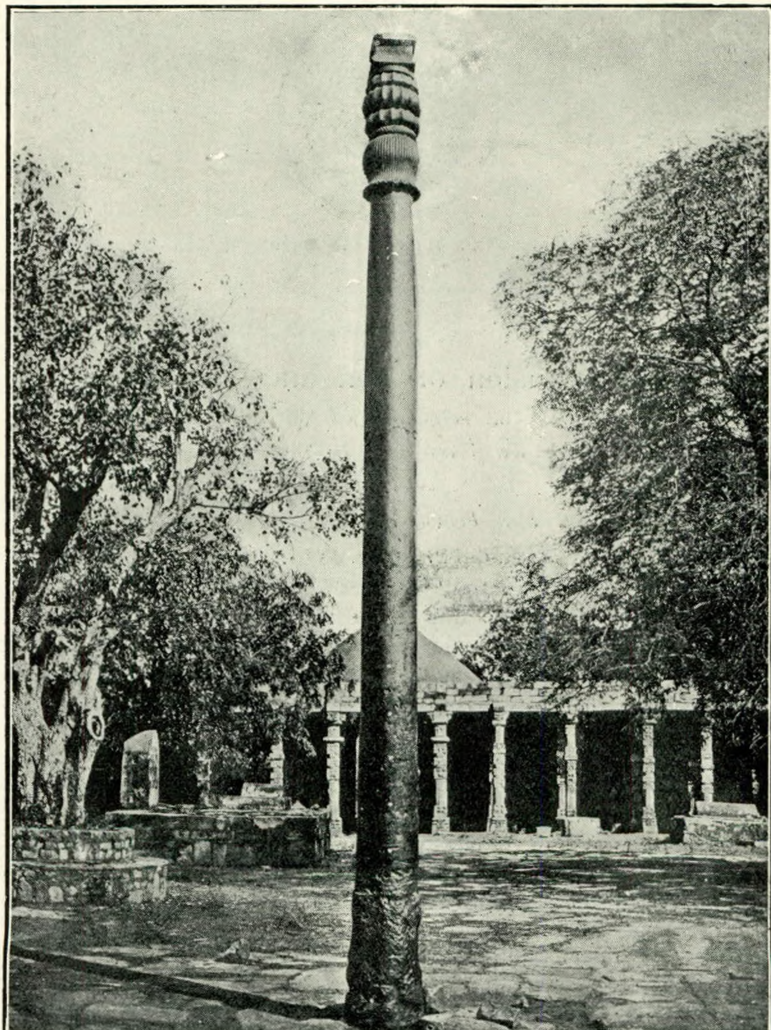


Fig. 1.—The Delhi Column. Erected about 319 A.D.

This illustration is reproduced by the courtesy of Messrs. N. Hingley & Sons, Ltd., Netherton Iron Works, Dudley, who have also kindly lent the block.

Iron is mentioned several times in the Bible—in Genesis 4/22; Numbers 35/16; and Deuteronomy 4/20 and 3/11. The Amorite giant, King Og of Bashan, defeated by the Israelites 1200 B.C., possessed an iron bedstead. At Delhi is an iron pillar 50ft. high and 16in. diameter. This was erected about 319 A.D., and even to-day the surface is but tarnished. It is thought that the stone anvil used in the preparation of this pillar transferred silicon to the skin of the metal. Further, the atmosphere is very dry. The Chinese have been familiar with iron as far back as 2357 B.C., also Homer (1880 B.C.), mentions "Iron wrought with much toil." Julius Cæsar stated that he found the early Britons using iron bars for coin when he visited here. Some of these iron bars are now in the British Museum.

The study of corrosion of metals has received attention for a long period, and the following facts may be of interest:—

The essential distinction between corrosion by strong acids which involved the production of hydrogen in gaseous form, and corrosion by nearly neutral waters in which oxygen is present, received attention 100 years ago.

M. Hall in 1819 pointed out that iron did not rust in water which was free from oxygen, whilst Sir Humphrey Davy in 1824 proved that copper in the presence of sea water from which air had been removed was unaffected.

Both these investigators considered that carbon-dioxide (CO_2) played an important part in the rusting of iron, and it will be seen, therefore, that they inclined to the acid theory of corrosion.

Modern views on corrosion regard it as being an electro-chemical phenomenon, and Thenard expressed this opinion in 1819.

Davy in 1824 proposed the use of iron and zincs to give electro-chemical protection for copper against corrosion by sea water.

In the second half of the 19th century it was considered that corrosion was chiefly an oxidation process. During the last half century the study and investigation of corrosion can be summed up in the following main theories:—The Acid, the Hydrogen-Peroxide, the older Electro-Chemical, the Colloidal, and the newer Electro-Chemical Theory.

The Acid Theory.—Supporters of this consider that there must be a small amount of acid present to initiate corrosion, and for iron and steel in neutral water this will be carbonic acid, which in the presence of water and oxygen is continually regenerated, and acts as a sort of catalyst. Whilst there is a good deal to be said for it, it does not satisfactorily explain all the points in connection with corrosion, *e.g.*, in those cases where there is no free carbonic acid, and again where corrosion takes place in those parts of the boilers which are less exposed to dissolved oxygen.

The Hydrogen-Peroxide Theory.—Time will not permit a discussion of this, but this theory is now considered as not fitting in with the facts.

The Older Electro-Chemical Theory.—According to ionic ideas on solution, this theory of corrosion postulates that iron has a natural tendency to dissolve very slightly in water. Some think that that quantity of iron which would dissolve in water when oxygen is absent is limited to the amount necessary to polarize the cathodic portion of the metal. Oxygen acts as a depolarizer, *i.e.*, any hydrogen found on the cathode would be continuously removed, and the corrosion would then continue indefinitely. If the hydrogen is not removed, it is considered that the corrosion comes to a standstill, except in those cases where, in the presence of acid, the hydrogen is continuously evolved as a gas. It will be remembered that electric batteries of the Lèclanché type depend for their action on the removal of hydrogen by the use of a depolarizer, in this case manganese di-oxide. Whilst the older electro-chemical view recognised that oxygen was needed for the continuous action of ordinary water on iron, it failed to show the effect on the distribution of oxygen in determining which part of the metal should be cathodic and which part anodic.

The Colloidal Theory.—This theory was propounded in 1921 by Dr. Newton Friend. It points out that colloidal agents in the corrosion-product influence the course of corrosion. The theory is of interest and has been of value, but there are objections to it, and like preceding theories, it does not explain all the facts. Dr. Friend demonstrated that there is a marked retardation of corrosion by certain colloidal substances.

Prior to 1916 none of the theories was able to explain why corrosion can proceed quite quickly at the bottom of a deep pit, since such places seemed practically inaccessible to oxygen and other corrosive agents. The newer electro-chemical theory does provide an explanation, in that it takes account of the variation in the oxygen-concentration at different points on the metal. As early as 1813 attention was drawn to some of these points, but unfortunately they were overlooked.

In 1916 J. A. Brooks pointed out that when two similar pieces of iron are immersed in the same solution, and one is exposed to the action of dissolved oxygen, while the other is shielded from it by means of wet rust, a current is set up, and the shielded rusty electrode (which is the anode) is the one that suffers the most corrosion.

U. R. Evans in 1923 made a study of the electric currents set up by the differential-aeration of many metals, and he was able to suggest the reason why corrosion is often found to take place most readily at just those places to which oxygen has the least direct access. This provided an explanation of pitting —an intense local corrosion upon areas shielded by porous debris, or porous-corrosion-product, such as rust. (This matter will be dealt with later on). Many names can be mentioned in connection with the investigation of corrosion, and to save repeating throughout the paper, the following names are given as being most prominent:—

G. T. Moody; E. Heyn; O. Bauer; W. R. Dunstan; W. R. Whitney; A. S. Cushman; Sir R. A. Hadfield; Dr. W. H. Hatfield; F. N. Speller; Seligman and Williams.

In the fore rank we have the names of Dr. Newton Friend and Mr. U. R. Evans. There should also be mentioned the extensive work of Dr. Bengough and his colleagues, especially in connection with the corrosion of condenser tubes, the results of which have been embodied in a series of reports to the Corrosion Committee of the Institute of Metals.

Electro-Chemistry and the Study of Corrosion.—A simple demonstration will now be given to illustrate the principle of the electric battery. A galvanometer will be used to show that a current is flowing. The electrolyte oı solution used here is dilute sulphuric acid. Hydrogen gas is evolved at the positive pole, and the bottom of this electrode in the acid is the cathode. The zinc is attacked and where it is in the solution it is the anode. In connection with corrosion of metals, the important point to know is which part is the anode and which part the cathode. Almost invariably it is the anode part which is attacked. The demonstration will be repeated using the same metals and apparatus, but with a solution of common salt in place of acid.

When carbonic acid acts upon iron in the absence of air, its behaviour is comparable with that of a mineral acid, such as hydrochloric, a regular stream of hydrogen gas being evolved. Owing to the ease with which carbonate of iron decomposes in the presence of air, a given amount of carbonic acid will exert a much greater corrosive effect upon iron than will an equivalent amount of a stronger acid, other things being equal. In general, the purer the metal, the slower the rate of its solution in acids—in other words it is more highly resistant; this depends on the metal, since no one would claim that the purer the metal potassium was the less it would react with water.

It is unwise to jump to conclusions that because a certain strength of solution of a substance will cause corrosion, a stronger solution will cause increased corrosion or *vice versa*.

Differential-Aeration Corrosion.—There is no difficulty in understanding why corrosion can take place when there are two dissimilar metals, or even when a piece of iron contains particles of impurities, where such impurities are more resistant to corrosion than the iron. The use of zinc plates in marine boilers is an example of deliberately introducing a dissimilar metal which will be corroded rather than the iron. Given a sheet of good metal only, it is not easy to see why corrosion can go on then, but the differential-aeration principle makes it clear.

If a piece of iron is placed in a solution of salt, action goes on to a small extent only, in which chloride of iron is formed, plus caustic soda, plus a thin film of hydrogen over the metal. No further action would proceed in the absence of oxygen, but if air is present in the solution, the film of hydrogen is gradually oxidised to water. The chloride of iron now reacts with the caustic soda to produce eventually iron hydroxide, which is deposited on the plate as a rust. This upsets the equilibrium and more metal now dissolves. That part which is covered by the iron rust becomes the anode, whilst the part free from rust is the cathode. Around the cathode will be found the caustic soda. So long as oxygen is supplied in the form of air, corrosion will steadily go on *underneath the rust*, and even if the piece of metal be several feet long, similar remarks apply. It will be seen, therefore, that so long as oxygen is supplied to act as a depolarizer, corrosion will steadily continue.

A demonstration will be given to show this differential-aeration principle, in which two pieces of the same kind of iron are suspended in a salt solution.

It is necessary now to proceed further, and to show that a piece of metal will become corroded when in a solution where the amount of oxygen varies at different depths.

In a glass vessel containing a vertical piece of metal it will be agreed that there is more oxygen finding its way to the liquid at the top of the vessel than at the bottom.

The next demonstration has been arranged to show this. The current is taken from the top of the metal representing one pole and the bottom of the metal representing another. The current generated is very small but is quite definite, and here again that portion of metal which receives the least oxygen is corroded.

As showing the same phenomenon, a piece of iron had string wrapped tightly around a portion of it, and the whole piece was then immersed in a 1% salt solution. This piece of iron will be passed round, and it will be seen that the metal is more attacked where the string has been than elsewhere, although one would naturally expect the reverse.

Application of the Differential-Aeration Corrosion Theory to Internal Corrosion of Steam Boilers.—Given the soluble salts present in natural waters, scale-forming salts, the dissolved gases, and the metal of the boiler, let us consider what factors bring about corrosion, and those which tend to inhibit it. If a uniform scale obtained all over the boiler, so that no portion whatever of the metal was exposed to the action of the water, practically no corrosion would go on.

This seldom occurs in boilers used for marine work. Portions of the boiler are more or less free from scale, with the result that those parts which are covered either with adhering scale or even loose deposit, are corroded, and even those parts of the boiler where oxygen will have the least access may show heavy pitting.

Corrosion which goes on underneath scale in boilers has puzzled engineers for years. It was felt that most corrosion should occur about the water line; it sometimes does—and explanation of this will be given in a moment. When corrosion was found at the bottom of a boiler, even under thick scale or heavy deposits of sludge or the like, the idea that oxygen was the cause of it did not seem to fit in, until the differential-aeration principle made the whole thing quite clear. The increasing concentration of the soluble salts will accentuate the corrosion unless the water in the boiler becomes very concentrated, and also there is new feed entering daily conveying a further supply of dissolved gases. Whilst these gases are being boiled off into steam, they have time to exert some effect. It is not possible to drive out all the gases from the water; a small proportion is always left behind. Condensate contains carbonic acid gas, as can be shown by testing it with a sensitive indicator, when it will be found to be slightly acid. Condensate also contains oxygen, often to the extent of 2 c.c.'s per litre.

Two Main Types of Corrosion.—Most cases of corrosion can be divided into two main types; one in which hydrogen is steadily evolved, such as occurs when a piece of iron or zinc is dipped in sulphuric acid.

This type of corrosion is decidedly accelerated by the presence of oxygen, and also if chlorides are present. Secondly, corrosion due to differential-aeration. Here dissolved oxygen plays an important part. When certain substances attack a metal, a protective film is formed, which stops further action or corrosion, as for example, the action of dilute sulphuric acid on lead. In quite a number of cases a protective film would occur in ordinary practice—for example, on the metal of a boiler, the film being hydrate of iron—if it were not for the presence of a soluble chloride, such as common salt on magnesium chloride The chloride has the power of penetrating such a film as though the film was porous to it, and thus contact is maintained between the metal underneath the film and the solution. The corrosion thus continues.

Water Level Corrosion.—At the water level where the metal rises above the liquid, a lessening of the film may occur. In many cases where the formation of a protective layer practically prevents corrosion over the immersed part of the metal, marked attack may take place at the water-line, and when once started at a few points will often extend right along the water level, and spread to some extent above it or below it.

As illustrating how scale on a plate has a marked bearing on the question of corrosion, there will now be demonstrated an experiment in which two pieces of iron are dipped in 3% salt solution. A portion of one of the pieces of iron has been covered over with a thin coat of sulphate of lime to represent scale. Quite a strong electric current is obtained, as would be expected from the differential-aeration theory, which clearly shows that without suitable treatment of the water a boiler that is partly coated with scale and partly not is liable to be seriously corroded. A further illustration of this is given in the next demonstration. Two pieces of boiler tube (in fact actual pieces of iron tube used in marine boilers) will be placed in 3% salt solution. One of these pieces is an old tube which has been removed from a boiler. Although this corroded tube is free from scale, there is a thin film of rust over it, and it will be seen that an electric current is set up in the presence of salt solution. The corroded tube becomes the anode, in other words, it will continue to corrode. Old tubes in a boiler corrode preferentially to new tubes, and in fact to a certain extent protect the new tubes, assuming the latter are free from deposit.

There are many other points in connection with the mechanism of corrosion which are of importance, but time does not permit of them being dealt with now. Before dealing with the prevention of corrosion in steam boilers, the opportunity will be taken of mentioning some other factors which influence corrosion, especially in connection with boilers.

Factors which Influence Corrosion.—Stray currents leaking from electrical machinery can be and are a source of corrosion. Lasche is of the opinion that part of the trouble experienced in marine condensers is due in some cases to this cause, although in this country it is not generally thought so. U. Evans reports that he has heard of cases where stray currents have caused considerable damage to the holds of ships lying in dock, and says that the existence of these currents is somewhat disconcerting. They can set up corrosion in the absence of oxygen where otherwise the rate of attack would be regulated by the rate of supply of that gas to the metal. Bengough and Stewart in 1922 pointed out that local corrosion on any part of a piece of metal could be obtained underneath cotton-wool, glass fragments, paraffin wax, coke, and many other bodies. The connection between this and the localised attack on brass condenser tubes produced by foreign bodies such as sand or seaweed will be appreciated. In connection with the effect of stresses and strains on corrosion, some writers are rather of the opinion that it plays an important part. In the case of steam boilers different parts are under different conditions, and the well-known grooving which occurs, especially at the root of the flange where the flue tubes join the end plates of a Lancashire boiler, is considered to be accelerated by the stresses and strains at that part. Whether one agrees with that view or not, it is a factor which should be borne in mind. The same piece of metal cold-worked, and a similar piece annealed, when placed in salt solution, generates an electric current, the cold-worked metal generally being the anode, and becomes corroded. Different varieties of metal have different resistances to corrosion, and it is well-known that cast iron feed pipes resist corrosion much better than wrought iron or mild steel; in fact in many ways cast iron resists corrosion better than steel.

Supposing corrosion is going on in a boiler, there may be a few spots covered with a deposit, with the rest of the boiler fairly clean. Oxygen is being continually supplied by the incoming feed water, and this maintains the corrosion in the presence of various salts which are there. The part not corroded is the cathode, and as this is large in area, most of the corrosive effect will be concentrated upon the much smaller anodic areas.

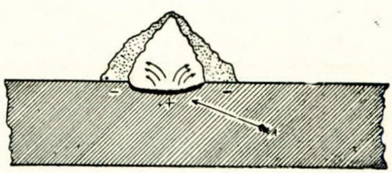


Fig. 2.—Formation of Rust Cones and Pits.

Crannies or " pits " are formed there. When corrosion of this type is going on, there is generally produced a sparingly soluble substance, but not just at the seat of the corrosion, so that further attack is not prevented. On the contrary, Evans points out that it will shield the interior of the cranny from oxygen, and will thus facilitate the corrosion. The rate of penetration under the conditions just mentioned becomes rapid, with the result that pitting occurs, *i.e.*, isolated crannies which have penetrated into the metal. The more " pits " there are in a boiler the more general the corrosion, but the less the depth of the same will be. Where serious pitting occurs at only a few places, it may quickly penetrate to a sufficient depth to necessitate the removal of that plate or tube from the boiler, whereas a more general type of corrosion might take months or years before renewal of the parts was required. At the elevated temperature of a steam boiler, magnesium chloride in the presence of iron splits up, giving eventually hydrate of magnesium and hydrochloric acid. The acid attacks the iron, no doubt on the lines of the ordinary hydrogen type of corrosion. It has been shown that the corrosion of mild steel by 4% hydrochloric acid proceeds fifteen times as quickly in the presence of oxygen as when it is absent. The hydrochloric acid attacks the iron, with the formation of iron chloride, but this is attacked by the water, resulting in the formation of black oxide of iron (the well-known graphitic type or corrosion)—and hydrochloric acid. The same acid then attacks some more of the metal, so that the magnesium chloride acts as a kind of catalytic agent. In evaporators this can reach such an extent that a portion of the hydrochloric acid may be actually distilled over with the steam before it has had a chance of attacking the metal of the evaporator. The acid mixes with the condensate—there to have a most destructive effect on the boiler —hence the advisability of not having too great a density of the water in the evaporator.

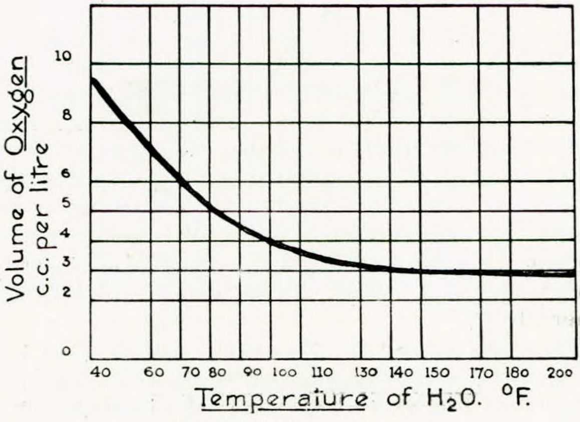


Fig. 3.—Solubility of Oxygen.

Calcium nitrate, calcium chloride, magnesium chloride, magnesium nitrate, carbonic acid gas (carbon-dioxide) and oxygen, are the chief corrosive substances in boiler feed waters, and it is their influence and effect which have to be neutralised if corrosion is to be prevented.

De-gassing plants can certainly remove a large amount of oxygen and carbonic acid gas, and decrease corrosion, but they do not remove the soluble salts mentioned, which are capable of causing corrosion in a boiler, chiefly of the hydrogen type.

Even when oxygen is reduced to a minimum in the feed water, either by vacuum de-gassing, or passing through steel turnings, the feed water may contain nearly as much free oxygen as it originally contained owing to defective pumps, or other agencies putting air or oxygen into the water.

Many ships have trouble owing to leaking condensers, or in the absence of these, to the types of water picked up en route. Any treatment should be capable of dealing with the dissolved gases, and especially with oxygen. Again, corrosion due to acid substances, say from magnesium chloride, must also receive attention.

In connection with the use of colloids in boilers, Dr. Newton Friend has demonstrated that certain colloids bring about the retardation of corrosion, and he has pointed out that the comparatively long life of vessels employed in cooking may be ascribed to colloids in the food. When boilers are emptied out, corrosion may occur internally due to drops or patches of liquid or sludge being left on the sides, tops, etc., which in the presence of air will cause drop-corrosion. On the table is a piece of tube taken from a marine boiler, and kept in the atmosphere of an ordinary room for two months. The tube was quite dry when received, but the magnesium chloride adhering to the rust has absorbed moisture from the air, resulting in the formation of drops, and corrosion is going on steadily under them. Where boilers are being left empty for weeks on end, means should be adopted to render the metal dry. Similar remarks apply also to turbines.

Prevention of Corrosion.—From the remarks that have been given to-night showing that the chief type of corrosion in steam boilers is due to differential-aeration, the importance of keeping the boilers free from scale will be realised. Further, when a boiler is opened up which is found to be patchy both on the tubes, combustion chambers, and plates, the opportunity should be taken of removing as much as possible, especially loose deposits. When new tubes are put in similar remarks apply to the old tubes. Where any active corrosion has been found to be going on, as shown by patches of rust or black oxide of iron, they should be cleaned and wire-brushed, so as to assist in stopping further corrosion of the pitting type due to the presence of the rust.

Where vessels have occasion to pick up a number of feed waters en route, choice is important. Other conditions being equal, the softer the water the less scale formation there will be, and if any information is obtainable as to the suitability of the water from a corrosion point of view, all the better. Vegetable matter when decaying gives rise to what are called humic acids, and moorland waters often contain vegetable acids which exert decidedly corrosive action on boilers. Birkenhead town's water, although comparatively soft, is more corrosive than Liverpool town's water, for the reason mentioned, although Birkenhead water is quite excellent for boilers with suitable treatment. Salt water will naturally be avoided as much as possible, and also waters containing large amounts of suspended matter, such as cloudy river waters. Such suspended matter may settle on plates, tubes, etc., and if the water in the boiler is in a corrosive condition, the deposit will accentuate the corrosion of certain parts of the boiler. Pumps and the like should be kept as tight as possible to avoid air being drawn in.

In Conclusion.—There is the action of greasy water upon iron; corrosion of tubes; condenser tubes; question of alloys; non-ferrous metals; boiler feed pipes and auxiliaries; superheaters; steam turbines, as well as external corrosion of boiler plant and other iron and steel structures. To go into this fully as well as into the various theories of corrosion would require a series of lectures, but our object in reading this paper to you to-night has been two-fold.

1. To review briefly the old theories of corrosion and to put before you the modern view.

2. To stimulate thought on the question of corrosion of steam boilers, as it is a subject where much more observation is required. To-day one cannot dogmatize or say that this or that theory explains everything. It may go a long way, and the theory is good if it indicates *practical means* of overcoming the corrosion. We have had the opportunity of studying and treating severe cases of corrosion in marine and land practice. In that direction we would just like to say that cases of corrosion are essentially distinct, and must be treated as such. Individual attention and care with treatment on correct lines is the only permanent remedy. There are some interesting specimens of corroded tubes, fusible plugs, and such like, for inspection on the tables.

We propose, before concluding, to show some lantern slides, and will then invite questions and discussion.

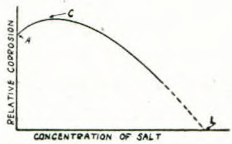


Fig. 4.—Showing the Infiuences of Saline Concentration on the Rate of Corrosion.

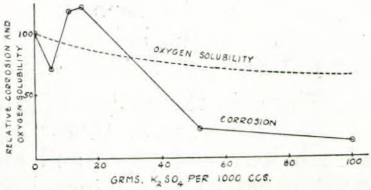


Fig. 5.—Showing the Influence of Saline Concentration on the solubility of Oxygen and on the Rate of Corrosion.

(Reproduced by courtesy of the Iron and Steel Institute, London).

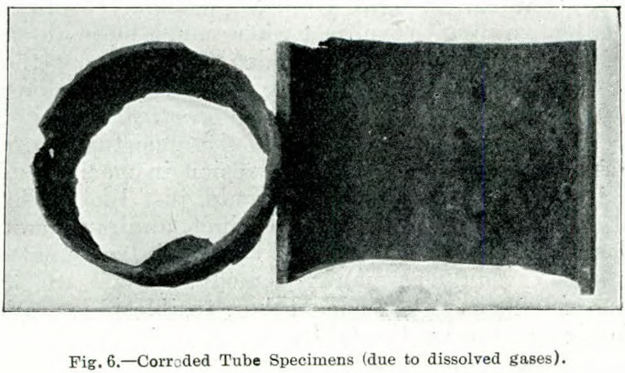


Fig. 6.—Corroded Tube Specimens (due to dissolved gases).

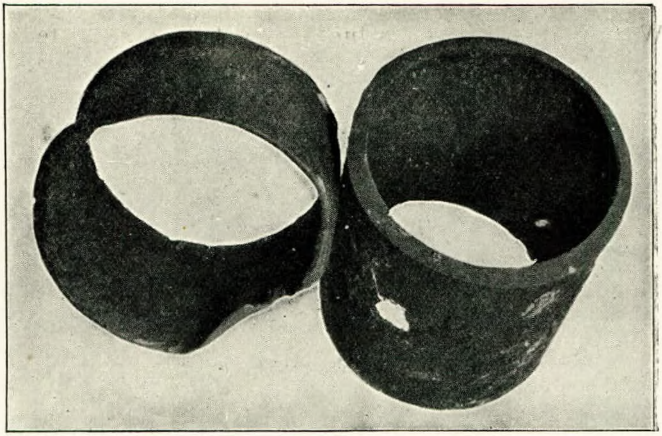


Fig. 7.—Sections of Corroded Tubes from Water Tube Boilers.

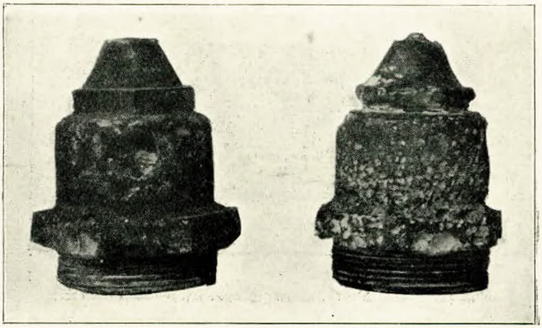


Fig. 8.—Corroded Fusible Plugs from Marine Boilers.

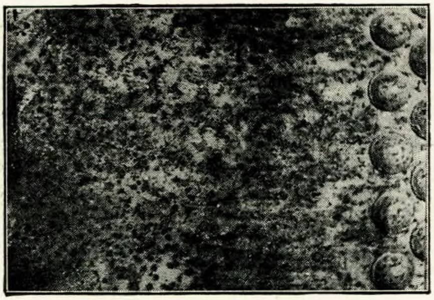


Fig. 9.—Heavily pitted Boiler Plate.

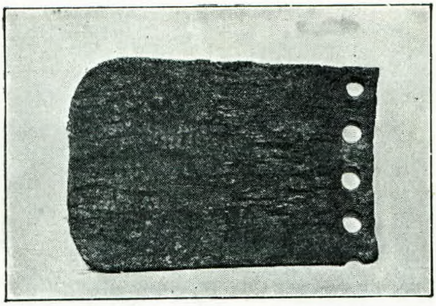


Fig. 10.—Shell Plate—General Corrosion.

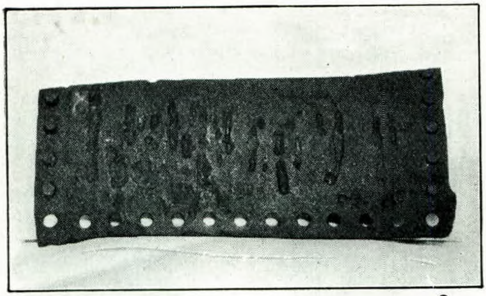


Fig. 11.—Shell Plate, showing corrosion (channelling).

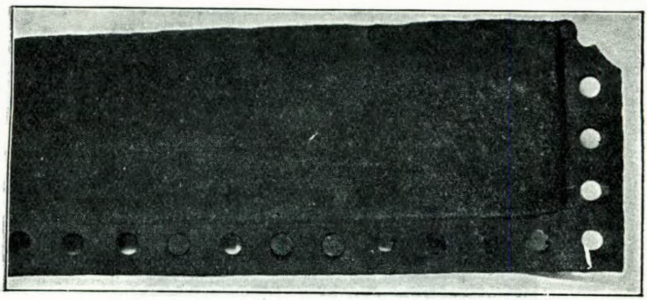


Fig. 12.—Shell Plate, showing uniform wasting (Corrosion).

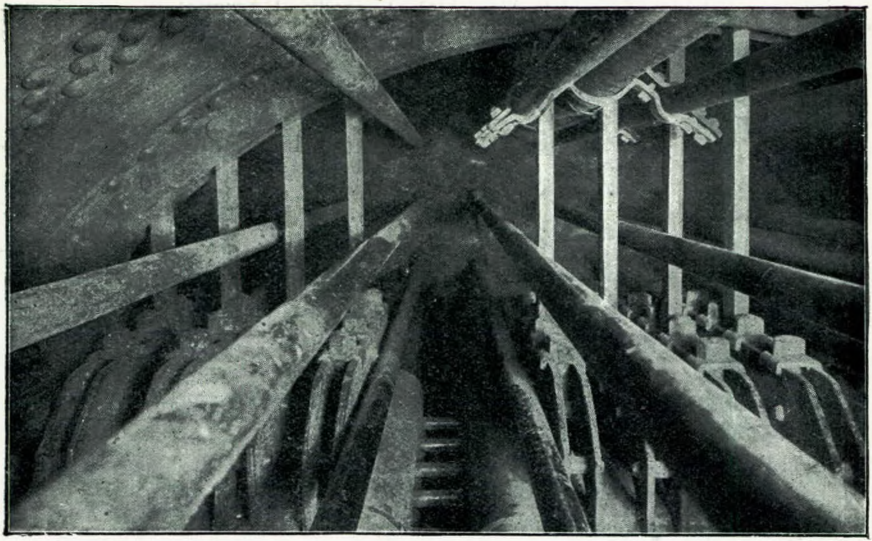


Fig. 13.—Interior of Marine Boiler under correct Treatment. 4 months' steaming. No Zincs. Note clean and healthy state of Combustion Tops.

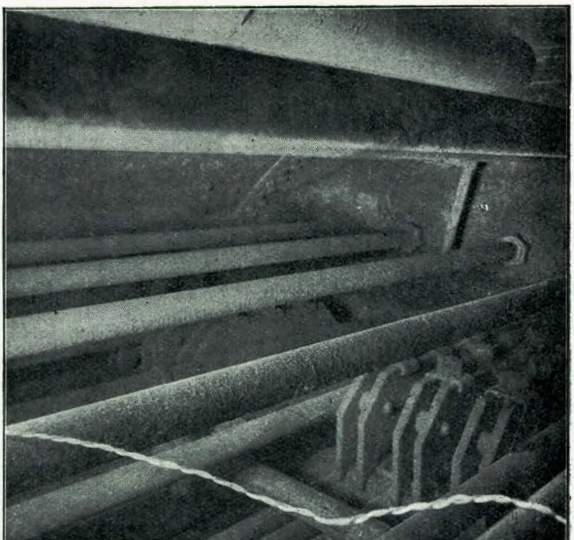


Fig. 14.—Interior of Marine Boiler under Correct Treatment. 3½ months' run. No Zincs. (Compare detail of Electric Flex with cleanliness of Boiler—particularly Combustion Tops.

DISCUSSION.

Mr. Horace J. Young, F.I.C.: I have been amazed by the authors' presentation of their paper. In my opinion the title is wrong because they dealt solely with boilers. Moreover, they had not dealt with the written document and their slides even did not correspond with anything therein. I am unimpressed, moreover, by seeing zinc drillings dissolve in sulphuric acid, and when the test-tube was passed round the audience I felt like being back at about nine years of age. All the experiments were of this nature, being suitable for an elementary night school rather than for a meeting of an important scientific society.

It is my desire to have you understand that in no way do I criticise the authors' knowledge of and cures for the ravages of corrosion. They have shown none; apparently, they have deliberately shown none. It is left to the audience to give information concerning corrosion. I have given papers myself and am willing always to meet any criticism, therefore I feel entitled to express my feelings to-night when I have been so misled. The Chairman had kindly invited me to take part in the discussion and I came here for that particular purpose. I had come to discuss science in an impersonal and scientific manner. On the slides appeared in large letters the name of a Company. I do not know the authors—I have never heard of them; the name of the Company is strange to me, I do not know if it is the authors' Company. Therefore, I do not know if I am harming anyone's business by my remarks. I know only that I am placed, as a critic, in a distasteful and disadvantageous position. I hope that this audience and this Institute will forgive me for thus taking my courage in my hands and for having said what I felt it was a duty to say.

Before coming to the meeting I scanned the written paper and made a few notes. Probably these will make a happier conclusion to these remarks than might be the case were they omitted.

I agree with the authors that corrosion falls into two distinct classes or types, but, unfortunately, I disagree with them as to those types. In my experience, one class of corrosion, and a very distinct one, is that which we talk about in public or explain, lucidly or otherwise, to anyone suffering from the delusion that we know something about it. The other and equally distinct type of corrosion is that which occurs in practice.

Despite the authors' claim to have presented the modern theory or corrosion I would suggest that one needs to read the stop press news in order to be really up-to-date. I have found always the most modern theory is that one which is claimed to explain, no matter how inadequately, the latest corrosion mystery.

It is ancient history that little drops of water and little grains of oxygen lead to mighty corrosion; more logical thought, however, leads us directly to the fact that in the majority of cases they do not. Therein lies the fundamental "snag" peculiar to most, if not all, theories concerning corrosion.

Wrought iron rivets corrode less than steel ones, the latter being the purer and more homogeneous material. Swedish steel corrodes less than ordinary steel, the latter being the less pure material. Cast iron corrodes less than steel, the latter being by far the purer and more homogeneous.

Cast iron is not only not pure but is porous. Why then should it resist better than steel? On the other hand, it is our experience now and again to come across a cast iron casting which has corroded with almost incredible rapidity although a casting apparently similar to thousands of others and working under similar conditions.

In the case of condenser tubes, we may learn by heart the whole ninety and nine volumes of theories, but we order cupro-nickel.

A royal road to successful explanation of any inexplicable case of corrosion is to use the adjective "electrolytic" about five times in every sentence. This provides a sanctuary and a recreation ground of untold value to those who would otherwise be in grave trouble and doubt. Even should there be on the vessel nothing stronger than an electric bell, are there not those other ships using wireless, not to mention household sets? Would not many of the programmes be likely to corrode anything of greater activity than the average listener-in? You may take it that the electrolytic theory forms the basis of the explanation par excellence.

Next in utility comes the sea-water theory. It must be granted that most ships have sea-water somewhere about them. It must be granted likewise that those ships which experience serious corrosion have sea-water also. The logic is obvious. Ships—sea-water—corrosion. The fact that the great majority of ships do *not* suffer from serious corrosion need not be mentioned. The merest amateur would not bring in that argument.

Speaking again upon the electrolytic theory, I forgot to mention "dis-similar metals." One might almost say that these form the harlequinade, the grand finale. To bring this off successfully it is necessary to have some vague knowledge of the arrangement of the metals in accordance with their electrode potentials. Given this, there are few who can stand against the electrolytic theory.

In a recent case I was lucky enough to discover that the corrosion was caused by the oil which had become contaminated with other bodies than sea-water; also I found that the same bodies were present frequently in oils not only from ships but also from land-engines. This is very unfortunate for the electrolytic and sea-water theories, but after all, it applies merely to certain cases and the others still provide plenty of scope. It might be mentioned, however, that too little notice has been taken of oil or oily matters in boiler-water. Much work remains to be done on that point.

I have recollection that water-treatment and water-softening is no modern science. So far as I observe to-day of the treatments recommended, they are those produced by the processes of evolution and time upon the application of long known chemical reactions. A search in old classics, for instance, Bloxam's Chemistry, will prove the truth of that.

The authors omit to mention the fact that many sea-going engineers put into their unfortunate boilers a compound not very dis-similar to that used by gardeners for killing weeds, and occasionally by people desiring to quickly inherit money from near relatives. Such engineers will produce fact and figure to prove that their boilers benefit greatly from these lethal doses. Other engineers, equally intelligent, will tell you that they have tried the same remedy with little or no result.

When my telephone bell rings and a client says he wishes me to investigate a case of corrosion, may I legitimately say, "Worry no further, I have attended an Institute where the modern theory of corrosion was explained?"

I admire the authors' courage in concluding by pointing out that "*cases of corrosion are essentially distinct and must* *be treated as such,*" and particularly for the following advice, "*individual attention and care with treatment on the right lines is the only permanent remedy.*" It is far from me to dispute the utter truth of each of those statements; "treatment on the right lines" will cure any case of corrosion, however distinct or indistinct.

Engr.-Capt. A. TURNER, R.N., Admiralty (Visitor): I agree with Mr. Young's remark on the title of the paper inasmuch as it deals almost entirely with the corrosion of steel and iron in boilers. The author prefaces his remarks by touching on the early history of iron, taking us back to the bronze age before proceeding to discuss certain aspects of the general question of what may go on in the inside of a boiler.

He even mentions Homer among others, and I was left wondering at first whilst reading the paper, "What on earth had he to do with boiler corrosion?" Yet there may be a connection between the two, for did not Homer give us one of the finest descriptions of a job of work being done for its own sake when he told how Vulcan forged the shield for Thetis, the mother of Achilles? One cannot read that description without seeing the flames of the forges, the smoke, the sweat and the glare, nor without hearing the noise of the hammers and the roar of the furnaces—something like a remarkably busy and noisy boiler shop. The shield, I believe, was of bronze and the greaves or shin guards of tin, but of that no matter.

But apart from this Homer presents to us a study of human nature in almost every form, and one cannot but feel that the human element does play an important part at times in even such dry subjects as those pertaining to boilers.

The previous speaker mentioned instances where no corrosion at all took place, whereas in other apparently similar instances the corrosion was very bad.

Many years ago there were two four-funnelled cruisers built to the same drawings by one firm of the highest repute, but in one ship the boilers soon became in a very bad state indeed, nasty accidents occurred—some of them fatal—and yet in the other ship all was peace, and freedom from unusual boiler work left the engineers nothing to do but titivate up the whole of the machinery and render it most efficient.

It puzzled many of us who were youngsters at the time as to the reason for the difference, but some years afterwards it was rumoured that a storekeeper ashore in his cups had blabbed out the fact that for two years he had been treating the boiler water of the ship in question with Portland cement instead of lime—the naval practice having been for many years to keep the boiler water slightly alkaline by the occasional introduction of milk of lime—unslaked lime—into the boilers. If that man spoke the truth it may be that human nature may have a great deal to do with corrosion. In fact, it must be so, but then the author warns us in his concluding remarks against becoming dogmatic in such matters, and in this I think he is wise.

In H.M. Navy, with water-tube boilers and frequent high degrees of forcing power out of them obtaining on service, it is imperative that the thin heating surfaces be kept free from deposits, scale, pitting, etc., and these boilers would last no time with internal scale such as the lecturer has shown us to-night. I really believe that in H.M. Navy one must be far more careful with the boiler water than appears to be the case with some shore plants—and some even in the Mercantile Marine—and water from the shore is strictly forbidden in these water-tube boilers.

In some ports such as Plymouth, the water is sometimes used, but at Portsmouth the water is much too hard and chalky for use, whereas the water at Sheerness is so much poison as far as boilers are concerned. At other spots the water is coloured with peat, etc. In such estuaries as the Thames estuary it is rather risky even to distil—the water may be very nasty indeed as much water which is not good enough for boilers is good enough for drinking, and the drinking water can be easily spoiled.

So from this point of view it is not a personal matter, it depends on the locality in which the boilers are used to a very large extent. Yet establishments near the Thames have used distilled water from it with varying degrees of success, the tubes in some cases being coated with a scale like marble. The conditions vary so that one is driven to the conclusion that the water must be kept clean at all costs.

In this respect the cause of the troubles in the boiler room may be traceable, not to the boilers, nor to their personnel, but to the engine room. The water from the evaporators may not be absolutely pure, and there is no room for any compromise in this respect; there may be incipient leakage of salt from one of the many condensers or storage tanks, there may be access of air or even grease to the boiler water. At times things seem to go all wrong at once and at others they behave themselves properly and it is largely a matter of luck as well.

I am in agreement with one of the diagrams shown by the authors on the screen, which shows that a little salinity in the water could be worse than a great deal, as after a period of difficulty with condensers, etc., the boilers generally seem to open out not so well as usual although the trouble was never allowed to become very bad.

It is sometimes claimed that the corrosion is a matter of material, imperfections in the drawing, such as laminations, or to impurities. This may be so, but it is noticeable that pitting inside tubes, for example, is almost invariably on the fire side of the tube, showing that the rate of generation of steam, or the effects of temperature, or rate of transfer of heat through the steel, may, either individually or collectively, have a say in the matter.

On the whole, the best remedy for corrosion in water-tube boilers appears to rest in untiring efforts in keeping the boiler water as pure as possible, free from any acidity, air in solution, or grease.

Mr. W. Hamilton Martin: The authors' very informative paper to-night has shown us another interesting possible theory on the question of internal boiler corrosion, from which they conclude that it is important to keep boilers free from scale, loose deposits should be removed, soft water made use of, etc. These facts have, however, been realised as necessary by boiler users for many years.

In one of their pamphlets entitled, "Water and Boiler Efficiency," available in the Institute's Reading Room, it is stated:—

"Wherever scale is likely to form, more than ordinary care should be taken in the elimination of even a *trace* of grease.

"The lower the amount of scale-forming constituents, the greater the amount of grease deposits formed, and as oil effectively retards heat, the danger from overheating is made more manifest.

"Oil or grease present in scale increases its over-heating propensities, causing serious weakening of the metal of boiler walls which will bulge or burst under steam pressure.

"Tubes heated to such high temperatures, especially in water-tube boilers, are often 'burned' externally. Layers of oxide of iron are formed and these peel off, the metal becomes thinner and eventually bursts.

" It is as well to remember that Mr. C. E. Stromeyer, the former Chief Engineer to the Manchester Steam Users' Association, states that ' a film of grease 1/100th of an inch thick offers resistance to the passage of heat equal to a steel plate ten inches thick.' In other words, grease offers 1/1000th times the resistance of steel to the passage of heat.

" If oil happens to be present on the surface of the water in the boiler where it will collect during periods of cooling down (as well as on the walls and tubes) it will lead to priming, bumping, or foaming, as any impurities are likely to do which increase the surface tension.

" It is further stated that ' the merest trace of oil in a boiler can initiate what may subsequently become serious corrosion, and it is pointed out that mineral oils are less liable to attack the iron acidically.' "

Now if one takes the above stated facts into consideration, would the suggestion not occur to many of us that careful removal of oil from boilers is probably as important, if not more so, than the elimination of scale?

In marine practice especially, which chiefly interests us here, the necessity for doing so is more often felt than in land installations, where feeding arrangements lend themselves better to the exclusion of oil and a more plentiful supply of water is usually available.

It occurs to one that the chemist might with advantage give closer study to the question of oil elimination from boilers.

Where higher steam pressures are coming into more general use to-day and water-tube boilers are finding wider adoption in consequence, this question of heat retardation, caused by oil or grease on boiler walls and tubes especially, will probably become more serious, and the necessity for having a means which would indicate the presence of oil in boilers in the smallest quantities was urged recently by Sir Robert Dixon, Engineer-in-Chief of the Fleet, during discussion of the paper on High Pressure Steam by Professors A. L. Mellanby, D.Sc., and Wm. Kerr, LL.D., read to the Institution of Mechanical Engineers.

The authors tell us that the colloidal treatment is not able to remove the oil entirely from feed water, and they mention other methods which are widely used, of the separator or filter type.

Both types, however, require frequent cleaning (either by cleaning of separator parts or renewing of filtering media) if the particles of oil mixed up in the feed water in the finely divided state which forms an emulsion are to be sufficiently trapped.

A difficulty then arises here to know just when the separator or filter has become clogged enough to require cleaning.

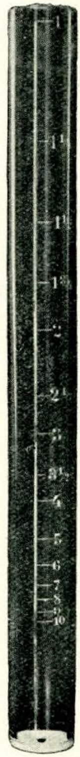
It should be pointed out here that the small amount of oil which is sufficient to do damage to boilers when present in the feed after leaving the separator is such a minute amount that it cannot be ordinarily detected by the eye or otherwise. The fact, therefore, that the effluent from the separator looks as clear as fresh drinking water is no criterion at all of its being free from oil.

What is wanted therefore is an *indicator which will show us*, or what is better still, *definitely measure minutest amounts of oil in water* after it has been cleansed to our best ability. Having such an indicator, which must be simple and easy to use and preferably of little cost, we can at all times satisfy ourselves of the actual condition of the water entering our boilers, and by keeping it well within the danger limit of its maximum oil contents remove the trouble caused by excess oil or grease in our boilers, which will materially increase their useful life and save time in repairs and lessen cleaning periods, to the good of all concerned.

The maximum amount of oil which a boiler can contain in its feed water in a state of emulsion without causing serious damage to walls or tubes is *three grains per gallon of water*. This limit should thus never be exceeded, and to enable the engineer to see to it that this is kept below the amount stated, an indicator is now available.

As this question seems of sufficient importance at the present time, and as to-night's discussion offered a suitable opportunity to bring it before the Members of this Institute, I have brought with me two examples of the gauge in question. It will be noted that it is of the simplest kind, has nothing to go wrong with it, being made out of one piece, and requires no manipulations, chemicals, connections, delicate gauges or mechanisms to be constantly needing re-checking. Anyone can use it with the utmost exactitude, and resulting benefit.

This " Feed Water Oil Gauge " as it is called, consists of a simple graded glass tube, one end of which is closed by a white porcelain bottom, in the centre of which is a conspicuous black spot.



All one has to do is to hold this tube in the hand, in a good light, and slowly pour the feed water to be tested into the tube while watching the black spot, looking down through the rising liquid. Just as this spot is on the point of becoming invisible the height of the column of liquid read off on the scale gives one the grains of oil per gallon or water in the sample tested. The scale is sub-divided in particles of grains. For countries using the metric system these gauges are supplied reading in milligrams per litre.

These gauges are used by well known steamship lines, some of which specify them on all their steamers; navies use them, and they find good use in many engineering industries, especially where use is made of process steam, either for heating or coming into direct contact with articles produced. In the former case heat retardation from oil lowers the efficiency of the steam, while in the latter there is the added drawback of the articles either being spoilt or their taste becoming impaired.

Sugar works are regular users of these gauges, while breweries, distilleries, oil mills, chocolate factories, water works, power stations where water is scarce and water-tube boilers at high pressure are in use, also use them.

In hospitals where a lot of sterilising and heating is done they are utilised. Once the boiler operator realises that this gauge removes for him the worry which oil in his boilers has given him, and enables him to get the best out of his separator, and reduces his boiler cleaning blow-downs, etc., he will always use it, we have invariably found to be the case.

A more recent application of these gauges is to indicate the oil-contents of the effluents from oily bilge water separators, now coming into more general use for preventing oil pollution in harbours and coastal waters.

While it gives the operators means to decide when to stop separating for cleaning their separators, it also is a handy pocket-size means for the Harbour Board Inspector to satisfy himself at any time during the operations that the discharge of the water into his areas is sufficiently free from oil.

Oil at best is a very elusive substance, and although this gauge up to the present has proved a sound guard against its entry into boilers, it nevertheless remains for the chemist to search for a means to completely rid our feed-water of it, or to give us a boiler material which will not be attacked by its presence, failing which the engineer will have to design his feed arrangements in such a way that oil is either not required or cannot find its way to the boilers.

I would add my appreciation to the authors for the time and thought they have given to corrosion questions and the clear way in which they have put their subject before us to-night.

Mr. F. O. Beckett: I must congratulate the speakers to-night on giving us a little Biblical history.

Referring to the illustrations shown on the screen, the authors showed the pitting of a tube. I would like to ask the authors whether they could illustrate to us a mode of stopping this pitting. I have under observation four water-tube boilers which are fed by an economiser and the farther one goes away from the economiser the deeper becomes the pitting. On examining the first drum the year before last there was scarcely 1/32nd inch of pitting; this year there is 1/16th inch, and in the second drum it is 3/32nd inch. These pittings are taking place nearly on the bottom of the steam drums. I do not know what is going on in the tubes. Several of the tubes of the economiser were condemned four or five years ago owing to internal corrosion near the top boxes. These economiser tubes are made of cast iron. We have had them analysed, taken out and broken and sent to chemists, metallurgists, and the makers. We brought a Frenchman over and he put in a de-gassing plant, but we have stopped that since. We have even stopped the economiser. My view was that the specific gravity of the water has something to do with it. We have some of the finest oil separators that man has been able to invent, and we supply feed-water at about 230°F., but we still have this difficulty. If the authors could tell the engineer how to treat a pitted boiler they would be doing a signal service. These drums have been chipped and left simply polished, yet the pitting goes on more briskly the next year.

With regard to the question of oil in boilers, I think I must agree with Captain Turner about the importance of clean boilers. Many people neglect to blow down a boiler. Some would rather put the blow-off cock on the shelf and save it. I am not thinking of the boilers on land the same as we do at sea, but the thought has just struck me owing to the diagram shown being from a low degree of density to a higher, that the graph comes down as the density increases. I agree with that. In the Atlantic I was once in a cattle ship and one of my jobs was to supply the drinking water for the cattle. We had no evaporator or anything like that. Our stokers had to make it, and I had to put it in the condenser. The salinometer used nearly to jump out of the pot when we got to London, but the boilers were clean, that is to say they were free from scale. I thought we were mad, but I was a junior then. The higher you go in density the lower is the scale formation. That simply goes to show that you can have excessive saline without incurring serious trouble from scale. In the Atlantic you get some very fine water, better than in the Mediterranean. The water at Genoa nearly brought our furnaces down. The authors showed on the screen some smooth wasting. I do not know whether they could tell us what brought that about? Was it bad design or workmanship, or was it a question of water discharged from a chemical works being used as feed water? Anyone could get that. I remember an occasion near Glasgow when feed water was being used which contained sulphuric acid, and it ultimately ate through the plates to about 1/64th inch thickness. The whole surface was as smooth as possible, and deceptive to those in charge.

In conclusion I wish to say that I have greatly appreciated the paper.

Mr. W. McLaren: I think the authors are to be congratulated on bringing before us their method of trying to prevent corrosion. I cannot just understand what they have described to-night, but from my own experience corrosive action commonly occurs in Lancashire boilers using hard town's water or well water. I know a good deal about these boilers. Having been advised to keep the hardness down to as low a degree as possible, we have been using a water softener. I think we got down to about three, and that took us about three years. When we were working at a hardness degree of eight we had scale formation. The boilers referred to have been running about 32 years. They are a battery of three, and the last of the three to be put in is the one with which we have had the most difficulty, due to pitting. We have had trouble since using the water softener. Prior to that we used to open these boilers three times a year. Since the softener has been used we have reduced these operations to two per year. That is on the south side of London. On the north side of London we tapped well water. That water had five degrees of hardness, and I can state from my experience that there is no better water to be found, even at my own home in Edinburgh, but if you allowed that water to remain in the boiler without keeping the boiler in working order, it would bore holes in it in about six weeks. With proper care in this respect, however, after twelve months run, if there had not been the necessity of cleaning the flues we could have gone on for another twelve months. One man could clean out that boiler in about three hours. I have been in boilers while at sea and have come out like a red Indian. That was on the Eastern trade; when we crossed the Western Ocean we had no such difficulty. Whether the cause is associated with the age of the boiler or the treatment it receives I cannot tell, but pitting and corrosion certainly requires to be met and counteracted. I think, with the authors, that each individual case must be treated on its merits. At one time on the Tyne we were recommended to use a certain lime. We were not many days at sea before we had priming and when we opened up the high pressure casing we found about eight inches of the lime in it. In another case with a new set of engines and boilers going on the South American trade we had also a great deal of priming, but that was put down to the design of the new boilers. We ran those boilers very heavily with salt, allowing them to salt up, and that cured them. As regards boiler tubes, we had a small Scotch boiler for the donkey boiler. We had a Chinese crew and we could hardly get those Chinese to go inside that boiler. My method was to allow the boiler to salt up, then to cut the tubes out and re-tube!

The CHAIRMAN: One point which no speaker has brought forward is the treatment a boiler receives during its manufacture. In the Admiralty every precaution is taken during the manufacture of the boiler to ensure that it is in perfect condition and all the tubes, especially of water-tube boilers, are pickled, zinced, and after cleaning and testing, lime is put inside so that no corrosion can take place while the boiler is being manufactured. Consequently it has a good chance of starting well. I think a great deal of the trouble may be due to the fact that boilers are frequently allowed to lie about some months in the shops before being put into the ship.

Distilled water should be used if possible. Also you must try to get out all the air in the feed water. It has been my privilege to watch lately the process of "Fescolising" of tubes. Mr. Young is familiar with this process. I would "Fescolise" the water side of tubes and it would then be found that the life of those tubes would be very greatly prolonged. You can "Fescolise" a tube and a stay. The important point, as Captain Turner said, is to keep your feed water absolutely pure. Given proper care, I see no reason why boilers should not last twenty years. The tubes go first; the life of a boiler is the life of the tubes. If you "Fescolise" the tubes, I think they should last as long as the boilers.

I should like to add my thanks to the authors for coming here to-night and giving us this paper.

The AUTHORS' REPLY (Mr. W. B. LEWIS): On behalf of Mr. Irving and myself I thank you for your courtesy this evening, and appreciate the remarks and discussion which have contributed in a great measure to an interesting evening.

In responding to the Chairman, we had the pleasure of reading a paper to the members of the Institute on the scientific treatment of feed water for ships' boilers, introducing the colloidal aspect, on the 3rd February, 1925. The problem of corrosion being an individual and also a national one, has necessitated a large amount of research work, and in fact many noted investigators are still engaged in this direction.

Remarks made in regard to Admiralty procedure are distinctly interesting, and it is true that corrosion is often initiated in new boilers, especially due to active causes prior to installation, and more care we feel sure could be exercised with advantage in this direction.

Proceeding with the further remarks of the Chairman, air is unquestionably one of the contributory factors in the process of corrosion. De-aerating plant serves a useful purpose, but it is often the case that air is found in the boiler itself after the initial process in a sufficient quantity to initiate corrosion. Even as little as one cubic centimetre of air per litre of water can act as an influence in corrosion, whereas the average analysis of water taken from boilers shows something like 2 c.c. per litre.

Dealing with the particular process mentioned, we have heard of this newer method of adhesive deposit. In a somewhat similar direction we have heat blowing, the Coslett process, and the Parkerising process.

Replying to Mr. Young, the title of the paper indicates that there would be special reference to boilers. Time did not permit of a comprehensive survey of such a field. The written paper may not have been read word for word, but in substance and fact it was not changed. The slides correspond with the paper, each slide being an actual photograph of tube or plate, etc. Other slides illustrated differential-æration. For Mr. Young to contend that the slides did not correspond with anything in the paper is absurd.

The zinc and sulphuric acid demonstration showing the production of hydrogen gas is elementary chemistry. The authors were under the impression, and still are, that they were addressing Steam Engineers. Whilst appreciating Mr. Young's criticism as a chemist on this point, just as there are elementary factors from an engineering standpoint that can be new to chemists, the converse applies to chemistry and the engineer.

With regard to Mr. Young's statement that the authors have shown no knowledge of, or knowledge of cures for corrosion, he is invited to inspect our records in the field of actual practice, as he is also requested to re-read the paper. The paper gives reasons for corrosion, suggests some cures also. We purposely refrained from describing our direct cures for corrosion, out of respect to the Institute and the usual conditions associated with the reading of technical papers. In refraining from advertising our methods we are accused by Mr. Young of not giving methods of prevention.

Would the Council have permitted us twice to present papers if there was substance in Mr. Young's remarks? The paper was first of all submitted to the Institute for approval, and our presentation of it in person is with the Council's approval. Either Mr. Young is all right, or the Council and ourselves all wrong.

The authors and the Company are one and the same. Mr. Young states he does not know the authors—has never heard of them, also the name of the Company is strange to him. That shows how little he is in touch with the literature, despite the fact that he mentions 99 books on condenser corrosion. Papers by us have appeared in "Engineering and Boiler House Review," "Power" (leading American Journal), the Transactions of the Institute of Marine Engineers, the "Fuel Economy Review" (issued by the Federation of British Industries), "Water and Water Engineering," "Engineer," "Engineering" and other papers throughout the world.

Mr. Young states that there is one class of corrosion which we talk about in public, or explain. The other and equally distinct type, is that which occurs in practice. We agree. It is with the corrosion that occurs in practice that we have our main experience. In fact our very existence depends on acquaintance with, and cure of it.

Mr. Young says that it is ancient history that little drops of water and little grains of oxygen lead to mighty corrosion; but that more logical thought, however, leads us directly to the fact that in the majority of cases they do not. We reply that if the water was absolutely pure (and no one yet has succeeded in making it so), Mr. Young's remarks might apply. In our address we were dealing with waters found in Nature, and in boilers. Such waters are impure. Authorities besides ourselves agree that oxygen in water does play a very important part in the corrosion of steam boilers. We also refer (and it is stop-press news because it is a 1928 publication) to " Art and Principles of Chemistry," by H. E. Armstrong, as a source of up-to-date information bearing on the point raised.

Mr. Young mentions wrought iron rivets corroding less than steel ones, cast iron corroding less than steel—that cast iron is not pure and is porous, and asks why should it resist better than steel. In our opinion no better constructive help on these features is afforded than that by U. R. Evans in the Journal of the Society of Chemical Industry for March 9th, 1928. Although Mr. Young's remarks consist entirely of destructive criticism with an occasional statement of fact without any proof, we wish to be constructive, hence this further trespass on the columns of the Institute's Journal. U. R. Evans states:—

" As regards the question of choice of materials, it would appear that Friend was correct when he said that ' certain makes of wrought iron will prove most useful in certain circumstances, whilst under other conditions, the palm will have to be given to steel.' Every case requires to be considered on its merits. In general, it may be said that under favourable conditions there is no reason why steel should not have a life similar to that of wrought iron, but that the peculiar structure of wrought iron gives it, under certain circumstances, a definite advantage in deflecting an attack of an intense localised character."

U. R. Evans further states, in his book " Corrosion of Metals," 1926 edition, page 186: " There is a wide-spread belief that wrought iron withstands corrosion better than steel. Yet a very useful study of the evidence made by Friend—who quotes the opinion of numerous practical engineers, leaves the reader with the impression that there is, for many purposes, little to choose between the two materials; Friend thinks that for some purposes, wrought iron may be superior, and for others, steel. More recent laboratory tests by Friend, some of which have been extended over a year, also appear to show that the superiority of wrought iron—if it exists at all—is comparatively small. On the other hand, some two-year tests conducted by Andrews about 1885 (Proc. Inst. Civ. Eng. 82—1885, figures 281) indicate wrought iron as being decidedly the best material. It is quite likely that at one time wrought iron was really superior to the steel of the period, the quality of which—both in respect to physical soundness and homogeneity of composition—was probably inferior to that reached by steel to-day.

" But as early as 1890, thirty-seven shipbuilding firms were requested by Howe (Metallurgy of Steel, Volume 1 (1890), page 101) to furnish their opinions regarding the relative corrodibility of wrought iron, and steel; of these, seven firms regarded steel as the more corrodible, eight firms regarded iron as the more corrodible, whilst the other twenty-two were uncertain, or considered there was no difference.

" Wrought iron sheet is believed very widely to be superior to mild steel sheeting. One explanation which has been suggested is that the slag in wrought iron sheets may exist in layers, which obstruct the progress of rusting."

(See our Paper read before the North of England Institute of Mining and Mechanical Engineers—published in their transactions, Volume LXVII., 1924).

The comparison of cast iron and steel is quite another matter. Some varieties (of cast iron) withstand corrosion well, whilst others become softened rapidly; further, in a given piece, the depth of softening may vary from place to place; finally, the softening matter may easily escape observation since the metal may appear unchanged until it is tested with a knife, when the softened material can be bored, or whittled away quite easily. The fact that in cast iron—in contrast with steel—the corroded material remains in its original place, may be partly due to the quality of the silicous skin, and partly to the presence of the net-work of unchanged graphite flakes in the material. The variation of behaviour of different types of cast iron may be partly due to the wide variations of composition. One would imagine that the nature of the graphite net-work would be important.

" It is also likely that the physical character of the material is important. Newman (" Metallic Structures," published by Spon) states that hard cast iron with a close even grain resists corrosion better than soft grey, foundry iron; undoubtedly white cast iron resists better than grey iron. Corrosion tends to penetrate along cracks, if they occur, whilst porosity in castings, whether due to includings with scoria or other cause, is very liable to promote attack.

" The fact that cast iron must (for equal strength) be thicker than steel—however disadvantageous in other respects—is favourable to the long life of the cast iron. Even if steel were, as a material no more corrodible than cast iron, one could hardly expect a thin steel pipe to withstand corrosion as long as a thick cast iron pipe."

Mr. Young stated that a royal road to successful explanation of any inexplicable case of corrosion is to use the adjective "electrolytic" about five times in every sentence. Our reply is that the ambiguity of that statement is self-evident, because in the fifty-one paragraphs that constitute our paper "electrolytic" is not mentioned once.

He also says that the fact the great majority of ships do not suffer from serious corrosion need not be mentioned; the merest amateur would not bring in that argument.

We are not concerned with the "degree" of corrosion as we are with its existence. And it does exist quite definitely on most of the ships known to us by experience gained through internal inspection. As to whether it exists on the majority of ships referred to by Mr. Young is something on which we cannot opinionize, because we have not inspected the majority of ships that constitute the World's Marine Service. Has Mr. Young? We doubt it, because from several hundred ships' boilers we have inspected in European countries, U.S.A., and Canada, we have seen corrosion, and serious corrosion at that. That statement is made as professional business men.

Mr. Young states that he has recollection that water treatment and water softening is no modern science. It is modern so far as "water conditioning" is concerned. Apparently Mr. Young is not acquainted with the "stop press" developments, to use his own expression—the up-to-date method.

With regard to his remark, "When my telephone bell rings and a client says he wishes me to investigate a case of corrosion, may I legitimately say, 'Worry no further. I have attended an Institute where the modern theory of corrosion was explained'"? We reply, "Promise nothing until a careful diagnosis has been made of such a case by those qualified to do it."

Finally, this subject of corrosion and the measures required to subdue it are not as difficult as Mr. Young imagines, provided one has a thorough knowledge of electro-chemistry. The corrosion of metals is not a fickle phenomenon, but is controlled by laws in a similar manner to ordinary chemical reactions. There are guiding principles, and if those are understood, the approach to, and solution of, the problem are greatly facilitated.

We are glad to have had this opportunity of replying, in, as we hope, a constructive manner. Our policy is fair play for all —success to the best.

We thank Mr. McLaren for his interesting commentary.

Mr. Beckett's remarks are noted with particular interest, and should he care to write to us further on the matter we will have pleasure in replying to him in detail. A number of questions would have to be put on the principle of individual investigation, following which we would be in a position to submit our opinion. Smooth wasting is usually due to the influence of free acid, and pitting to the effects of gases. From an experience in treating corrosion problems throughout a number of responsible jobs both on sea and land, and in replying to his suggestion—we are in a position to provide the remedy for such corrosion.

We listened to Mr. Hamilton Martin's comments with especial interest, and quite agree that oil may have quite an important bearing on the question of corrosion. It will not be necessary to dilate upon the evil of vegetable oils, which decompose, liberating free fatty acids, and also on the disadvantage of mineral oil in boilers which can quite easily cause overheating. The gauge he mentions appears to have distinct advantages.

Engr.-Capt. Turner's remarks were distinctly interesting, and we much appreciate his comments at length. We are in agreement with him regarding the importance of keeping boiler water pure, and internal conditions as clean as possible.

Mr. G. S. Irving: There are perhaps one or two points which the other speakers raised that might be dealt with now. Captain Turner referred to Homer, and we are much obliged to him for his interesting remarks. We heartily agreed with his view point about keeping the water pure. Every effort is no doubt made in marine practice to that end, but of course difficulties do arise and the problem is what to do when corrosion does begin.

Mr. Hamilton Martin dealt with oil and scale. Mr. Young also mentioned the importance of oil. Certainly that aspect of the problem is one well worthy of consideration. The trouble is that in a paper of this nature there are so many points that could be dealt with; corrosion of condenser tubes we left entirely out. One could not deal with them all in one paper. No particular reference was made to corrosion caused or exaggerated by oil. There are, of course, mineral oils and vegetable oils; the latter are known to be definitely corrosive.

Mr. Beckett raised a very interesting problem in connection with water-tube boilers, and the economiser. To answer his question fully would, of course, necessitate asking quite a number of questions regarding the plant, type of water used, etc. It would seem from the particulars he has given that whilst the de-gasser is dealing with the oxygen there are still substances in the water, perhaps magnesium chloride, which are setting up the corrosive influence.

The same speaker raised a question about uniform corrosion, in connection with one of the slides illustrating this phenomenon. To the best of my knowledge that particular case was one where impure water was being used and that water contained sulphate of iron, which in a boiler splits up, giving sulphuric acid.

Mr. McLaren mentioned some interesting points about the use of a water softener and corrosion following. That is not an uncommon occurrence, because in softening down to three or four grains per gallon one may still leave residual magnesium compounds which are rather harder to remove. Unless the water is correctly dealt with, a water softener cannot be expected to prevent corrosion. It is a very fine example of the human element which crops up in numerous cases. The correct use of a water softener is essentially the job for a chemist. Without the water softener the boiler would no doubt be protected by the scale which formed on it. We have observed the same features in the waters of the North and South areas of London, as mentioned by Mr. McLaren. In one area boilers would be found in good condition, in another, one would find heavy scale and corrosion.

As regards the Chairman's remarks, we heartily agree with his views about the treatment of boilers during manufacture. Boiler manufacturers should take greater care on that point; also those who buy boilers and have occasion to store them before they are put into commission.

I believe some boiler manufacturers are taking a great deal of interest in the rivets that are used in order to ensure that that there is no great dissimilarity in the metal when they are joined up together.

Mr. John Menzies: I have great pleasure in proposing a very hearty vote of thanks to the authors who have given us this interesting paper. I think they realise that we do appreciate it, and that they will take in the right spirit the criticism which has been so freely bestowed on them. I think it is one of the privileges and one of the pleasures of this Institute, being permitted to express contrary views so freely, and I think we obtain much profit by such frank interchange of ideas. We are here to discuss and criticise, to find out the cause of trouble and eliminate it.

Mr. W. B. LEWIS: We thank Mr. Menzies for his remarks, and would like to assure him that we always look forward to criticism and discussion on such occasions as this, recognising that out of an interchange of views and ideas only good can come.

Notes.

ADVANTAGES OF COAL AS FUEL FOR CARGO VESSELS. — The recent trials of the Canadian Pacific Steamship Company's Cargo Steamer *Beaverhill*, which is equipped with water-tube boilers and turbine machinery for propulsive purposes, and cylindrical boilers for use for the auxiliary machinery, gave interesting information as to the comparative merits of the use of coal as fuel with boilers, or oil as fuel, either with boilers or with internal combustion machinery for ships of this class.

The *Beaverhill* is one of five cargo vessels which have been built to the order of the Canadian Pacific Steamship Company, and is the fourth vessel to run her trials. The machinery arrangement has been designed under the superintendence of Mr. J. Johnson, Chief Engineer Superintendent of this company, and the ships are designed to use coal as fuel in association with water-tube boilers for the propelling machinery and cylindrical boilers for the auxiliary machinery.

The first three vessels were fitted with water-tube boilers of the three-drum type, and with mechanically fired grates. Two other vessels of the class of which the *Beaverhill* is the first to run her trials, have water-tube boilers of the Babcock and Wilcox type, and the coal is fired to the boilers by hand.

The results achieved in the *Beaverhill* on a consumption trial of about ten hours' duration at approximately 7,500 S.H.P. showed a coal consumption of 1·07 lbs. of coal per S.H.P. per hour for all purposes. The coal used had a heating value of 13,700 B.Th.U.'s per lb., and it will be readily recognised that the cost of fuel used per S.H.P. is considerably less with coal in comparison with the use of oil fuel, either used as fuel in the boilers, or with internal combustion machinery.

The coal used was a mixture of Gartshore and Polmaise obtained from Scotch collieries.

The saving in fuel running cost with this installation of steam machinery in the *Beaverhill* at 250 lbs. pressure and a final steam temperature of 650° F. is readily apparent, and there is no doubt that this economy in coal consumption can be improved upon by the use of higher pressures and superheat temperatures.

The results with the mechanical grates show an improvement in boiler efficiency, as compared with hand firing, and with this further advantage the trials of these ships demonstrate still more definitely the superiority in fuel running costs to be obtained by the use of coal fired boilers and steam machinery.

The following paragraphs are from "The Sun News-Pictorial" of January 2nd, Melbourne:—

A Resolution Worth Making.—Of course, we all make our individual resolutions for the New Year, which began yesterday. But national resolutions are unknown. Yet what a great thing it would be if Australia could resolve to make 1928 a great year of industrial peace and goodwill.

The year 1927 has not been altogether as we should like it. It brought us trade depression, unemployment and even so, was not free from industrial trouble that added to distress.

The New Year would be a better year for Australia if we could all resolve to pull together, peacefully, with goodwill and reasonable give and take; and to make 1928 a record year for the small number and triviality of its industrial troubles.

The Shipbuilding Outlook.—Promise of a Revival?—By Sir Walter Runciman, the well-known Shipowner. — From "The Liverpool Echo," February 24th, 1928:—

The economic outlook for British shipbuilding is distinctly better than it was at the beginning of 1927.

Signs of material improvement are not wanting, and, indeed, it heralds a promise now long overdue of partial revival. That this revival should be so long in coming is due to many reasons outside British control, mainly to the general commercial impoverishment of the world, apart from the United States, and the short-sightedness of European countries adopting a protectionist fiscal policy.

The realisation of complete revival in British shipbuilding will not materialise even during 1928, unless the commercial countries of the world are persuaded or forced by stress of economics and the breakdown of international finance to abandon or greatly lessen their import taxation. British shipbuilding and shipping, more than that of any other country, depend upon the free and unfettered flow of international trade.

This being so, British shipbuilders mainly are hoping for a speedy ratification, by all Protectionist countries, of the Free Trade findings of the World Economic Conference at Geneva. Not only would this reflect prosperity to British shipping in general, but all nations would join in the economic revival.

During the past year one of the most interesting signs in shipbuilding circles is the return of the Transatlantic competition in passenger service. Germany and France have made notable challenges, and the United States Shipping Board has competed with a measure of success. But the laurels have gone to the British ships, for not only have they maintained a splendid service, but they have increased the number of passengers carried.

One of the shipping events of the year has been the acquisition of the White Star Line by one of the largest British line groups, and the complete elimination of all foreign interest in this large block of first-class passenger tonnage. Also, towards the end of the year, the announcement that the Cunard Line are to build two new Atlantic liners of one thousand feet in length, exceeding 60,000 tons displacement, and engined to run from Southampton to New York in four days, thus reducing the Atlantic journey by nearly twenty-four hours.

This is the answer to the German and French challenge, and also to the suggested challenge of the United States.

Two other movements in British shipbuilding call for notice when reviewing the work of the past year. First, there is a growing controversy amongst shipping industrialists that the changing commercial economics in the world demand more passenger cargo liners, and far fewer cargo carriers. This idea, however, is not viewed with any great seriousness by practical shipowners, who know that the trade of the world at present is calling for more cargo steamers than before, and many of these new vessels are being built in British shipyards.

Secondly, that the time has come, according to Sir Alexander Kennedy, chairman of the British Engineering Standards' Association, for standardising shipbuilding. This latter movement has received but little attention, however, and the majority of shipbuilders' and shipowners' views regarding standardisation of shipbuilding suggested indifference, and not a little hostility and suspicion.

During 1927 the labour question in shipbuilding has not been so acute as in the preceding post-war years. The workers and their leaders have at last taken the economic view point, and a great measure of common agreement has been reached which has had the effect of eliminating strikes and stabilising conditions in the repair shipyards, with consequent beneficial results in renewed repair contracts from other countries.

In this connection, also, the Trade Facilities Acts of the Government have helped considerably to reduce the quantity of unemployment, and to keep together during this critical period the personnel of the great British shipbuilding establishments.

The Government, however, refused to entertain proposals for direct subsidising. This was a wise and economic move. Shipping is the servant of commerce, and until the commercial situation in the world gets better, it is harmful and uneconomic to build ships for which there would be little or no use.

A practical idea of the tonnage of new shipbuilding in British yards may be had by comparison of tonnage under construction in all the other countries.

Outside Great Britain and Ireland the total tonnage of new construction was, at the end of 1927, approximately 1,537,644 tons, which only exceeds the British total tonnage under construction by 1,200 tons.

This illustration gives ample evidence that British shipbuilding is reviving, and gradually taking its accustomed leadership in the world.

In the world there are at present under construction 37 vessels of between 10,000 and 20,000 tons each, and fifteen of 20,000 tons upwards. Seventeen out of the 37, and seven of the larger vessels are being built in British shipyards.

In Great Britain, the motor tonnage under new construction shows a great increase, being 653,342 tons, which is 74·1 per cent. of steam tonnage under construction.

The foregoing facts give a general idea of the actual position in British shipbuilding, and show, in spite of the world depression in commerce, remarkable stability and enterprise in the shipping industry.

This position has not been accomplished without a good deal of research and readjustment in the industry itself to bring its working equipment up to date, and make it the finest in the world. It reflects, also, the practical faith the British shipbuilders have in the ultimate revival of world trade, and their determination to be ready for international carrying service when such time arrives.

There is much evidence of determined courage and sagacious planning for the future, and the present slight revival gives much promise to the industry for increased prosperity throughout 1928.

Many orders for large and small vessels are coming to the shipyards on the Tyne and Clyde, and the number of unemployed in the industry is slightly decreasing. In the smaller centres contracts for repair work are coming in, and with a better industrial outlook, and the atmosphere free from strikes and labour unrest which mitigates against framing and keeping contract dates, there is now little doubt that the great shipping and shipbuilding industry of Great Britain is regaining confidence in foreign countries, in the carrying trade, in new construction, and repair work, and is well on the way towards complete restoration and prosperity.

The following is from " The Daily Mail " of March 6th, and it is hoped that the will for the common good will prevail:—

Rival Seamen's Leaders. (From Our Own Correspondent), Sydney, Monday.—Chaos in the Australian Seamen's Union is following the result of the annual election of officers which resulted in the defeat of Mr. Johanssen for the presidency and the unopposed election as secretary of his rival, Mr. Tom Walsh.

Stop-work meetings at Sydney and Melbourne have since carried motions for the " recall " of Mr. Walsh, which may mean the cancellation of his election.

Mr. Walsh is much more moderate in his views than formerly and his retention of the appointment would promote an era of peace on the Australian waterfront. That is why a large section is hostile to him.

Reports of efforts still being made by a few to counteract the goodwill and harmony in relationship between all who are associated with the industry and commerce of our country, emphasise the steps taken by the nobler and better spirited who recognise what is best for all. The strike of marine engineers in China was brought about by folly and caused much loss, to the senior engineers especially. Had the right spirit pervaded negotiations all might have been well and losses avoided on shore and afloat.

In a letter from Mr. Jas. Stewart (Member 36), he calls attention to an interesting case of prompt delivery for renewal of a cylinder liner which is worth recording. The *Walton Hall* was on a recent voyage towards Cape Town, when it was found that it would be necessary to remove the L.P. cylinder liner and replace it by a new one. A wireless message was sent to Messrs. Wright, Boag and Mackay—of which Mr. A. B. Mackay is managing director, the other partners having died. The message gave the dimensions of the liner, and ordered it to be cast, machined and finished for delivery on the wharf at Cape Town on the arrival of the ship. The order was carried into effect and delivery was made in 10 days. The works of the firm are at Johannesburg. Mr. A. B. Mackay was formerly in the Orient Line, as was Mr. Stewart, and it was when we were referring back by correspondence to acquaintances in 1888 when the Institute was in course of formation that the case of the *Walton Hall* occurred as worthy of note in connection with the Johannesburg firm.

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Boiler Explosion Reports.

Report No. 2,828. S.S. *Wreathier*.

The boiler is made of steel, and is of the ordinary marine type, single-ended, with two furnaces. It is about 12 feet internal diameter and 9 feet 9 inches in length. It is provided with the usual mountings, including two spring-loaded safety valves, which at the time of the explosion were adjusted for a working pressure of 135 pounds per square inch. The manhole from which the explosion occurred is situated in the lower part of the front end plate, between the furnaces. The aperture is oval in shape, the axes being 15¼ and 11¼ inches respectively. The door was formed of two plates riveted together, the outer plate forming a spigot.

The last repairs to the boiler consisted of a small amount of electric welding in lower part of furnaces, where slight leakage had occurred in way of weld. These repairs were carried out by Messrs. Dibles, Limited, Southampton, about February, 1926.

A portion of the jointing material of the front lower manhole door was forced out, thus allowing water and steam to escape from the boiler. Attention was drawn to the failure of the joint through the sound of escaping water and steam; the explosion was not of a violent nature.

The explosion was due to the spigot of the manhole door being a bad fit in the manhole, and to an uneven jointing surface due to local wastage of the boiler end plate. When the manhole door was in a central position the clearance all round the spigot was ¼ inch.

General Remarks by the Surveyor, Mr. L. Parker.

This twin screw vessel, formerly "Hopper No. 1," was converted to a collier, and since 1919 has been used for that purpose. The original engines and boilers remain, and comprise two sets of triple-expansion engines and two cylindrical, marine type, two furnace boilers.

On the 20th December last the vessel arrived at Southampton with a cargo of coal from Goole. During the passage two tubes in the starboard boiler had shown signs of leakage, necessitating the fitting of stoppers, and, after getting alongside, a third tube had similarly shown leakage. The boiler was accordingly blown down in order to give attention to this tube, steam being kept on the port boiler for discharging cargo.

On the 22nd, fires were set away in the starboard boiler, and about midnight, all cargo being out, the vessel was unmoored, but as steam was not yet available on the starboard boiler the vessel proceeded to anchorage on port boiler only. At 6.30 a.m. on the 23rd, steam was available on the starboard boiler, the anchor was hove up and vessel proceeded. About 7 a.m. a portion of the lower manhole door joint of starboard boiler blew out; the feed pumps were set away, the safety valves eased back, and as soon as possible the fires in this boiler were drawn. The vessel was again anchored, and steamed back to Southampton under steam from the port boiler later in the day.

On examining the manhole door and spigot I found the conditions were as previously described. Repairs had been put in hand, and these have since been continued, the vessel being laid up at Southampton for this purpose. The wasted portion of the end plate forming the jointing surface for manhole door joint has been built up by electric welding, the doubling plate around the manhole opening has been renewed, and a new manhole door with properly fitting spigot has been supplied.

It is fortunate that no one was injured through the failure of the manhole joint or boiler tubes. The delay occasioned to this vessel, apart from the greater question of safety, shows the need for adequate periodical inspection and upkeep of boilers.

Observations of Engineer Surveyor-in-Chief.

The insecurity of the jointing of a badly fitting manhole door is so obvious, and the defect in the door can be remedied so easily that the neglect of such important parts is quite inexcusable.

Fortunately in this case no person was injured, but for a time the vessel was unable to proceed to sea.

REPORT NO. 2,835. S.S. *Empire Star.*

This deals with an explosion from a boiler stop-valve chest on the s.s. *Empire Star,* which occurred fortunately without injuring anyone. On November 9th, 1926, the ship was in the Thames, homeward bound from Campana, Argentina. A violent explosion was heard on the boiler tops, with a rush of steam into the boiler room. The boilers were then at work on oil fuel, and the supply was at once shut off with the result that the steam pressure fell. The refrigerator slowed down and indicated that the valve chest connecting steam with it was the cause of the explosion. There were four single-ended boilers in the ship with a steam pressure of 200lbs. fitted with forced draught, and arranged to burn oil or coal. The engines were of triple expansion reciprocating type with cylinders of $25\frac{1}{2}$in, 44in. x 74in. x 51in. stroke. On the outward voyage when no cargo was carried, only three boilers were in use, but on the homeward passage when chilled meat was carried, and when coal was in use, the four were under way to keep the refrigerator at work; when oil was in use the three boilers were adequate for all purposes, and this was the case on the voyage home when the explosion occurred. The starboard forward boiler was the one out of action, and it was the stop-valve chest on this boiler connected to the range supplying steam to the refrigerator which gave way. The after port boiler was supplying steam to the refrigerator and no change had been made in the connections on the passage homeward. The investigation of the circumstances leading to the explosion was conducted by Mr. H. Scott, Board of Trade Surveyor, London, and in his report he stated it was found that on the forward starboard boiler the side of the refrigerator engine stop-valve chest above the valve had blown out, leaving a large hole through which the steam had escaped. The arrangement of the steam pipes was such that while the pipes from the valve chests on the port forward boiler and both the after boilers rose vertically to the main range, the pipe from the starboard forward boiler ran horizontally from a side branch on the valve chest on that boiler to a corresponding side branch on the port forward boiler valve chest.

As the starboard boiler forward was not in use, this horizontal pipe would form a comparatively large pocket in which water, due to condensation, would collect, resulting in water hammer action, accentuated by the rolling and pitching of the vessel, leading to the bursting of the chest. The examination of the fracture did not lead to any indication of weakness; the thickness was $\frac{7}{8}$in. uniform, the metal was of coarse grain. The drain cocks were not fitted in the best positions, and when the chest was renewed, the draining system was improved as advised.

The observations of the Engineer Surveyor-in-Chief were that attention had been directed in several previous cases of a similar nature to the danger of allowing water to collect in horizontal branches of steam pipes connecting a main range under steam with the stop-valve of a boiler not in use. Several fatal explosions due to water hammer from this cause have occurred on steam ships, and if it is anticipated that all the boilers connected to the main range may not be in use at one time, additional stop valves should be fitted at the junction of the branch and main range pipes to isolate them and prevent water accumulating.

REPORT No. 2837. S.S. *Yewforest*, O.N. 129510.

The boiler was cylindrical and multitubular, the internal diameter was 16 feet and its mean length 11 feet. The shell plates, 1 5/32 inches in thickness, were in one course, with two longitudinal joints made with double butt straps, treble riveted. The inner and outer butt straps were 1 1/16 and ⅞ inches in thickness respectively Both end plates were in two portions; the upper were 1 3/32 inches in thickness whilst the back lower was 23/32 inch, and the front tube plate was 29/32 of an inch in thickness. There were 23 longitudinal stays connecting the plates, but two of these around the centre manhole had at some time been removed. The boiler was fitted with four corrugated furnaces of the Deighton type, 3 feet 3 inches least diameter internally and 15/32 of an inch in thickness, each being connected to a separate combustion chamber, the back and tube plates of which were 9/16 and ¾ of an inch in thickness respectively, and the wrapper plate 19/32 of an inch in thickness. The back and wrapper plates were supported by screwed stays. There were 208 plain tubes 8 S.W.G. in thickness, and 92 stay tubes 5/16 of an inch in thickness, 3½ inches diameter externally. The boiler, which was of steel, except the tubes, which were of iron, was built under the survey of Lloyd's Register of Shipping for a pressure of 160 pounds per square inch. The mountings include two spring-loaded safety valves; main and auxiliary stop valves, the chest of the latter being mounted on that of the main stop valve; whistle valve; one water gauge on column which was connected to the steam and water spaces by pipes terminating at valves on the end plate of the boiler; blowdown and scum valves; and four "Diamond" steam blowers on the end plate.

The following particulars of repairs have been extracted from the reports of the Surveyors to the Classification Society:—

May, 1911.—Two of the longitudinal stays in the bottom of the boiler removed at the request of the Superintendent, the lower back plate in way of same being properly strengthened by an efficiently riveted doubling plate.

January, 1912.—A number of rivets renewed in the port and starboard lower chamber bottoms where joined to furnace. A few rivets connecting the front end plate to shell plates at bottom recaulked. Boiler tested to 200 pounds per square inch by hydraulic pressure.

March, 1915.—Some plate landings in lower combustion chambers welded.

June, 1916.—Several rivets in furnace landings renewed and local electric welding carried out in way of same in the two low furnaces.

December, 1916.—Boiler examined, general condition good, except the welding and leaky rivets referred to above in low combustion chambers, and rivets in lower shell end seams; these were caulked and made tight for the voyage, to be further dealt with at the end of January.

February, 1917.—The defective rivets in the two lower furnace landings renewed. Note.—The two low furnaces have at some time been renewed, as there appears to be some slight evidence of straining in way of lower bottle neck of these furnaces (Gourlay type). It has been suggested to the Superintendents that two longitudinal main stays in way of these furnaces should be fitted at owners' convenience.

November, 1917.—Owing to the wasted condition of the two centre combustion chamber bottoms the working pressure has been reduced to 145 pounds per square inch, subject to the bottoms being renewed within nine months.

April, 1919.—Back plate in lower combustion chambers cropped along the line of third row of stays. Bottom plates in these chambers renewed. Flange of lower bottle neck of furnaces adjacent to bottom built up. Several local places made good by electric welding.

July, 1921.—The two lower furnaces built up by electric welding on both sides along the line of fire bars.

September, 1921. Rotterdam.—This vessel towed in at this port on account of the boiler leaking badly. Found upon examination S.B. lower furnace grooved in way of bottle neck. Grooving cut out and welded. In view of the general condition of the S.B. lower furnace in way of the connection to the combustion chamber at bottom, it has been recommended that this furnace should be re-examined within six months.

October, 1921.—The two lower furnaces renewed on account of giving trouble in the lower part of flange where joined to combustion chambers.

October, 1924.—All plain tubes and five stay tubes renewed. Tube plate in starboard combustion chamber cropped and part renewed in starboard corner, longitudinal stay in way renewed. Similar repair in the port corner of the port combustion chamber. Port saddle plate in starboard lower chamber cropped at bottom and part renewed, lower part of saddle plate in port lower chamber cropped and part renewed. Boiler tested by water pressure to 200 pounds per square inch.

January, 1926.—Boiler found or put in safe working condition.

The explosion which is the subject of this Report occurred on November 21st, 1926, when a hole, $\frac{3}{4}$ of an inch in length and $\frac{1}{2}$ an inch in width, formed in the plate at the bottom of the neck of the port lower furnace, through which the contents of the boiler escaped. The vessel was towed into Flushing. The hole was found to be caused by internal grooving and pitting of the neck of the furnace.

General Remarks by Mr. S. L. Watson, Surveyor, Swansea.

The vessel on which this explosion occurred was a home trade cargo ship, and was fitted with one boiler for all purposes, working at a pressure of 160 pounds per square inch with natural draught. The vessel was on a voyage from London to Antwerp in light condition, and had left the former port on the 19th November, via Gravesend for bunkers, leaving there about 3 a.m. on the 20th November. At 7 a.m. on the 21st, whilst the chief engineer was on watch, the fireman reported a leak in the port lower furnace. When the chief engineer went into the stokehold to inspect, he heard a loud hissing noise, but owing to the dense vapour could not locate the leak. He noticed that the water gauge indicated about $\frac{3}{8}$ glass of water, and started the donkey to pump sea water into the boiler. He then reported to the master, who asked him to keep the engines running, if possible, so as to enable the vessel to reach a safe anchorage. After about 15 to 20 minutes the engines stopped for want of steam, and the vessel was anchored behind the Westhinder light vessel. When an examination of the boiler was made it was seen that a hole, about $\frac{3}{4}$ of an inch by $\frac{1}{2}$ an inch in size had formed in the radius of the flange at the bottom of the coned neck of the port low furnace where it joined the combustion chamber. The vessel was towed into Flushing, where the defect was repaired by electric arc welding. From a perusal of the reports of repairs to this boiler made by the surveyors to the Classification Society, it will be noticed that the two lower furnaces had given continual trouble in the bottom radius of the coned necks by straining, which is also one of the causes of grooving. The first mention was in January, 1912, when some rivets apparently in the furnace flanges were renewed. In June, 1916, rivets in this position again were slack, and again in December the same rivets were leaking and were caulked to enable one voyage to be made. These were renewed in February, 1917. The Surveyor, in his report at this time, mentions that the low furnaces appear to have been renewed, but there is no classification report as to this having been previously done; but it is possible that this may have been done without their cognisance. In April, 1919, the flanges of the necks of the lower furnaces were built up. In September, 1921, the vessel was towed into Rotterdam owing to leakage from the neck of the starboard lower furnace due to grooving. These furnaces were renewed in October, 1921. This type of furnace neck appears to be particularly susceptible to grooving, especially in the lower furnaces of boilers fitted with four, due, apparently, to the stresses set up by the longitudinal expansion of the boiler being localised on the necks of these furnaces. Possibly the replacement of the two lower longitudinal stays, which were removed in May, 1911, would mitigate the trouble in this boiler. No examination of this boiler was made by me immediately after the explosion, but from the previous repairs executed and the report of the Classification Surveyor at Flushing, who inspected the boiler after the explosion, together with my subsequent inspection of the boiler in February last, when I found active grooving in the neck of the starboard low furnace, it is in my opinion evident that the explosion was caused by the material in the neck of the furnace becoming wasted by grooving and pitting.

Observations of Engineer Surveyor-in-Chief.

When this boiler was constructed the boiler makers arranged two longitudinal stays at the sides of the furnaces and between the lower part of the end plates, as is usual in cases where the furnaces are fitted with Gourlay backs. Those responsible for the maintenance of the boiler removed these stays about twelve months later. The trouble experienced seems to have been in the zone which would be affected by the removal of the stays, and this is what might have been expected under such conditions, which would allow of considerable movement at the place where fracture actually occurred.

No. 2892. S.S. *Queen Alexandra* O.N. 114840.

The explosion occurred at about 11.0 a.m. on the 27th September, 1927, when the vessel was in Yarmouth Roads.

The vessel is owned by the Royal National Mission to Deep Sea Fishermen, 68, Victoria Street, London, S.W.1.

Alfred Mantripp, the Chief Engineer, was slightly scalded on the feet whilst attempting to draw fires after the occurrence. He resumed duty next day.

The boiler is of the ordinary cylindrical multi-tubular marine type, and is made of steel. It is 11 feet 6 inches in diameter and 9 feet in length and is fitted with two corrugated furnaces 3 feet 4 inches in diameter. The manhole, from which the explosion occurred, is situated in the lower part of the front end plate between the two furnaces, the end plate being flanged inwards round the circumference of the opening for compensation purposes. The major and minor axes of the opening were 16 inches and 12 inches respectively, when new. The door was of the McNeil embossed type and was secured by two $1\frac{1}{2}$-inch diameter studs, $6\frac{3}{8}$ inches apart, which passed through the usual crossbars, for holding the door in position. The boiler is fitted with the usual mountings, including two spring loaded safety valves adjusted for a working pressure of 180 lbs. per square inch.

The boiler was made by Messrs. Hawthorns and Company, Limited, Leith, in 1902.

With the exception of renewing a few defective rivets in the combustion chambers, no repairs appear to have been necessary.

The vessel and machinery is classed with Lloyd's Register of Shipping, and has been periodically inspected by one of their Surveyors, the last occasion being at Yarmouth in January, 1927, when the boiler was lifted out of the vessel, on the occasion of the second No. 3 special survey.

The boiler was insured with the Excess Insurance Company, 25, Birchin Lane, London, E.C.3.

A piece about half an inch long was blown out of the asbestos ring, which formed the door joint, near the top of the door, thus allowing the contents of the boiler to escape into the stokehold.

The explosion was due to the spigot of the door being a slack fit in the manhole.

General Remarks by Surveyor.

The *Queen Alexandra*, O.N. 114840, is a steel single screw trawler of 250 gross tons, built and engined at Leith in 1902, and is equipped with one boiler for supplying steam to the propelling and auxiliary machinery. She is owned by the Royal National Mission to Deep Sea Fishermen, and is primarily used as a hospital ship in attendance on the fishing fleet when at work on the fishing grounds.

The vessel was fitted out in readiness to accompany the fishing fleet and on Saturday, the 24th September, steam was raised slowly on the boiler. The nuts on the manhole door studs were hardened up during the period of raising steam, as new joints had been fitted to both top and bottom manholes when the boiler was closed up.

Fires were banked and on the following Monday, 26th September, the boiler was under steam all day for supplying steam to the winches, stores being taken on board. The next day at about 10 a.m. the vessel proceeded outside to Yarmouth Roads to adjust compasses.

After being under weigh for about an hour the bottom manhole-door joint failed suddenly. Mr. Alfred Mantripp, the chief engineer, went into the stokehold and attempted to draw the fires, but was slightly scalded about the feet by stepping into the hot water that had accumulated on the stokehold plates. The second engineer then put on sea boots and succeeded in drawing fires.

The vessel returned to Yarmouth, but as the steam pressure was falling rapidly, the master thought it inadvisable to attempt to enter the harbour between the piers, and the vessel was therefore anchored, being subsequently towed in.

On arrival at the berth the boiler was emptied and it was found that the bottom manhole door was about $\frac{1}{4}$ inch slack in the hole. The manhole was, therefore, built up by the electric welding process, and the door refitted.

When I visited the vessel the above-mentioned repairs had been carried out and the boiler was under steam. From what could be seen under these conditions the door appeared to have been made a satisfactory fit, and was perfectly tight.

The joint which failed was produced for my inspection, but as it had not been carefully removed from the face of the door, it was impossible to say what portion of it had been blown out, but it was estimated by the chief engineer to be about half an inch. The joint appeared to have failed, however, when the material was butted when it was manufactured.

The vessel proceeded to sea the day after my visit, and it is reported that no further trouble has been experienced.

Observations of Engineer Surveyor-in-Chief.

This is another case of a joint blowing out due to a badly fitting manhole door. The spigot was considerably worn and this appears to have been overlooked when the boiler was last inspected. Bottom doors should be a good fit to support the joint and prevent it from being blown out and causing injury to the boiler attendant. Such defects as this are easy to discover and can be made good at trifling expense. Neglect of them is therefore inexcusable.

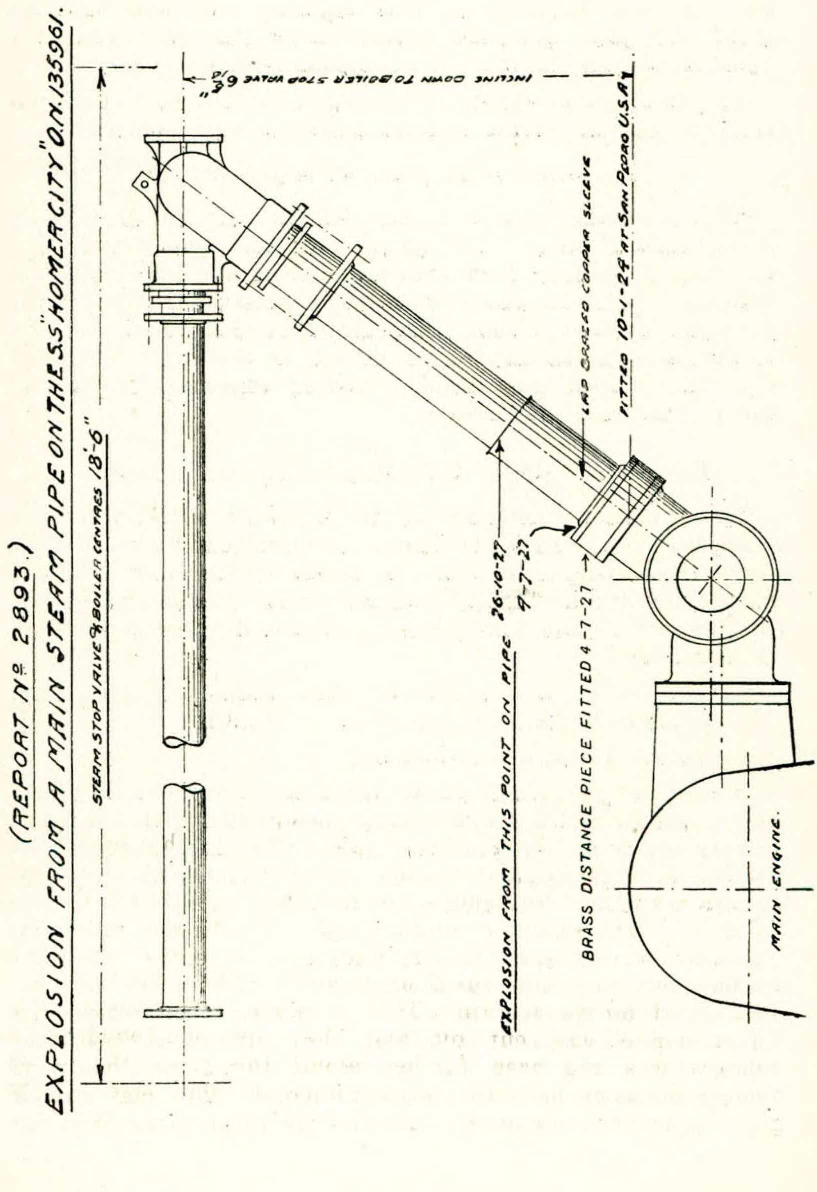
REPORT NO. 2893. S.S. *Homer City*, O.N. 135961.

The explosion took place on the 4th July, 1927, when the vessel was in the English Channel outward bound for the Tyne to Portland, Oregon, U.S.A. A second explosion of a similar nature, but of minor extent,took place from the same pipe when the vessel was homeward bound passing Gibraltar on the 26th October, 1927.

The vessel is owned by the St. Just Steamship Company, Limited, Merthyr House, James Street, Cardiff.

No person was killed or injured.

The steam pipe from which the explosion occurred was a short straight solid drawn copper pipe 5 feet 2 inches long, 8 3/16 inches outside diameter, and 7 7/16 inches inside diameter, joined to the steam-regulating valve on the main engines by a brass flange 14 inches diameter and 1 inch thick, having 12 bolts $\frac{7}{8}$ inch diameter on a pitch circle 12 inches diameter. The other end of the pipe was plain and extended into the stuffing box on a cast iron Y piece which formed the arrangement for the expansion of the steam pipes. On the pipe at a distance of $13\frac{3}{4}$ inches from the plain end an over-shaped brass guard ring $\frac{7}{8}$ inch thick was brazed. This was provided with two steel guard bolts $1\frac{1}{8}$ inches diameter. The cast iron Y piece formed the connection between the steam pipes from the stop valves on the two single-ended main boilers, and the steam pipe from the regulating valve on the main engine. (See plate.)



A second stuffing box on this Y piece provided for the expansion of the straight length of pipe between the two boilers.

The pipe was supplied by the makers of the engines and boilers, Messrs. Blair and Company, Limited, Stockton-on-Tees, in 1914, when the vessel was new, and was therefore 13 years old at the time of the explosion.

The steam pipe was repaired by having the sleeve piece fitted, at San Pedro, Los Angeles, U.S.A., where the vessel put in for that purpose, on the 10th January, 1924.

The steam pipe was inspected by the Surveyors to the British Corporation, Register of Shipping, by whom the vessel is classed.

The explosion was of a very trifling nature on each occasion, precaution having been taken in time to avert more serious results.

The explosion was due to the working of the steam pipe through the vibration of the machinery, especially when the vessel was in light trim and the engines racing.

General Remarks by Surveyor.

The s.s. *Homer City* is a cargo vessel of 4,914 tons gross, built in 1914 by Messrs. Ropner and Sons, and engined by Messrs. Blair and Company, Limited, both of Stockton-on-Tees. The working pressure of the boilers is 180 pounds per square inch. As far as can be ascertained the main steam pipes gave no trouble until on a voyage in ballast trim, from Liverpool to Vancouver, Canada, via the Panama Canal, when off San Pedro, Los Angeles, on the 10th January, 1924, a crack developed in the neck of the pipe, on the flange next to the steam-regulating valve on the main engines. The vessel put into San Pedro where the steam pipe was repaired. A suitable piece of new pipe could not be obtained, and a sleeve of copper was made with a brazed longitudinal seam. This repair continued to give satisfaction until the vessel was on a voyage, again in ballast trim, bound from the Tyne to Portland, Oregon, U.S.A. When going down the English Channel, a slight crack was noticed in the neck of the flange on the sleeve piece in the same position as the previous failure. The vessel put into Falmouth on the 4th July, 1927, where a repair was effected. The flange was cut off and the pipe shortened. The flange was re-brazed further along the pipe, the length being made up by fitting a cast brass distance piece. This repair was satisfactory, and the vessel arrived safely at her destination where she loaded for Naples, and proceeded later to Malazzo, Sicily. The vessel was then ordered home for a general overhaul of her boilers and machinery. Bunkers were taken at Algiers, and whilst proceeding in the direction of Gibraltar on the 26th October, 1927, a further slight leak of steam was noticed coming from the grazing around the sleeve at the end away from the flange. It was decided to put into Gibraltar to have this repaired. The interior of the pipe was loaded with spelter around the junction of the sleeve and the original portion of the pipe.

The pipe was satisfactorily tested by hydraulic pressure to 300 pounds per square inch, in the presence of the British Corporation Surveyor. The vessel then proceeded to Barry Dock where the whole main steam pipe was removed, and an entire new arrangement made. A new cast iron branch piece is joined to the flange on the intermediate steam stop valve on the main engine. From this, two large easy bends of solid drawn copper leading to the port and starboard boilers respectively have been fitted.

The original arrangement of the main steam pipe proved to be insufficient to allow for the movement and vibration of the main engines, which takes place especially when the vessel is in light trim, and the engines racing. The effect of this working showed itself on the expansion pipe where bright sharp edge grooves appeared on the end inside the stuffing box. With the arrangement as now fitted, sufficient allowance for both expansion and vibration has been provided, and thus it is hoped to avoid a recurrence of the trouble.

Observations of Engineer Surveyor-in-Chief.

The arrangement of the main steam pipes in this vessel was such that the neck of the pipe which failed was subjected to varying and heavy stresses, other than those for which it was designed, due to the movement and vibration of the main engines.

The engineers of the vessel appear to have kept the pipe under careful observation, and on each occasion had repairs made before the condition of the pipe became dangerous.

The owners have wisely had the whole main steam pipe range replaced with a more suitable arrangement affording greater flexibility.

REPORT No. 2896. S.S. *Ilvington Court*, O.N. 147615.

The explosion occurred at 5.55 a.m. on the 1st September, 1927, when the vessel was lying in the South Dock, Newport, Mon.

The vessel is owned by the United British Steamship Company, Limited, Leadenhall Street, London, E.C.

No person was killed or injured.

The stop valve chest was of the upright type, made of cast iron about $\frac{7}{8}$ inch in thickness, and was attached direct to the boiler shell by 8 studs 1 inch in diameter. A brass valve and seat were fitted, the valve being 5 inches in diameter and operated by a screwed brass spindle $1\frac{1}{2}$ inches in diameter. The branch to the boiler and the branch to the main steam pipe were each 5 inches in diameter; another branch $3\frac{1}{2}$ inches in diameter on the side of the chest was provided for the attachment of an auxiliary stop valve chest.

Neither the name of the maker, nor the age of the stop valve chest had been ascertained; it is thought to have been one of those fitted to the boilers when the vessel was built in 1919.

Since April, 1924, no repairs beyond maintenance overhauls appear to have been necessary; prior to that date the history of the stop valve chest has not been traced.

The stop valve chest has been under the periodical inspection of the Surveyors to Lloyd's Register of Shipping, and the supervision of the engineers of the vessel.

Judged by the noise made, the explosion was not of a violent nature, but the stop valve chest must have been subjected to a severe shock, as the upper part was broken into a number of pieces, and the cover was also broken as shown on Plate II. As the stop valve on the centre boiler, the only boiler under steam at the time, was opened a small amount only, the escape of steam through the fractured chest was limited.

The explosion was caused by water hammer action.

General Remarks by Surveyor.

The *Ilvington Court* is a steel cargo vessel of 5,187 tons gross, built in Hong Kong in 1919 by the Hong Kong and Whampoa Dock Company, Limited, who also fitted the boilers and single screw propelling machinery. The vessel formerly sailed under the Greek flag as the *Meandros* and *Iolcos*, and was taken over by her present owners in April, 1924; prior to this date the history of the stop valve chest cannot be ascertained.

The boilers, three in number, are of the ordinary marine type, and work at a steam pressure of 180 lbs. per square inch. They are placed abreast and the steam is led from them through three lap-welded iron pipes $5\frac{1}{2}$ inches in outside diameter to a three-way junction piece bolted to the main engine stop or throttle valve. To allow for expansion, the pipes from the two wing boilers are provided with horizontal bends, and that from the centre boiler with a vertical loop. The main steam stop valve chests are bolted direct to the boiler shells, and are each fitted with a drain valve and pipe $\frac{1}{2}$ inch in diameter; these pipes discharge into a tank situated between the port and centre boilers. A small drain cock was also fitted to the engine throttle valve at its lowest part. The arrangement of the main boiler stop valves and steam pipes is as shown on Plate I.

The vessel arrived in Newport on the 26th August last, and moored to the buoys in the South Dock. The main steam stop valves on the three boilers were closed by the Fourth Engineer, and at the same time the drain valves on the chests were opened about two turns. Steam for port use was maintained on the centre boiler only.

On the 1st September, to assist moving the vessel from the buoys to the loading berth, steam on the main engines was required, and for this purpose the Chief Engineer at 5.30 a.m. opened the engine throttle valve, and saw that the drain cock on this valve, and that on the high pressure engine casing were open. At 5.45 a.m. the Fourth Engineer eased the stop valve on the centre boiler "off the face." He states that he did not interfere with the drain valves on the boiler stop valves, but is certain that they were open, as he saw steam issuing from the drain tank. At 5.55 a.m. the explosion occurred.

It is stated definitely by the three engineers on duty in the engine room that no shock or jar was heard or experienced by them, and that the sound of steam escaping was the first indication they had that something was amiss on the boiler tops, to where the sound was traced. The Chief Engineer was able to close the stop valve on the centre boiler and stop the escape of steam; a short search revealed the stop valve chest on the port boiler to be fractured as previously described.

I have examined the fractured chest, and found it to be fairly even in thickness between $\frac{7}{8}$ and 15/16 inch of good quality cast iron; there were a few minor defects noticeable in the castings, but these were not of such a nature as to account for the failure of the chest under a steam pressure of 130 lbs. per square

REPORT No 2896.

EXPLOSION FROM A MAIN BOILER STOP VALVE CHEST ON BOARD THE S.S. "ILVINGTON COURT," O.N.147615.

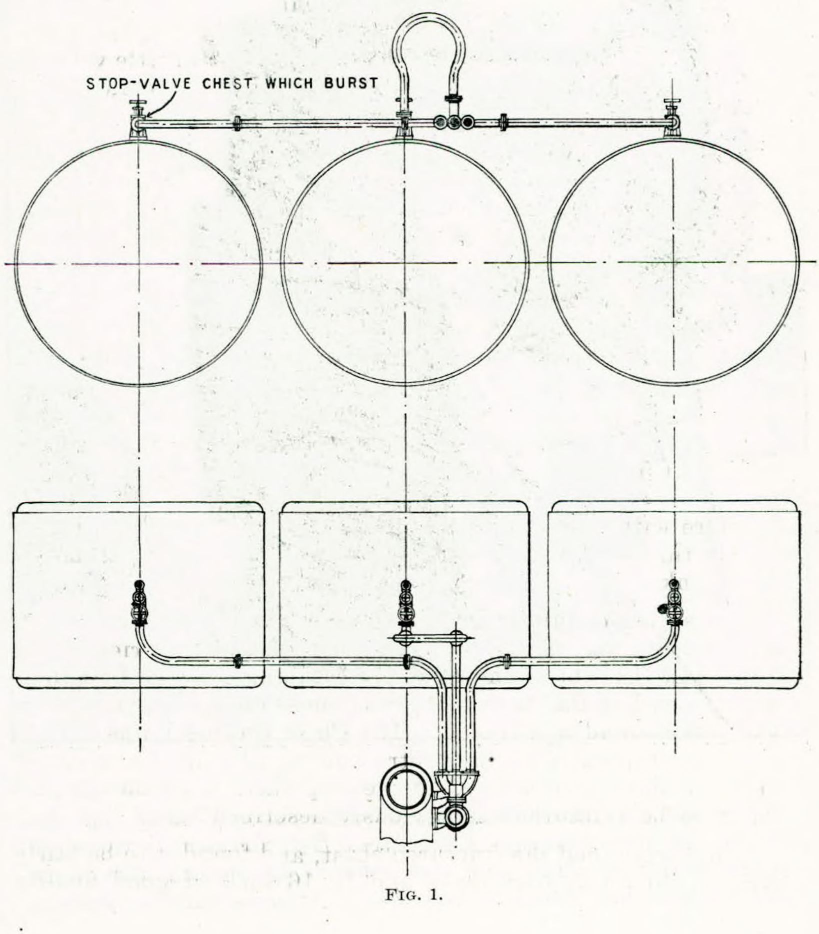


FIG. 1.

inch, which is stated to have been the pressure at the time. From the nature and extent of the fractures in the burst chest, the explosion can, I think, be attributed to one cause only, viz., water hammer action.

REPORT No. 2896.

EXPLOSION FROM A MAIN BOILER STOP VALVE CHEST ON BOARD THE S.S. "ILVINGTON COURT." O.N.147615.

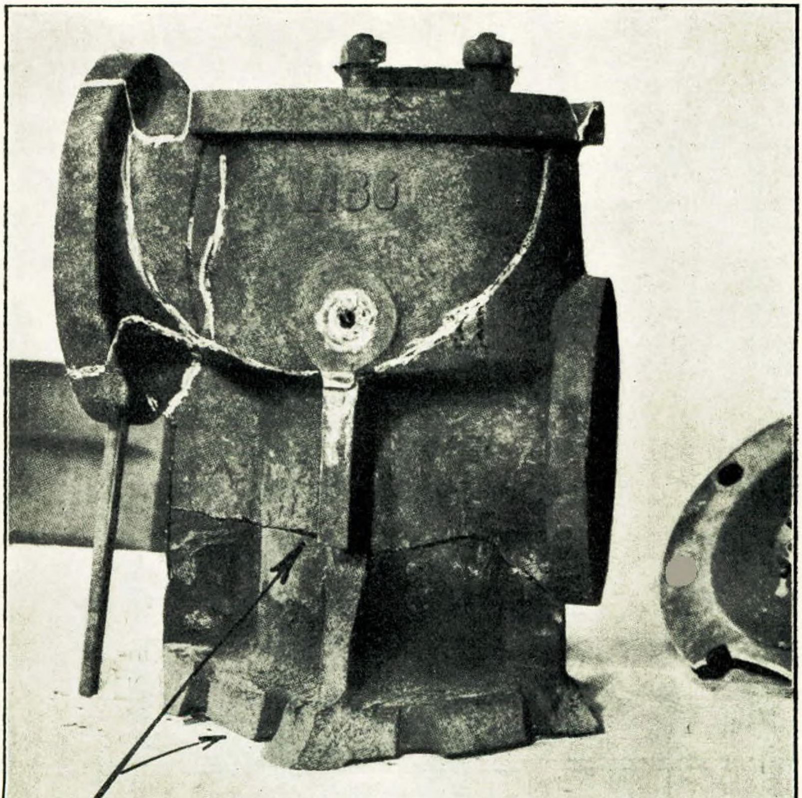


FIG. 2.

On examining the cock on the throttle valve, I found that the port in the plug measured $\frac{3}{8}$ by $\frac{1}{8}$ inch, but the port in the shell on the outlet or drain side was reduced by casting fins to an opening less than $\frac{1}{8}$ inch in diameter. At some time the operating handle on the cock had been broken off, a substitute handle fitted on to a square formed on the end of the plug, and a mark indicating the position of the port in the plug put on with a file. This mark had been incorrectly placed, with the result that when the mark was turned to the "open" position, the port was nearly blind in the shell and rendered the cock practically inoperative. The Second Engineer states that he found the drain valve on the stop valve on the port boiler to be slightly open after the explosion.

The main steam pipes, with the exception of the vertical loop on the centre pipe, are in a plane parallel with the keel of the vessel which at the time was trimmed approximately 3 feet 8 inches by the stern. In this trim any water of condensation would drain to the after end of the three pipes and remain there, although the drain cock on the throttle valve was turned to the apparently "open" position, and steam could escape to the drain tank from the drain cocks on the stop valve chests. The opening of the throttle valve, followed shortly after by the opening of the stop valve on the centre boiler admitting live steam to the pipes, probably before all the water had drained away, set up water hammer action which resulted in the fracture of a stoutly designed and well constructed stop valve chest.

The small drain cock on the engine throttle valve has been replaced by a valve 1 inch clear bore operated from the starting platform. Immediately behind the operating wheel on a brass plate in bold type is the following:—

CAUTION.—VALVE FOR DRAINING MAIN STEAM PIPES.
THIS DRAIN MUST BE OPENED WHEN MAIN BOILER STOP VALVES ARE CLOSED.

Observations of Engineer Surveyor-in-Chief.

The arrangement of main steam pipes on board this vessel is such as to require, for the avoidance of water hammer action, the exercise of considerable care in manipulating the stop valves and drain fittings when admitting steam to the range from one or more of the boilers and in maintaining the drain fittings in proper condition. The procedure followed in admitting steam to the range from the centre boiler appears to have been correct, but the drain fitting at the throttle valve was defective, with the result that water hammer action of sufficient violence to fracture the stop valve chest ensued. The necessity for strict supervision to ensure that drain fittings of steam pipe ranges are kept in a thoroughly efficient condition cannot be too strongly emphasised.

Books added to the Library.

The Council gratefully acknowledge the gift of the following books, which have been presented by Mr. C. W. Barnes (Member) :—

"Electric Motors," Hobart.

"Alternating Current Working," Hay.

"Elementary Practical Mathematics for Technical Students," Castle.

"Electric Light and Power," Brooks and James.

"Magnetism and Electricity," Yorke.

"Alternating Currents," Hay.

"Steam Engine Theory and Practice," Ripper.

"The Dynamo," Hawkins and Wallis.

"Engineering Estimates and Cost Accounts," Burton.

"The Engineer's Draughtsman," Varley.

"Applied Mechanics and Mechanical Engineering," Vol. II. —Strength of Materials, Jamieson and Andrews.

Presented by the Publishers :—

"Board of Trade Orals and Marine Engineering Knowledge," W. C. MacGibbon. Published by James Munro and Co., Ltd., Glasgow. Price 30/- net.

The rapid general progress in marine engineering has had considerable influence on certificate and other examinations held by the various examining bodies. The volume under consideration is the fourth edition of a work which has for its object the ready acquisition by candidates of the necessary engineering knowledge required by the Board of Trade in its certificate examinations. The author of such a work as this has little choice in his selection of subject matter and must of necessity follow the examinations, unless he exercises a certain amount of intelligent anticipation. Mr. MacGibbon has had a considerable measure of success with his books and the present volume enhances his reputation.

The book is well illustrated and explanatory notes on the sketches relieve the reader of much anxiety in determining the construction of certain machinery parts, etc. Most of the subjects which are included in the examinations are well covered.

At the risk of losing whatever reputation we may possess for artistic sensibility we must confess that the illustration on the cover is not at all to our liking; the book would be more dignified without it.

There is a certain looseness of expression which occasionally occurs: for example, " the valve is opened to allow the vacuum to draw in a supply of water "; also, the definition, " angular velocity is the angular rate a body may be revolving through in a given unit of time."

There is, however, much to commend in the book, and candidates who naturally wish to tread the primrose path to examination honours will find it to their liking.

" Hints on Gas Welding," Booklet No. 1. " Hints on Oxygen Metal Cutting," Booklet No. 2. " Gas Welding and its Applications," Booklet No. 4.

These booklets are published by the British Oxygen Co., London, N.18, and they contain, compressed into small volume, a remarkable amount of information on the subjects.

Most of our readers are acquainted with the everyday applications of gas welding, but it is believed that in Booklet No. 4 there will be found examples of welding construction and repairs that are both novel and interesting. The " Hints " on gas welding and metal cutting are most complete and useful, and full information is given on the care of equipment, generating plant, etc. There is also some valuable advice on welding of cast iron, stainless steel, aluminium, and a number of alloys. The books should be of considerable value to operators and those in charge of welding plant.

Purchased.—Instructions as to the Survey of Passenger Steamships, Vol. I., Text. Price 1/6. Vol. II., Standard Diagrams of Floodable Lengths. Price 6d. Issued by the Board of Trade. Published by H.M. Stationery Office.

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BOARD OF TRADE EXAMINATIONS.

List of Candidates who are reported as having passed examination under the provisions of the Merchant Shipping Acts, during the week ended 11th February, 1928 :—

NAME.	GRADE.	PORT OF EXAMINATION.
Lawson, Stewart	1.C.M.E.	Glasgow
Sinclair, John C.	1.C.M.E.	,,
Chapman, Thomas B.	1.C.	,,
Kelso, George G.	1.C.	,,
Brown, Robert A. M.	2.C.	,,
Johnston, John	2.C.	,,
Povey, William G.	2.C.	,,
Watson, George C.	2.C.	,,
Vickers, Joseph H.	1.C.	Hull
Pearson, Harold M.	2.C.	,,
Barclay, William W.	1.C.	Liverpool
Benson, Thomas W.	1.C.	,,
Drover, George W.	1.C.	,,
Jones, Albert E. M.	1.C.	,,
Jones, Caleb	1.C.	,,
Atherton, George W.	2.C.	,,
Compton, Aubrey F.	1.C.	London
Holmes, Thomas E.	1.C.	,,
Littlejohn, James	1.C.	,,
Walker, Hector H. R.	1.C.	,,
Quinnell, Benjamin T.	2.C.	,,
Adamson, Robert S.	1.C.	North Shields
McGuinness, Frank	1.C.	,,
Weston, Herbert J.	1.C.	,,
Graham, Burton	2.C.	,,
Carter, Fred T.	2.C.M.	Sunderland
Cassels, George C.	1.C.	,,
Catley, Edwin	2.C.	,,
Jenkins, Thomas	2.C.	,,

Ex. 1.C. Extra 1st Class. 1.C. First Class. 1.C.M. 1st Class Motor.
2.C. 2nd Class. 2.C.M. 2nd Class Motor. M.E. Motor Endorsement.

BOARD OF TRADE EXAMINATIONS.

List of Candidates who are reported as having passed examination under the provisions of the Merchant Shipping Acts, during the week ended 18th February, 1928 :—

NAME.	GRADE.	PORT OF EXAMINATION.
Stannard, Knowles	2.C.M.E.	London
Hampton, Alexander J. C. ...	1.C.	Leith
McBean, Lewis D.	1.C.	,,
Miller, James	1.C.	,,
Skinner, William	1.C.	,,
Bisset, James	2.C.	,,
Duncan, William	2.C.	,,
Johnson, Andrew H.	2.C.	,,
Macdonald, William J.	2.C.	,,
Rothnie, William	2.C.	,,
Houston, Sydney P.	1.C.	Cardiff
Balmer, Robert	1.C.	Liverpool
Cowling, Albert V.	1.C.	,,
Kagan, Reginald	1.C.	,,
Roberts, John D.	2.C.	,,
Shields, Rodney	2.C.	,,
Smith, Robert H.	2.C.	,,
Faulkes, Cyril	1.C.M.	,,
Hayman, Sidney H.	1.C.M.E.	,,
Gibson, Thomas	2.C.M.E.	North Shields
Bertram, William	1.C.	,,
Laver, John W.	1.C.	,,
Hendry, John	2.C.	,,
Martin, Robert W....	2.C.	,,
Briggs, Francis G....	2.C.	Glasgow
Brinkworth, William	2.C.	,,
Wills, Alfred J.	2.C.	London
Hatch, George J.	1.C.M.	,,
Pheasant, Francis B.	1.C.	,,
Youngs, Robert C.	1.C.	,,
Bee, William E.	1.C.	Southampton

Ex.1.C. Extra First Class. 1.C.M. 1st Class Motor. 2.C.M. 2nd Class Motor.
1.C. First Class. 2.C. 2nd Class. M.E. Motor Endorsement.

BOARD OF TRADE EXAMINATIONS.

List of Candidates who are reported as having passed examination under the provisions of the Merchant Shipping Acts, during the week ended 25th February, 1928 :—

NAME.	GRADE.	PORT OF EXAMINATION.
Savell, Robert E.	2.C.M.E.	London
Blake, Hugh S.	1.C.	Glasgow
Campbell, Donald	2.C.	,,
McNiven, Alexander	2.C.	,,
Dinwoodie, David	2 C.M	,,
Milne, Hugh	2·C.M.	,,
Smith, Ian M.	2·C.M.	,,
Acaster, Hubert J. G.	1.C.	Sunderland
Shakespeare, Gordon C.	1.C.	,,
Boys, George	2.C.	,,
Neesham, Robert	2.C.	,,
Clarkson, Harold	1.C.	North Shields
Lynch, William G.	1.C.	,,
Collingwood, Joseph B.	2.C.	,,
Gladstone, William E.	2.C.	,,
Bishop, Frederick W.	2.C.M,	,,
Robson, George G.	2.C.M.	,,
Connell, John	1.C.	London
Daglish, Robert F.	1.C.	,,
Hayward, Charles H. G.	1.C.	,,
Ingamells, Bernard P.	1.C.	,,
Newman, Wilfred J.	1.C.	,,
Philp, Ronald A.	1.C.	,,
Scott, William A.	1.C.	,,
Vickers, Mark	1.C.	,,
Wear, Richard E.	1.C.	,,
Moore, Alfred H.	2.C.	,,
Frankland, Edgar	2.C.M.	,,
Marshall, James	1.C.	Liverpool
Millar, James G.	1.C.	,,
Rhodes, Charles C.	1.C.	,,
Beazley, Joseph H.	2.C.	,,
Jones, Edward L.	1.C.M.E.	,,

Ex. 1.C. Extra 1st Class. 1.C.M 1st Class Motor. 2.C,M. 2nd Class Motor.
1.C. First Class. 2.C. 2nd Class. M.E. Motor Endorsement.

BOARD OF TRADE EXAMINATIONS.

List of Candidates who are reported as having passed examination under the provisions of the Merchant Shipping Acts, during the week ended 3rd March, 1928 :—

NAME.	GRADE.	PORT OF EXAMINATION.
Hastings, John	2.C.	Belfast
Stevens, Ernest A.	1.C.	Cardiff
King, Frederick W. L.	2.C.	,,
Mead, Leslie W. T.	2.C.M.E.	,,
MacFarlane, David A.	1.C.	Glasgow
Thom, Robert	1.C.	,,
Beed, Ronald E.	2.C.	,,
Melville, Robert A.	2.C.	,,
Newman, George F.	2.C.	,,
Hunter, John R....	1.C.M.	,,
Fasken, William S.	2.C.	Leith
Taylor, Andrew	2 C.	,,
Ogg, John T.	2.C.M.	,,
Adam, Alick P.	1.C.M.E.	,,
Barnes, Ernest G....	2.C.	London
Braithwaite, Edward A. V. ...	2.C.	,,
Lean, George A. E.	2.C.	,,
Cattell, William R.	2.C.	Southampton
Garroch, William J.	1.C.M.E.	Liverpool
Hucklesby, Laurence W.... ...	1.C.	,,
Symonds, William	1.C.	,,
Parkes, John B.	2.C.	,,
Prestwich, George J.	2.C.	,,
Riley, Joseph M.	2.C.	,,
Davison, Ernest	1.C.	North Shields
Graham, James A. C.	2.C.	,,
Irving, Richard H.	2.C.	,,
Marshall, William	2.C.	,,
Tate, Sidney R.	2.C.	,,

Ex. 1.C. Extra 1st Class. 1.C.M. 1st Class Motor. 2.C.M. 2nd Class Motor.
1.C. First Class. 2.C. 2nd Class. M.E. Motor Endorsement.

BOARD OF TRADE EXAMINATIONS.

List of Candidates who are reported as having passed examination under the provisions of the Merchant Shipping Acts, during the week ended 10th March, 1928 :—

NAME.	GRADE.	PORT OF EXAMINATION.
Bryce, John	1.C.	Glasgow
Paul, James H.	1.C	,,
Walker, James MacD.	1.C.	,,
Beattie, Walter C....	2.C.	,,
Smith, Joseph P.	2.C.	,,
Watson, John	2.C.	,,
Forrest, William M.	1.C.M.E.	,,
Laceby, Robert B....	1.C.	Hull
Maddick, Henry	1.C.	,,
Patman, Frederick N.	1.C.	,,
Pease, William	1.C.	,,
Rollerson, William H	1.C.M.	,,
Freshwater, Stanley	2.C.	,,
Scales, William H.	2.C.	,,
Clark, James A.	1.C.	Liverpool
Coe, Alfred	1.C.	,,
Durrant, Frank L.	1.C.	,,
Mason, John E.	1.C.	,,
Segar, William A.	1.C.	,,
Woodhouse, Laurence S. ...	1.C.	,,
Piercy, Walter	2.C.	,,
Appleton, Thomas F.	2.C.M.	,,
Christian, Charles H.	2.C.M.	,,
Duckett, Frederick A.	2.C.M.	,,
Andrews, Alfred G. N.	1.C.	London
Waugh, John	1.C.	,,
Marechal, Charles M.	2.C.	,,
Pepper, Maurice B.	2.C.	,,
Rooney, Alfred W.	2.C.	,,
Carmichael, Daniel	2.C.M.	,,
Gladstone, John A.	1.C.	Sunderland
Howard, Reuben	1.C.	,,
Johnson, Mark A.	1.C.	,,
Mallett, Samuel	1.C.	,,
Strother, Fleming...	1.C.M.	,,
Blakelock, Norman	2.C.M.	,,
Sanderson, Emmerson R. ...	2.C.M.	,,
Chicken, Thomas	1.C.	North Shields
Dunn, Samuel	1.C.	,,
Hartley, Thomas N.	1.C.	,,
Whitlock, Thomas M.	2.C.	,,
Burn, John E. F.	1.C.M.	,,
Hall, James D.	1.C.M.E.	,,

Ex.1.C. Extra 1st Class. 1.C. First Class. 1.C.M. 1st Class Motor.
2.C. 2nd Class. 2.C.M. 2nd Class Motor. M.E. Motor Endorsement.