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The Resistance to Failure of Condenser and Heat Exchanger Tubes in Marine Service

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Up to about thirty years ago the expectation of life for condenser tubes was very short. The types of corrosion that caused these failures are briefly discussed and the development of alloys resistant to these types of attack is outlined. The factors that are responsible for the small number of failures that still occur are listed and discussed. Foremost amongst the reasons for the failure of tubes at the present time is the use of polluted cooling waters, which are particularly liable to affect aluminium brass tubes, though all materials are liable to suffer in greater or lesser degree. Partial obstructions are another important cause of trouble.

The advantages and disadvantages of installing protector blocks in water boxes are discussed. Consideration is given to the possible effects of increasing nominal water speeds in condenser tubes above those commonly in use. The relative merits of aluminium brass and cupronickel are discussed from the point of view of heat transfer rates.

Amongst steps that can be taken to minimize condenser-tube troubles, the importance is stressed of avoiding polluted waters in the early days of service of a ship.

INTRODUCTION

Marine engineers will be well aware of the battle against condenser-tube corrosion that was continually being waged, with little success, until about the end of the first quarter of the present century. The way in which outbreaks of failures hampered the Royal Navy in the first World War is well known and was an extreme example of the seriousness of the problem. After about 1925 the tide of battle began to turn, and from then on progress was rapid. Today the situation is radically changed and condenser-tube materials are available which will withstand corrosion in all but the most adverse and abnormal conditions. Thirty years ago condenser-tube failures were all too frequent an occurrence. Today it is confidently expected that condenser tubes will last for the whole life of the ship, and a premature failure is an unusual and notable event. This is the background against which the present survey is set. There is no longer an overall condenser-tube problem, but there are still a number of individual problems which affect an extremely small percentage of the hundreds of thousands of miles of condenser tubing in service. Since a condenser-tube failure causes such inconvenience, it is important to eliminate even the few failures that still occur and investigations in progress are designed to reduce still further the incidence of failures and to improve the performance of tubes in those abnormal situations where the existing materials are not wholly adequate. This survey will be concerned mainly with the circumstances under which corrosion failures are still experienced.

I. CONDENSER-TUBE MATERIALS

It will be desirable first to give a brief account of the various condenser-tube materials at present available and of the types of corrosion to which they are resistant.

The foundation of modern knowledge of condenser-tube behaviour is the classical work carried out by G. D. Bengough(1) and his various collaborators for the Corrosion Committee of the Institute of Metals in the period 1910-1930. The eighth and last report to this Committee was by R. May(2), who continued his association with the work when it was transferred to the ægis of the British Non-Ferrous Metals Research Association in 1930. When May(3) published a survey of the situation in the TRANSACTIONS of the Institute of Marine Engineers in 1937 he was able to report that a considerable measure of success had been achieved in overcoming condenser-tube corrosion. More recently, accounts of the present situation have been contained in two papers(4) published in the TRANSACTIONS of this Institute and in other papers elsewhere(5).

The main types of attack suffered by the earlier types of condenser-tube material, such as Admiralty Brass (70/29/1), were impingement attack and dezincification. When the latter occurs, regions of the brass become replaced by porous masses of copper having virtually no strength. Bengough and May discovered that this type of corrosion could be inhibited in alpha brasses by a small addition of arsenic—about 0·02-0·06 per cent. Alpha brass condenser tubes produced in this country now always contain this addition, and for all practical purposes these are immune to dezincification, and this type of attack is now no longer a problem. It is claimed that additions of similar amounts of antimony or phosphorus will also inhibit dezincification and in some countries tubes containing these additions are marketed. No incontestable evidence appears to have been yet produced that these other additions are in any way superior to arsenic.

When seawater flows rapidly over copper or copper alloys, the turbulence may be sufficient to cause breakdown of the surface film. This is particularly likely to happen if air bubbles are entrained in the water stream which break when they impinge on the metal surface. The resulting corrosion is characteristic, producing clean-swept pits often of a "horse-shoe" shape. This "impingement attack" was first described by Bengough and May and one of the important results to emerge from their work was the recognition of the importance

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of the part played by protective films on condenser-tube alloys. To prevent impingement attack, it was necessary to develop an alloy which formed a self-healing protective film which was resistant to the action of impinging water containing air bubbles.

Such an alloy was aluminium brass (76/22/2) which was patented by the British Non-Ferrous Metals Research Association in 1928. This material, with the proper arsenic addition to prevent dezincification, quickly became a standard condenser-tube alloy and it has been, and is, widely used with conspicuous success in many vessels all over the world. Another alloy which became established at about the same time as aluminium brass was 70/30 cupronickel. It was found that the resistance of this alloy to impingement attack was greatly increased by the incorporation of small amounts of iron, and work at the British Non-Ferrous Metals Research Association established in some detail the effects of varying amounts of iron and manganese. At the present time 70/30 cupronickel normally contains 0·4-1·0 per cent iron, and 0·5-1·5 per cent manganese. At these levels the iron plays by far the most important part in increasing the corrosion resistance.

These two materials are the ones primarily responsible for the elimination of the vast majority of condenser-tube failures. Cupronickel—more expensive than aluminium brass and having slightly higher all-round corrosion resistance and reliability—is used in the main condensers of many warships and large merchant ships. Aluminium brass has given excellent service in the main condensers of many large and small merchant ships and of smaller naval vessels and in numerous auxiliary condensers and heat exchangers.

In recent times, shortages of nickel have prevented the supply of as many cupronickel tubes as have been called for and consideration has been given to alternative materials. One promising material is an alloy containing 10 per cent nickel with iron in the range of 0·7-2·0 per cent. The good resistance of an alloy with 10 per cent nickel and 2 per cent iron was demonstrated in work by the British Non-Ferrous Metals Research Association(6) carried out during the last war with the primary object of finding a more resistant material than copper for water-trunking, fire mains and other seawater-carrying pipes. An alloy containing 5 per cent nickel and 1·2 per cent iron was developed for this purpose and at the same time it was recognized that an alloy containing 10 per cent nickel and 2 per cent iron was a promising condenser-tube material. It was considered at the time that no useful purpose would be served in putting forward a new alloy as the existing materials, aluminium brass and 70/30 cupronickel, adequately fulfilled all requirements. Consequently there has been little service experience with the 10 per cent nickel alloy in this country. In the U.S.A., however, trials were put in hand and promising results were obtained. At the present time considerable amounts of 10 per cent nickel alloy with iron contents in the range 0·7-1·5 per cent are being put into service in that country, in some cases as a cheaper substitute for 70/30 cupronickel (resulting also in a considerable saving of nickel) and in other cases in certain power stations where other materials have not proved entirely adequate.

Another material which has given good results in laboratory tests, and in the limited practical trials to which it has so far been subjected, is a high-tin bronze containing 10-12 per cent tin. Although free from nickel, such tubes are relatively expensive.

From time to time varieties of aluminium bronze have been used for condenser tubes, and, although possessing good resistance to impingement attack, such tubes are liable to fail by pitting, particularly under deposits. Various other alloys have been used but the quantities in use for seawater service compared with the materials already described are very small.

The detailed compositions of a number of the alloys mentioned above are given in Table I.

It may be helpful at this stage to describe in a little more detail the characteristics of the different types of corrosion that may occur in condenser tubes.

(*1*) *Dezincification*

This is an attack of brass during which the original metal in the attacked region is replaced by a porous mass of copper having little strength but preserving the original shape of the article. (With a single phase brass all the metal in the attacked region is converted to copper, but with a two-phase brass the beta phase is preferentially attacked though dezincification may subsequently extend to the alpha phase also.) If dezincification is uniform (layer type), tubes are progressively weakened but no leakage may take place for a long time. If, as is much more usual, attack is localized (plug type), rapid failure of tubes may occur. When failure occurs the copper plug may be forced out at the point of perforation, leaving a hole of considerable size; dezincification that has proceeded only part way through the wall will usually be evident elsewhere on the tube, however. Dezincification takes place more readily at shielded areas such as in crevices or under deposits. It also proceeds more rapidly as the temperature rises. As already stated, dezincification of alpha brasses can be inhibited by suitable small additions to the metal.

(*2*) *Impingement Attack (or Corrosion-erosion)*

The impingement of rapidly moving water on a tube wall may lead to local breakdown of protective films. This is particularly likely to happen if entangled air bubbles of above a certain size are present, though with some of the less resistant materials, such as copper or Admiralty brass, sufficient local turbulence can occur to cause attack in the absence of air bubbles. The rate of impingement attack can be high since the rapidly moving water stream causes depolarization of the local anodes (corroding areas) by sweeping away corrosion products, and depolarization of the local cathodes (non-corroding areas) by

TABLE I.—COMPOSITION OF ALLOYS OF GOOD RESISTANCE TO SEA WATER CORROSION

Alloy	Per cent Cu	Per cent Zn	Per cent Al	Per cent Ni	Per cent Fe	Per cent Mn	Per cent As	Per cent Impurities
Aluminium brass	76—78	R	1·80—2·30	—	—	—	0·02—0·06	Total ≯0·3 of which lead ≯0·03
70/30 Cupronickel	R	—	—	30—32	0·4—1·0	0·5—1·5	—	Total ≯0·3 of which sulphur ≯0·08
Copper/nickel/iron	R	—	—	5·0—6·0	1·05—1·35	0·3—0·8	—	Total ≯0·2
Copper/nickel/iron*	≮86·5	≯1·0	—	9·0—11·0	0·5—2·0	≯1·0	—	Lead ≯0·05 Total others ≯0·5
Aluminium bronze	R	—	6·0—7·5	Total Ni+Fe+Mn ≯2·5 ≮1·0			—	Total ≯0·5

R=remainder

* A.S.T.M. specification (there is at present no British specification for this alloy).

bringing a plentiful supply of dissolved oxygen to them. The characteristic feature of impingement attack is that the corroded areas are swept clean of corrosion product. The pits are often sharply undercut on the downstream side. There are usually islands of unattacked metal in the corroded regions and attack round these sometimes produces the typical "horsehoe" configuration. If there is sand or other abrasive material in the water, sharp edges are rounded off. If the amount of sand is excessive, most materials will suffer a general and uniform wastage.

(3) Pitting

A number of different types of pitting can occur, varying from a single sharp pinhole to a widespread attack approaching uneven general corrosion. In laboratory tests very narrow deep pits are sometimes produced on materials such as aluminium brass and aluminium bronze under conditions of violent impingement. This type of pitting appears to occur very rarely in practice. Pitting that does occur is usually produced in stagnant conditions (e.g. under deposits) or with relatively slow water movement (i.e. with the water speed not much exceeding the designed velocity). As described below, most pitting troubles arise in polluted waters and in such cases the corrosion products are often black, owing to the presence of sulphides.

II. THE INCIDENCE OF CONDENSER AND HEAT EXCHANGER TUBE FAILURES

During the first World War there was a great increase in the number of condenser-tube failures, indicating that the materials then in use were quite inadequate to withstand arduous conditions involving long periods of high speed steaming. It was significant that during the second World War there was no such noticeable increase in the number of failures.

Analysis of the cases of condenser-tube corrosion investigated by the British Non-Ferrous Metals Research Association during the period 1939-1952 shows that only a small number of failures were investigated each year and that the number per year during the period 1939-1945 was very little higher than during the period 1945-1952.

Of the cases investigated since 1945, 50 per cent have concerned naval vessels, 27 per cent merchant ships and 23 per cent power stations. In 60 per cent of the cases the corroded tubes were from main condensers, tubes in the other 40 per cent of cases being from turbogenerator condensers, drain coolers, oil coolers, etc. In 85 per cent of the cases brass tubes were involved (55 per cent being arsenical aluminium brasses and 30 per cent other brasses) and in the other 15 per cent of cases the tubes were 70/30 cupronickel.

III. CAUSES OF CONDENSER AND HEAT EXCHANGER TUBE FAILURES

There are many factors which may contribute to a premature failure and, while it is sometimes possible for one single factor to be wholly or mainly responsible, it is more usual for several factors to be operating simultaneously. The factors which experience has shown to be the most important ones will be listed and each one then discussed in more detail.

The main causes of trouble are:—

1. The use of polluted cooling waters, particularly those containing hydrogen sulphide, sulphur or organic sulphur compounds.
2. Partial obstructions or deposits in tubes.
3. Inefficient protector blocks.
4. Sand erosion.
5. Steam impingement.
6. Mechanical factors connected with the installation or operation of the condensers.
7. Operating practice.
8. Use of incorrect or defective materials.

The Use of Incorrect or Defective Materials

Metallurgical defects or incorrect compositions are nowadays rarely the cause of failure, but from time to time materials of inadequate corrosion resistance are still used. The resulting failures could, in most cases, have been avoided by the use of more resistant materials. Thus, of the cases investigated by the B.N.F.M.R.A. in the period 1945-1952, about 35 per cent were due to the use of materials of low corrosion resistance (in many cases used in error), e.g. non-arsenical brasses that failed by dezincification, or Admiralty brass, 70/30 brass or iron-free cupronickel that failed by impingement attack. It is seldom advisable to use such materials for seawater service.

Mechanical Factors

Undue vibration in a turbine set has been known to cause corrosion in condenser tubes, sometimes in the form of pitting at points of maximum vibration. In extreme cases, evidence of vibration is provided by marks on the outside of tubes where adjacent tubes have knocked together. In other cases failure may occur by corrosion fatigue and such cracks can also be caused if proper provision for expansion and contraction is not made. Failures due to stress corrosion can occur if packing or end expanding of tubes is improperly carried out. Examples of this type of trouble were recently described by L. Baker(7). These types of failure are usually easily recognizable and steps must be taken to avoid the causes.

Operating Conditions

For reasons which will be discussed below it is undesirable to allow condensers to remain idle and full of stagnant water for long periods, particularly if there is any pollution or contamination in the water. Most harbour and estuary waters are contaminated in some degree. It is also undesirable in some waters to run at speeds where deposits may settle in the condenser tubes, i.e. with water speeds through the tubes below about 3ft. per sec.

Steam Impingement

Condenser tubes occasionally fail from the outside due to the impingement at extremely high velocity of minute droplets of water in the steam. If these water droplets cannot be avoided, it is necessary to introduce baffle plates to prevent direct impingement of the steam on the condenser tubes.

Sand Erosion

In certain estuaries the water contains considerable quantities of sand in suspension which will abrade the protective film from normal condenser-tube materials and cause general and comparatively rapid thinning. This problem, which is peculiar to certain power stations, though it might apply to coastal vessels operating in the waters in question, has been largely overcome by the use of a cupronickel containing 30 per cent nickel, 2 per cent iron and 2 per cent manganese, or high-tin (12 per cent) bronze, both of which are resistant to sand erosion except for slight attack at the inlet end.

Protector Blocks

It is a long established custom to fasten protector blocks in water boxes to protect tube plates from dezincification and stop inlet end corrosion of tubes. This practice is probably, on balance, beneficial, but in some circumstances it can give rise to trouble. A protector block can do nothing but good so long as it is providing an adequate current for the cathodic protection of adjacent metal parts. If the block ceases to function, however, it is possible for surfaces which were initially protected to corrode more rapidly than they would have done if no block had ever been installed.

The resistance to corrosion of condenser tubes depends on the formation of a thin protective film which forms naturally in clean seawater by a slight general and uniform corrosion all over the tube. If the end of the tube is made highly cathodic by the positioning near it of an active protector block, this initial slight corrosion is prevented and the proper protective film is not able to form over the first few inches of the tube length. Instead, a cathodic deposit containing calcium carbonate and sometimes metallic copper is produced. As long as the protector block continues to function, this is unimportant, but if for any reason the block ceases to work there is the risk of rapid corrosion at or near the inlet, since the cathodic deposit is not protective.

This is one reason why zinc protector blocks are not suitable for use in water boxes. Initially they are highly active but they subsequently become polarized and almost invariably cease to function after a time. There is evidence that very pure zinc will remain active indefinitely in seawater but even anodes of such material are not to be recommended because experience shows that the introduction of zinc corrosion products into the water is detrimental to the behaviour of condenser tubes, particularly those of aluminium brass. Zinc slabs should, therefore, in no circumstances be used in water boxes.

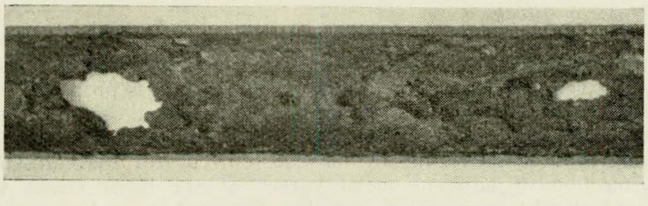
Steel blocks on the other hand remain active until corroded away and, moreover, the presence of iron corrosion products in the water appears to assist in the formation of a good protective film on condenser tubes. The only occasions on which trouble has been found to result from the use of steel blocks have been in small heat exchangers where only one or two blocks were fitted. Owing to the difficulty of access, such blocks may not be properly maintained and if they come adrift or are not replaced when exhausted, corrosion of the inlet ends of tubes may occur when the blocks become inoperative, for the reasons already explained. In general, therefore, it is good practice to install steel protector blocks provided they are properly maintained.

This is especially true where the water box is of a non-ferrous alloy such as gunmetal, for both the protective action on the tube plate and tube ends and the introduction of iron compounds into the water are beneficial. It is not so important where the water box is of steel or cast iron, for the obvious reason that the water box itself can function in the same way as the protector blocks. In this case, however, attack of the water box is accelerated. This can be largely prevented by proper painting, but repainting needs to be frequently carried out. More recently it has been demonstrated that corrosion in water boxes can be prevented by the installation of magnesium anodes. There is no evidence that these are detrimental to the performance of condenser tubes, provided, of course, that they are renewed before they are exhausted.

It should be emphasized that the protective current from protector blocks only flows a short distance along condenser tubes—a few inches at most—and there is no system which will give cathodic protection along the whole length of condenser tubes.

Polluted Waters

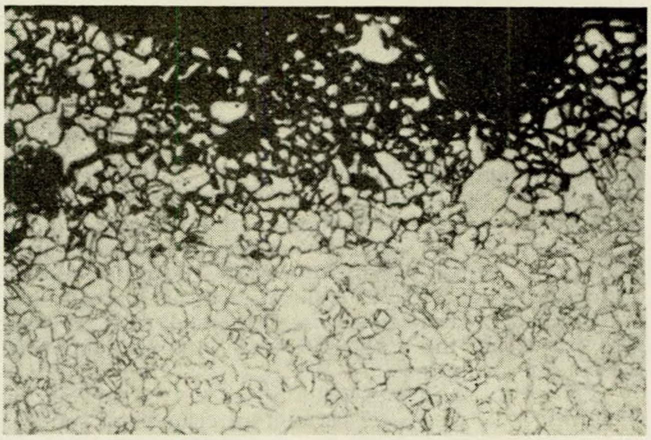
The most important single factor in the failure of condenser tubes at the present time is undoubtedly the use of polluted cooling waters. Harbours and estuaries may become more or less polluted for various reasons associated with the discharge into them of industrial wastes, sewage, etc. In the worst circumstances, organic matter uses up most of the dissolved oxygen, which falls to a very low figure, and sulphate-reducing bacteria on the sea or river bed becomes active, reducing the sulphates in the water to hydrogen sulphide. This occurs most readily at hotter times of the year, usually late summer and early autumn, and the degree of pollution, therefore, often varies in a seasonal way. There is often also considerable variation from year to year. Waters that contain hydrogen sulphide appear to be the most corrosive; an example of very severe attack produced by such a water on a 70/30 brass tube is shown in Fig. 1. It is also possible for bacterial processes to produce other corrosive substances, such as elementary sulphur or organic sulphur compounds such as cystine(8), some of which can act as accelerators even in very small concentrations.



× 1

FIG. 1—*70/30 brass condenser tube corroded by badly polluted water*

This problem is most serious for power stations situated at certain estuaries or harbours, for the cooling water available has to be used continuously whether it is polluted or not. There are indications, however, that the problem is becoming increasingly important for ships which now frequently have to spend appreciable times in harbours where the water is polluted (see, for example, the cases described by Baker(7)). To have the condensers standing idle, full of polluted water, or with water passing slowly through, is most undesirable. This is particularly so if the condenser tubes are new. If, during the early life of a ship, clean seawater passes through the condensers, good protective films will form which are likely to withstand subsequently all but the most adverse conditions. If, however, polluted waters are encountered during the early life, the films formed on the condenser tubes will not be fully protective and the risk of premature failure is considerably increased. The most critical period is during the first few weeks of service, or even the first few days. The longer polluted waters can be kept out of the condenser the better the chance of the formation of films which will give protection when polluted waters are subsequently encountered.



× 400

FIG. 2—*Severe intercrystalline corrosion of aluminium brass condenser tube after service in polluted water*

The nature of the corrosion that occurs through the use of polluted cooling waters varies. Under conditions of violent impingement, e.g. at inlet ends or at partial obstructions, failure by impingement attack can occur with alloys that would be unattacked under similar conditions with clean seawater. With aluminium brass under such conditions there is also the possibility of the development of a rapid and highly localized pitting attack. If the water speeds are more moderate and nowhere locally high enough to cause impingement attack, a more general but uneven type of corrosion is likely to occur with polluted waters. This may lead eventually to failure by pitting and it is characteristic of this type of attack that with brasses there is usually marked preferential attack at the grain boundaries of the metal. An extreme example of this on an aluminium brass tube is shown in Fig. 2. The use of polluted cooling waters results in the formation on the tube surfaces of corrosion products rich in sulphides and other sulphur compounds. If the ship subsequently passes into clean seawater, superficial oxidation of these corrosion products occurs, but the sulphur compounds can usually be detected beneath the oxidized layer for a long time afterwards.

All existing condenser-tube materials are adversely affected by polluted waters and power station experience indicates that the order of merit of different materials differs in different waters. It is not easy, therefore, to make recommendations as to the best alloys to use, but in general cupronickels are to be preferred. Corrosion by polluted waters is the most serious condenser-tube problem remaining unsolved and is the cause of the most frequent failures, particularly of aluminium brass tubes, at the present time. Research is in progress at the British Non-Ferrous Metals Research Association on the matter.

Partial Obstructions and Deposits

If the cooling water is flowing through condenser tubes at less than about 3ft. per sec., deposits of mud, silt, marine growths, etc., may settle on the tube. Beneath these, the protective film may be destroyed and pitting may occur and such "deposit attack" is sometimes a cause of failure. Marine growths or shellfish are particularly dangerous since, when dead, they decompose and produce water that is contaminated locally and, therefore, more corrosive than water associated with a deposit of, say, clean sand.

At higher water speeds shellfish, pieces of coke, etc., lodging in condenser tubes may cause failure by impingement attack, particularly if the water contains entrained air bubbles. The local water speed past a partial obstruction may be at least twice as great as the nominal water speed and often probably considerably more. It is, therefore, possible for impingement attack to occur locally even on materials such as aluminium brass and cupronickel. The fact that both these materials can fail by impingement attack at partial obstructions when the nominal water speeds are no more than about 7ft. per sec., indicates that very high local speeds can occur under these conditions—probably 30ft. per sec. or more. Again, the danger of failure is greater with organic bodies that decompose, causing local contamination, than with inorganic obstructions.

Another reason why partial obstructions are dangerous is that, in some heat exchangers, reduced water flow may cause local overheating, and most forms of corrosion proceed more rapidly at the higher temperatures.

To avoid trouble from partial obstructions, it is obviously necessary to ensure that the screening arrangements are as effective as possible. In some cases it may be necessary to carry out regular cleaning procedures.

The effects of several factors operating simultaneously can, of course, be more damaging than any one singly. For instance, in many of the failed tubes examined by the B.N.F.M.R.A., there has been evidence of both partial obstructions and the use at some time of polluted cooling water. About 90 per cent of the failures of aluminium brass tubes investigated were due primarily to polluted waters and/or partial obstructions.

IV. THE EFFECT OF WATER VELOCITY

At the present time the designed speed of the cooling water through the tubes of main condensers of merchant ships may be anything between about 4 and 9ft. per sec. The present-day tendency is towards higher water speeds to obtain smaller and lighter condensers, and it is, therefore, of importance to consider to what extent existing condenser-tube materials are capable of withstanding higher speeds than those commonly in use at present.

Laboratory tests show that both aluminium brass and 70/30 cupronickel are resistant to corrosion at an actual speed of 15ft. per sec. even when there is much entrained air in the water stream (unless the water is appreciably polluted). At 30ft. per sec. the probability of attack on aluminium brass is considerably increased, but 70/30 iron-bearing cupronickel is not often deeply attacked even at this speed. There is, therefore, a designed speed above which cupronickel would be recommended in preference to aluminium brass. It is difficult to define this speed precisely because of possible variations in maximum local speeds and degrees of turbulence for a given designed speed. Another unknown factor is the nature of the cooling water which will be used in the condenser.

There is ample practical experience to demonstrate the good behaviour of aluminium brass at nominal speeds of 7, 8 and even 9ft. per sec. In general there is no reason to prefer the more expensive cupronickel for such nominal speeds unless it is known that the vessel in question will operate in particularly polluted waters. If this is so there is some justification for using cupronickel since, in general, the risk of premature failure with this material in polluted waters is appreciably less than with aluminium brass.

The possibility of using aluminium brass for even higher designed speeds than 9ft. per sec. depends particularly on:—

1. Good design of water passages so that local water speeds and turbulence in the tubes are kept to a minimum.
2. Efficient screening arrangements so that the possibility of partial obstructions is as far as possible eliminated. Obviously obstructions become increasingly dangerous as the nominal water speed increases.
3. The avoidance of polluted cooling waters, particularly during the early life of a ship.

These factors are, of course, important at all water speeds and for all condenser-tube materials, but they would be the governing considerations determining how far nominal speeds could be increased above about 9ft. per sec., when using aluminium brass tubes.

V. HEAT TRANSFER

Rates of heat transfer and the efficiency of condensers are greatly reduced by the presence of films of corrosion products or solid deposits on the tube surfaces. As already explained, the corrosion resistance of condenser-tubes depends on the formation of a protective surface film and obviously the ideal film is one which is as thin as possible.

Considering the metal only, heat can be transferred through aluminium brass about 3½ times as quickly as through cupronickel. This difference is very much reduced when account is taken of the various solid and liquid films on both sides of the tubes in a condenser, but assuming that films of equal thickness are formed on both materials there is still an appreciable advantage in favour of aluminium brass. For a condenser transferring heat at a rate of about 400 B.Th.U./sq. ft./deg. F./hr., this advantage is of the order of 10 per cent. While there is no precise information available on the thickness of films formed on condenser-tube materials in various conditions, there is, in general, no reason to think that the films formed on aluminium brass are in normal circumstances any thicker than those formed on cupronickel—indeed they may well be thinner.

It appears, therefore, that if aluminium brass is suitable for other reasons, there is the additional advantage that it will probably give an appreciably better heat transfer than cupronickel. There is, in fact, practical experience that this is so.

This situation refers to service in clean or relatively clean seawater and the same may not hold under abnormal conditions. There is some power station experience to show that with polluted waters which cause the formation of thick sulphide-bearing scales, or with waters from which thick mud deposits are produced, better heat transfer rates can be obtained with cupronickel than with aluminium brass.

A considerable aid to maintaining heat transfer rates at many power stations is intermittent chlorination of the cooling water. This is hardly practicable on board ship, however.

SUMMARY

1. Most condenser-tube corrosion troubles have been eliminated following the introduction of inhibited aluminium brass and iron-bearing 70/30 cupronickel. Other promising materials are also now available.
2. A number of factors are responsible for the occasional

failures of normally resistant materials that still occur. These factors have been listed and discussed. Foremost amongst them is the action of polluted waters containing hydrogen sulphide or other sulphur compounds. None of the alloys at present in use are immune from attack in polluted waters but, in general, cupronickels are to be preferred. Another factor often contributing to failure is the presence of partial obstructions in tubes.

3. Zinc protector blocks should not be used in water boxes. Steel blocks are beneficial providing they are properly maintained.
4. Aluminium brass is satisfactory for normal service at designed water speeds up to about 9ft. per sec. It is possible that it could be used with success at even higher speeds if the conditions were favourable. It is likely to have some advantage over cupronickel in giving better heat transfer rates in relatively clean seawater.
5. It is important, particularly with aluminium brass tubes, not to allow polluted waters to remain in the condenser for any appreciable length of time during the early life of a ship. It is especially important for clean waters to be used during the first few weeks of service. Adequate screening arrangements are important to ensure that trouble due to partial obstructions is reduced to a minimum. These precautions become more important the higher the nominal water speed.

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Discussion

MR. H. F. SHERBORNE, M.C., M.A. (Associate) said it always gave him particular pleasure to be present at the reading of a paper before the Institute, and especially so when the subject, as on this occasion, was one to which he had devoted a great deal of study, and had observed it from close quarters for such a long time, and could, therefore, he hoped, contribute something of interest to the discussion. On the present occasion he had been asked to open the discussion, and was much honoured at the invitation to do so. In his opinion, the paper was characteristic of the author—accurate, scholarly, comprehensive, and fully up-to-date. Dr. Gilbert was to be congratulated on the style and quality of his work, and the efficient way in which he had put on record the facts in regard to the problem as it existed today. Mr. Sherborne could not find anything new in the paper, but he said it was none the worse for that, nor could he find anything with which he really disagreed, so naturally he thought it was all the better for that.

Having been honoured with the invitation to open the discussion, he had naturally given careful thought as to how he could do so to the greatest interest and perhaps even benefit to members. When he read the paper he had anticipated that a number of distinguished metallurgists would be present, and clearly he was not far wrong. They were there from Cambridge, Birmingham, London, Leeds, and elsewhere, the most eminent metallurgists in the country. He hastened to say that he had no intention whatever of stealing these gentlemen's thunder and addressing the assembly on dezincification, arsenic, antimony and phosphorus inhibitors, the evils and iniquities of protector blocks in water boxes, superiority of heat transference between one metal and another, and so on. He had thought that it might be of interest to the older members, and be very good for the younger ones, if he gave a brief historical survey of the problem; it would also be useful to place this on record in the TRANSACTIONS of the Institute. In addition to that, he wished to make one or two remarks on films, and in connexion therewith to show four slides. Also he wanted to say something about pollution, having observed with particular interest that in the summary of the paper it was correctly recorded that foremost amongst the reasons for the failure of tubes at the present time was the use of polluted cooling waters.

What he had done, was to dive again into the history of the subject in order that they might all have a better appreciation of the tremendous advances that had been made in the last quarter century, to pay due honour to those who blazed the trail, and so perhaps face the future rather better equipped at a time when this new and ugly phase of pollution was manifesting itself in an aggressive form.

The first historical reference was to a paper read exactly fifty years ago that month before the Institution of Civil Engineers. It was entitled "The Decay of Metals", by James Taylor Milton and William James Larke; the last named they would all recognize as Sir William Larke, Director of the British Iron and Steel Federation, 1922-46. On the opening page of this paper occurred the following:—

"The following examples of deterioration may be mentioned:—

1. The pitting of the tubes of marine surface-condensers, which is a source of frequent trouble to marine engineers.

"The most serious feature of such deterioration which has been observed is that the action to which it is desired to call attention seems to be erratic; considerable trouble arises in certain cases, while in others, under similar conditions, no such results occur".

It was sometimes said that at the time this paper was published, that was to say, fifty years ago, there was no impingement attack to any great extent, but only dezincification and pitting. It was certainly true that these two last mentioned forms of corrosion were the most troublesome at that time. The very interesting plate of illustrations, however, containing twenty-two photographs, showed some very clear instances of impingement attack.

He turned next to the state of affairs in the first World War. This was already adequately on record in the TRANSACTIONS, and he himself had already referred to many extracts from Jellicoe's book, "The Grand Fleet"; in the first 250 pages of that book there were no fewer than twenty-three references to capital ships not being at the Commander-in-Chief's disposal due to condenser tube trouble. He would refer those interested to his remarks on the paper, "Notes on the Behaviour of H.M. Ships during the War".* Let it be remembered that in those days there was no cupronickel and no aluminium brass.

In October 1923 there was read a paper† entitled "The Causes of Rapid Corrosion of Condenser Tubes". Thirty years ago this was the standard work on the subject, and he remembered that on entering the non-ferrous metal industry shortly after the publication of this paper, it was handed to him and he was told he must read and understand it. The following was an extract from a very long and comprehensive paper:—

> "Unfortunately the problem is urgent—a statement that may be illustrated by the present authors' experience of ordinary 70/30 brass tubes failing repeatedly in certain power station plants in periods varying from seventeen days to six weeks, and in marine practice in three or four months. In other condensers, apparently quite similar and working in the same station or sister ships, the average life of a tube may be measured in years; fortunately the latter is the usual case, but the uncertainty is a serious matter".

The next reference was to a paper‡ by Sterry Baines Freeman, chief superintendent engineer for many years of the Blue Funnel Line. Perhaps he might be allowed to pay a pious tribute to the memory of this very great man, to whom he owed a special debt of gratitude for having put him into the Institute many years ago. The opening words were as follows:—

> "The corrosion of condenser tubes is a matter of painful interest to both land and marine engineers, in fact to all who are engaged in the production of power by steam plant, and consequently appeals to a body such as the Liverpool Engineering Society, which embraces so many branches of engineering".

At the conclusion of the paper occurred the following:—

> "In conclusion, the author feels that an apology is due to the Society for the almost entirely negative character of this paper. It is so by the force of circumstances. No fully satisfactory explanation of corrosion phenomena are available; they are too complicated and variable. It follows that no one cure will apply to every case.
>
> "As constructive suggestions, the author would point out that an entirely new metal, cheap and non-corrodible, may be evolved; that steam may be returned to the boiler by other means than via a tubular condenser; or that some coating which will resist corrosion and not impede heat tranference may be developed.
>
> "If condenser tubes were entirely reliable the use of water tube boilers would be much more feasible, priming would be lessened, and a great deal of worry and expense avoided".

At the very time those words were uttered the metallurgists were beginning to develop cupronickel, but they had no 70/30 as yet, or if they had it was only just becoming available experimentally, and nothing else was really any use. It should be stated that lower nickel alloys, e.g. 85/15 cupronickel and 80/20 cupronickel, whilst something of an improvement on brass, were really very little better, particularly in the days before the work in connexion with iron and manganese, for which Mr. J. Wilkinson (Associate) had principally been responsible, had been carried out.

In a paper* on this subject occurred the following:—

> "All these alloys used for condenser tubes depend for their success on the formation of a protective film on the metal surface. It is the properties of this film which decide the adequacy of the resistance of the alloy to attack. A weak film, such as is formed on Admiralty brass, is easily broken by even mild impingement attack and the film on a pure cupronickel alloy is only a little more effective".

Next came a monumental work,† and no less a person than Sir Charles Parsons himself, at the very zenith of his power, had taken a hand. His intervention came because he could not get on with his work as he might otherwise have done in the absence of a tight condenser. He started off:—

> "The problem of the failure of the tubes of surface condensers is so well known that it seems only necessary here to allude to a few of the salient facts bearing upon the question. Whilst no adequate explanation has as yet been assigned for such failure, many attempts have been made to overcome it. On the theory that it is caused by electrolytic corrosion, counter-electromotive force has been applied to neutralize the action; on the theory that it arises from chemical action, such means as coating the inside of the tubes with a bituminous paint or with a protective scale of oxide have been tried. None of these measures have proved to be more than palliative in their effects, and sometimes not even that. In a few cases more expensive metals are being adopted for the tubes, such as cupronickel or monel metal".

It was a wonderful paper, but he must not take up time reading it. Two or three pages of the discussion gave a very accurate picture of the situation as it then existed.

Mr. Sterry B. Freeman in the discussion on the paper said:—

> "Some months ago on a visit to his works I ventured to tell Sir Charles that in my judgment he ought to direct his wonderful gifts to fathoming the causes and prevention of condenser tube troubles, because that was the greatest stumbling-block in the path of extending the use of turbines for marine propulsion. He told me that he already had that problem in hand, and we are receiving some of the benefits today".

Mr. John Austin, then superintendent engineer of the Cunard Line, said:—

> "This paper deals with a subject of vital interest to all engineers, particularly to those connected with marine engineering. Of late years the troubles have been so widespread, and the consequences so serious, that unless some

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* Holt, N. G. and Clemitson, F. E. 1948. Trans.I.Mar.E., Vol. LX, p. 207.

† Bengough, G. D., May, R., and Pirret, R. 1923. Trans. N.E.C.I.E. and S., Vol. XL, p. 23.

‡ Freeman, S. B. 1924. "Corrosion of Condenser Tubes". Trans. Liv.Eng.Soc., Vol. XLV, p. 92.

* Johnson, L. W., and Bradbury, E. J. 1951. "Corrosion-resistant Materials". Trans.I.Mar.E., Vol. LXIII, p. 59.

† Parsons, Sir Charles. 1927. "Some Investigations into the Cause of Erosion of the Tubes of Surface Condensers". Trans.I.N.A., Vol. LXIX, p. 1.

> remedy is found it will undoubtedly restrict the development of steam propulsion".

Many other passages of great interest could be quoted, but these extracts gave an accurate picture of the situation at that time.

All the time progress was being made, and about this time the first 70/30 cupronickel came into service. In those days, however, a lot of people jibbed at the high cost, and demanded something cheaper and, as far as ocean-going vessels were concerned, equally good if not better. Aluminium brass then came on the scene, and on 27th December 1927 the first patent appeared. The patentee was Professor Robert Hutton, and there he was in the audience, brought down from Cambridge for the occasion. They were all very pleased to see him. From that time on, it was a question of practical trial and error, and the modern history of the alloy was well known.

With regard to film, Sir Harold Carpenter said in the introduction to the Eighth Report to the Corrosion Research Committee of the Institute of Metals:—

> "In the course of the work which led to the publication of the Seventh Report, it had become increasingly apparent that corrosion (and resistance to corrosion) depends to a very great extent on the behaviour and properties of films consisting chiefly of corrosion products which form more or less completely on the surface of the metal under corrosive conditions and exhibit varying degrees of resistance".

That was in 1929.

When the first aluminium brass tubes came in after successful trial and were split up, no one could find anything wrong with them. They looked and were absolutely perfect. The characteristic feature of the inside of every one of them was a kind of orange or brown-orange colour, but this was not the film. He used to think it was until one day he scrubbed it with a nailbrush and off came the "film", which was nothing but a ferric scale. He continued to hear and read about films and tried to understand about them to the best of his ability, but he never really saw one until one evening some years ago when he went to Sheffield to hear Dr. Ulick Evans give a lecture. Dr. Ulick Evans was Reader in Metallic Corrosion in the University of Cambridge, and his work in the field of corrosion was internationally known and regarded; he was a Fellow of the Royal Society and one of the greatest living authorities on the subject. He could not remember what the occasion was nor what was the subject of the lecture. Perhaps Dr. Evans, who was present, would make some comments later on. He (Dr. Evans) had shown some slides of these films being removed from metal, which Dr. Evans had kindly lent him. He had selected four of them, and proposed to put them on the screen (Figs. 3, 4, 5 and 6). No doubt some members of the audience would then see film for the first time.

FIG. 3

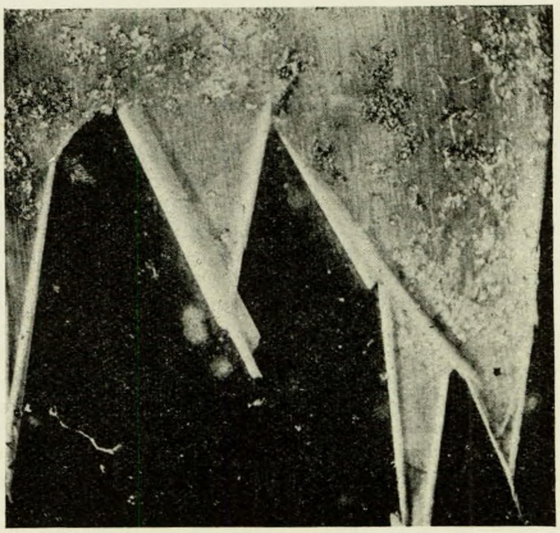

FIG. 4

In a letter Dr. Evans had written to him answering his request for the loan of these films, he stated in characteristically lucid terms as follows:—

> "All ordinary metals (except perhaps gold) become covered with invisible oxide when exposed to air, but such films keep developing discontinuities, and they will only be protective if conditions exist under which there is automatic repair".

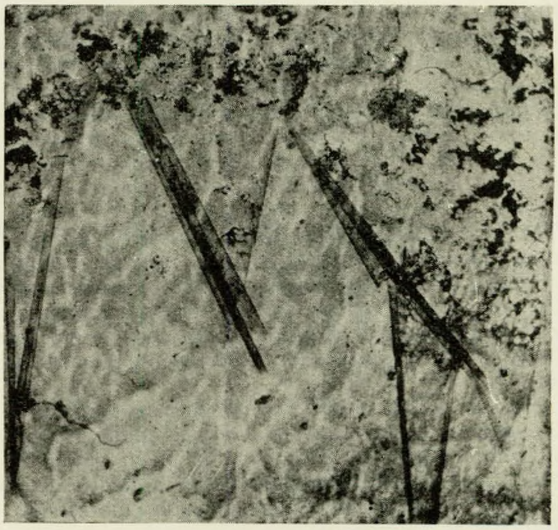

FIG. 5

The slides shown on the screen and reproduced in the paper illustrated films from heat tinted nickel, transferred to vaseline coated glass so that they could take up their unconstrained shape. Note the wrinkling in Fig. 3, and the curling on Figs. 4 and 5, which represented the same film viewed by reflected and transmitted light respectively; wrinkling was a sign of internal compressional stress, whilst curling was a sign that the stress was different at the two surfaces. Fig. 6 showed a film from heat tinted nickel which, after tinting, had a line drawn on it with a lead pencil; the film showed the pencil line after transfer and the line was seen to pass right round the curl of the film. The illustration of these films

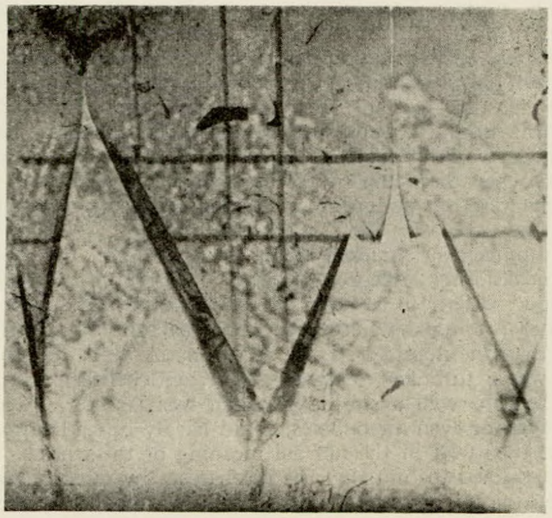

FIG. 6

showed in a convincing manner the nature of the film that formed on aluminium brass and other corrosion resisting alloys in contact with salt water. These films had made a great impression on him when he first saw them. From that day onwards, films meant something real that could be touched and seen. The nature of the films might be familiar to academic gentlemen working in their academic conditions, but to him at any rate, and possibly to other "working types", they had previously been like the imaginary line running round the earth, something one had never seen, and accordingly did not know was there. Before leaving films, it would not be inappropriate to refer to a publication by Mr. R. May,* entitled "Condenser Tube Corrosion: Some Trends of Recent Research", where the following paragraph occurred:—

> "The actual course and distribution of the corrosion which takes place is profoundly influenced by the formation and breakdown of films and scales often consisting mainly of corrosion products, and it is this aspect of the corrosion mechanism which serves as the connecting link between the practical conditions in condensers and the varied corrosive effects which they are able to produce.
>
> *The Relationship between Film Formation and Corrosion*
>
> "When samples of various condenser tubes made of copper alloys are immersed in a liquid such as ordinary sea water, there is at first a rapid action and the surface of the metal soon becomes covered with a thin film of insoluble corrosion products. The film hinders the diffusion of the corroding substances to the metal and reduces differences of potential over the surface and the initial action slows down.
>
> "If the film becomes uniformly less and less permeable, either by a gradual thickening or by appropriate changes in its texture or composition, then the initial protective effect may become greatly augmented. On the other hand, if the formation of the film is hindered, or if changes occur which make its porosity non-uniform, then the protective action becomes less effective and various kinds of corrosion may appear.
>
> "Obviously a protective film or scale may break down in a number of ways and, as would be expected, the nature of this breakdown has an important influence on the nature of any corrosion which may take place".

Finally, he wished to make a reference to the question of pollution. The subject was considered in a paper† by Mr. W. H. Dickie, and he wished to refer to his own contribution to the discussion on that paper where he pointed out that neither aluminium brass nor cupronickel was impervious to this type of corrosion. It only seemed to occur in new ships or after a retubing.

> "Neither aluminium brass nor cupronickel is impervious to this type of corrosion. It only seems to occur in new ships or after a retubing—that is to say, when the pollution conditions are present before the tubes have had sufficient work in salt water to give them a thorough protective film.
>
> "We await developments with some little anxiety as there is not yet any metallurgical answer to this type of trouble".

The most recent thing he had seen on the subject was a letter in the "Daily Telegraph" last July entitled "Malodorous Thames". It was signed by George E. Hill, Gravesend, and by the kind offices of the editor of the paper he had discovered that Mr. Hill was the Borough Engineer and Surveyor of Gravesend and not some æsthete with an over-sensitive nose. It read:—

> "I recently arrived in London by ship, and spent the night on board in Blackwall Reach. The murky water one associates with most estuaries changed at Long Reach to an ugliness which became more malodorous as we approached the sewer outfall of Crossness.
>
> "For the remaining ten miles of the journey it was impossible to escape from the smell of septic sewage, and by the time Blackwall was reached all the brasswork on the ship, which had been bright at sea, changed to a greenish brown. I was informed that within a matter of days the white paintwork would be similarly discoloured and that all metalwork would begin to corrode.
>
> "Are we so careless of our heritage, our amenities and our health that we will allow the Thames to become the septic tank of London?"

He wrote to Mr. Hill commending his observations and said that there was no doubt that the harbours and estuaries of the whole world were getting fouler and fouler and, incidentally, ships were tending to stay in them longer: his remarks in regard to the Thames in particular were most appropriate and very accurate.

Mr. Hill replied as follows:—

> "You may be interested to know that over the reach of the river to which I referred in my letter to the Press, both the river water and the mud bottom are strongly contaminated with sulphuretted hydrogen at all states of the tide. This is undoubtedly the cause of the corrosion of both ferrous and non-ferrous metals that are in contact with either the water or the gases coming to the surface.
>
> "It is my opinion that unless some speedy action is taken in respect of the Thames, conditions will become so bad that certain sections of the river will be virtually unusable".

PROFESSOR R. S. HUTTON, M.A., D.Sc., said that it was a great pleasure to have been dug out by Mr. Sherborne and the Institute to attend the meeting. It was always exciting to take one's memory back a quarter of a century and then see what progress had been made on a technical subject with which one was connected in the early days.

After the Navy's experiences with condenser tubes in the first World War, which had been described in Lord Jellicoe's book and Sir Winston Churchill's statements, the corrosion research programme of the Institute of Metals under Dr. Bengough and his colleagues was intensified. Important new knowledge was acquired and some mitigation of the trouble was secured, but the frequency of breakdowns was still "the bane of the marine engineer's existence", to quote one of their statements.

The time was ripe for some new condenser tube material which would be free from the calamitous troubles which so frequently occurred with brass condenser tubes. The British Non-Ferrous Metals Research Association, under his direction, was carrying out at the Research Department, Woolwich, exten-

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* Trans.I.Mar.E., Vol. XLIX, p. 171.

† Dickie, W. H. 1952. "High-powered Single-screw Cargo Liners". Trans.I.Mar.E., Vol. LXIV, p. 167.

sive researches on improving the surface quality of brass sheet. Attention was drawn to some work in France by Durville on a new and simple method of casting aluminium bronze ingots for the French coinage, and he was able to arrange some visits by the Association's researchers and later on by their industrial members.

The Woolwich work had no direct connexion with condenser tubes but, when he heard that certain aluminium brass alloys they were trying out were strongly corrosion-resistant, he suggested that they should be tried for condenser tubes. As they were also looking for improved ways of communicating the Association's research results, he thought it might make a useful Christmas present to the members if he applied for a provisional patent for the use of aluminium brass for condenser tubes. This was done on Christmas Eve, 1927.

The first effect, however, was rather disheartening, as the Tube Association members to whom the invention had been communicated did not appreciate its value. Another handicap was the general experience of the trade that the presence of aluminium in brass was anathema, which no doubt was true without the use of the Durville or similar methods of casting.

The properties and behaviour of the aluminium brass were studied in the laboratory by Mr. May and described in his Institute of Metals Report in September 1928, in which he emphasized its exceptional ability to form a self-healing film. Even then, however, their troubles were not over, for it was obviously important to get some service trials undertaken. In this connexion they were greatly assisted by Engineer Rear-Admiral Mark Rundle, a retired naval officer, who was working on the staff of the Research Association. In the first World War he had been in the *Lion* as Engineer Officer under Admiral Beatty and fully appreciated the importance of overcoming condenser tube troubles. It was Rundle, he believed, who first succeeded in finding a steamship company ready to install aluminium brass tubes in one of its condensers, provided that delivery could be made in a very short specified time. As no one in the trade could satisfy this time factor, the staff of the Research Association itself bravely tackled the job, and he believed that in the next few months 192 × 70lb. ingots, about 6 tons, were made in the Association's own laboratory,* a job for which they were not primarily fitted at all.

With these recollections, it would be appreciated what a thrill he got from hearing of the success of these tubes in the last twenty-five years and the contribution they had made in overcoming "condenseritis", in spite of getting "all the kicks and none of the halfpence".

He feared this was no worthy contribution to the discussion of Dr. Gilbert's valuable paper, but he should like to ask whether the troubles being met with in contaminated waters could not be got over by more thorough and systematic pretreatment of the tubes. In his early work May reported that if an aluminium brass tube were tested (1) after pickling; (2) after subsequent immersion in chromic acid; and (3) after standing in reasonably pure sea water, a progressive, marked improvement was noted. This was a case of the old adage about human beings bringing up a child in the way he should go and in his old age he would not depart from it.

If sulphur compounds were the cause of the trouble, the work of Price and Thomas, which showed that an aluminium oxide film on silver, if perfect, completely stopped tarnishing, might give hope of overcoming the difficulty by suitable pretreatment of the aluminium brass tubes.

COM'R(E) J. SIDGWICK, R.N., said with reference to "condenseritis" that all marine engineers, not only naval engineers, owed a great debt of gratitude to the workers in the field of condenser tube research that the same state of affairs did not arise in the late war as in the first World War. Many of the research workers were mentioned in the paper, and some of them were present at the meeting.

The author recommended in his paper the avoidance of pollution in the early life of a ship, and subsequent discussion had emphasized this point; but it was not so easy. Most ships were built and fitted out in comparatively badly polluted waters. The suggestion had just been made that some form of pretreatment might be possible, but did the author think any advantage would be gained by draining down the main condensers when they were not in use, bearing in mind that many of them were not designed for drainage and some water might lie in the tubes.

Impingement attack was an accepted term, but it was a little misleading. According to the books on hydrodynamics, the flow pattern in a tube was such that there was a body of water passing down the centre of the tube at very slightly more than the nominal speed. Between that and the tube wall there was a turbulent boundary layer, and between that again and the tube wall a sub-layer which was laminar. Water in that layer, or even air bubbles, could hardly be said to impinge on the tube wall in the normal meaning of the word.

It seemed to him that the mechanism by which protective film on the tube was destroyed initially was bound up with the velocity gradient in the boundary layer, and that was a function not of the nominal water speed in the tube but of the Reynolds' number. It might well be that the Reynolds' number was the proper criterion of the safety of a tube of a given material, rather than the nominal water speed.

If this theory were true, it would appear that smaller tubes should be less prone to impingement attack at a given nominal velocity. He would be very interested to know whether there was any evidence to support this.

Further, since the heat transfer coefficient inside the tube was also a function of the Reynolds' number, it might be that a limit was imposed on the usable value of this coefficient by the resistance of the material to impingement attack.

MR. J. B. COTTON said that Dr. Gilbert had presented a very comprehensive paper on condenser tube corrosion and, as one who was occupied in much the same field, he was well aware that it was always difficult in a paper of this type to treat in detail certain aspects of the subject which merited detailed treatment.

He did not think too much emphasis could be placed on the deleterious effects of the intake of polluted water, particularly in the early life of the tube.

Summarizing the available evidence, one must recognize that vital damage to condenser tubes was far more likely to commence when the ship was in harbour than when she was steaming at speed through clean sea water.

Dr. Gilbert had mentioned the need for efficient screening of the water intake, particularly with aluminium brass. Unfortunately, it was virtually impossible to prevent the ingress of very small live shellfish during the breeding season. If young shellfish were present during that period, some of them, at any rate, would settle in the water boxes and tubes. They would adhere very tenaciously and subsequently would not be removed by normal water flow. In fact, once a settlement had taken place, a brisk water stream and a slight rise in temperature might help to sustain them in life. Whether they would remain to grow to an appreciable size would depend, amongst other factors, upon the copper leaching rate of the particular condenser tube alloy. The rate at which copper was leached from the surface of the metal was known within fairly close limits, and La Que and Clapp and also Bulow in the Transactions of the Electrochemical Society, 1945, Volume 87, had quoted a critical toxic figure of about 5 mm. per dm^2 per day. Recent work by his company had confirmed this figure. Aluminium brass usually had a copper leaching rate below this critical figure and cupronickel just above it. In other words, there was a tendency for aluminium brass to biofoul more readily than cupronickel.

What was the remedy? Fairly frequent cleaning, particularly during the breeding season, which in Britain was about March to June. Chlorination was often applied in land

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* See also Evans, U. R. 1951. "Chemistry and Industry", pp. 706-711.

stations, but Dr. Gilbert had indicated the impracticability of chlorination on board ship. Was it not within the bounds of possibility that one day one might see portable dockside chlorination units going into action just before a vessel proceeded to sea?

With regard to protector blocks, it should be realized that they would not protect the whole tube. The galvanic protection they provided for the tubes was strictly limited to the end portions and did not extend right down to the body of the tube. Occasionally, in polluted waters, there was evidence of this limitation.

MR. J. WILKINSON, M.Sc. (Associate) said that he wholeheartedly supported the five points set out in the summary of the paper, and he was particularly pleased that Dr. Gilbert, in his introductory remarks, made special mention of points 3 and 4. He would have liked to have seen magnesium included with zinc in point 3.

He had with him a photomicrograph somewhat similar to Fig. 2 on page 4, showing intercrystalline corrosion of an aluminium brass condenser tube. This particular aluminium brass tube had had more than the recommended medicinal dose of arsenic added, in fact it had had a fatal dose. The brass actually contained 0·12 per cent of arsenic, whereas most British makers stuck to an arsenic content of about 0·04 per cent. The tube was from a ship's condenser and there had been an opportunity to examine other tubes from the same condenser when it was found that those which had the correct arsenic content did not exhibit this type of intercrystalline corrosion. He wondered, therefore, if the particular specimen shown in the paper also had a high arsenic content or if there were some other peculiarity in its composition.

Under the heading, "Protector Blocks", it was stated that so long as a protector block continued to function it was satisfactory and provided protection, at any rate to the ends of the tubes. He had seen cases where tubes of film-forming alloys such as aluminium brass, iron-containing cupronickel and aluminium bronze, which had been damaged near to the inlet end with, in one case, a rough tail on a ferruling tool and, in another, with a damaged roller cage, and, despite the fact that new zinc plates were installed in the condenser water boxes, the damaged parts were rapidly and severely attacked by corrosion erosion or what is sometimes described as impingement attack. It might have been that the mechanical or erosion factor was more important than the chemical or corrosion factor in these cases, but the fact remained that the tubes were undoubtedly attacked despite the presence of active zinc blocks.

He had often come across cases where tubes had been severely attacked by a pitting type of corrosion some considerable distance away from the ends when zinc protector blocks were used. Admittedly, the cooling water in all these cases was polluted, but when the zinc plates were removed and replaced by soft iron blocks, tube failure ceased. It was most likely that when the zinc blocks were removed a large number of tubes in the condenser would already have been attacked by pitting and near to failure. How was it that when the zinc blocks were taken out and iron blocks fitted, no further trouble was experienced? He was not referring to an isolated case; this had happened in a number of cases.

MR. G. W. YOUNGER congratulated Dr. Gilbert on so ably summarizing the troubles met with in condensers. His own association with Dr. Gilbert had been that of a client asking for advice which he had never failed to receive. He would like now to ask for some clarification of one or two points in this excellent paper.

It was suggested that 2 per cent iron in 70/30 cupronickel tubes had been used in some power stations with advantage where there was erosion. In the table on page 2 it was shown that the Americans were using 90/10 copper/nickel with 2 per cent iron. Why, then, was the specification in this country limited to 1 per cent.

Another point puzzled him. On page 3 it was stated that 85 per cent of the tube failures in marine condensers had involved brass, 55 per cent being aluminium brasses and 30 per cent other brasses. He did not know what percentage of aluminium brass as against arsenical brass was used in marine condensers, but there was an indication from these limited statistics that perhaps aluminium brass was not as good as was thought. He hoped that would be qualified.

In the section on mechanical failures it was said that excessive vibration caused rapid failure. He did not see how it could be put right after the condenser had been built. He would, therefore, plead with the design engineers, now they had these modern materials, to take advantage of them and not waste them by utilizing designs which caused vibration.

He would also like to draw attention to steam impingement. With the use of more modern plant, impingement could become very serious from the impurities which came off in the steam. The breakdown of carbonates and ammonium-compounds produced carbon dioxide and ammonia in the steam; together with dissolved oxygen, this could cause serious condenser tube failures.

He was interested in Mr. Sherborne's comments about the "malodorous Thames", because his authority had condensers operating continuously on the Thames. He agreed with Mr. Sherborne that in the past one could smell the hydrogen sulphide. For some time this water had been used in 70/30 cupronickel tubes. The first specimens went in in 1941 and the others when the condensers were tubed in 1946. They had been examined recently by Dr. Gilbert and his experts, and Mr. Sherborne could rest assured that all the indications were that they should last as long as the turbines.

With regard to partial obstructions in condenser tubes, screening was a difficult problem. It had to be done at a certain point depending upon the design of the cooling system, if it was to be effective. One could get free-swimming mussel larvæ through very fine mesh screens into the cooling system. Later they could die and the shells might wedge across the tube. There had been serious failures of turbine condenser tubes in a matter of three to four weeks after they had been installed through mussel shells and dead mussels wedging in the tube and causing impingement.

He would like some guidance on the problem of heat transfer.

He agreed about the serious results of scratching the protective film formed on the tubes. Methods of cleaning had been instituted in many places, consisting of brushing with wire brushes, and some of these brushes were of such a nature that they did damage to the protective film. To expedite the job a technique of acid cleaning had been used. About 5 per cent of inhibited hydrochloric acid had been used. Did Dr. Gilbert think this was safe? Would it take off all the protective film? If so, would it be better to take it all off and let it form again rather than produce a discontinuous film by other cleaning methods?

He could see the difficulties of taking chlorination plant to sea, but had anyone investigated the possibility of producing chlorine *in situ* from seawater by electrolysis? A problem had arisen where condensers were fouled very rapidly; they appeared to contain debris coming from estuary water. Cleaning was resorted to nearly every night, but it was not very effective, and chlorination was tried; this had cleared the tubes. It seemed to prevent the deposition of mud and organic debris. The advantages to be gained from producing chlorine in the condenser water boxes by means of electrolysis were worth following up.

Dr. Gilbert had not dealt with the tightness of condensers which affected operators of relatively high pressure, high temperature boiler plant. Ferrule packing, staybolt leaks, etc., could cause serious trouble to other parts of the plant, such as boilers, economizers and feed heaters. Very great advances had been made in metallurgy by Dr. Evans, Dr. Gilbert and others, but was full advantage being taken of them? For example, certain condensers were tubed with good first-quality cupronickel tubes, or perhaps aluminium brass, but the ferrules in one case were

60/40 copper zinc. Greater advantage might well be taken of the widespread knowledge of the metals now available.

MR. FRANK LATIMER said that, as he had been associated for over forty years with the manufacture of condenser tubes, he was naturally interested to study papers such as Dr. Gilbert's, dealing with their behaviour in service.

On reading the paper, his mind was taken back over many years to a paper* read before the Institute of Metals by Engineer Commander G. B. Allen. It dealt with service experience with condensers and outlined the various types of troubles to which condenser tubes were prone in those days. For example, it stated that inlet end corrosion or corrosion-erosion amounted to approximately 30 per cent, local pitting to 20 per cent, obstructions to 3·2 per cent, steam impingement to 10·8 per cent, and external damage and crushed ends to about 5 per cent jointly. Splitting of tubes accounted for 6·4 per cent and general corrosion and incidentals for about 23 per cent. The failures attributable to action of polluted water amounted to about 1 per cent only—a figure which was very much lower than that of present-day experience and which indicated that harbour and dock waters had deteriorated considerably during the past thirty years or so.

The paper concluded with the statement that with every precaution taken during manufacture and with the adoption of any known preventive or protective processes, it must be admitted that freedom from deterioration could not be guaranteed, or at least a guaranteed life could only be obtained by the employment of an alloy other than simple brass.

Previous speakers had referred to the development of various tube alloys and some emphasis had been placed on aluminium brass. Some credit must, however, be given to condenser tube manufacturers in this country for developing cupronickel shortly after the termination of the first World War. The 80/20 cupronickel alloy tube was made commercially in 1921 and considerable quantities were supplied to ships and power stations up to 1925, when the 70/30 cupronickel alloy was evolved. This latter alloy was specified in 1926 by the British Admiralty for all future requirements and their lead was immediately followed by all European navies. It was very largely through the success of the 70/30 cupronickel alloy that the Canadian Pacific Steamship Company fitted tubes of this alloy in the *Duchess of Bedford*. This was the first mercantile ship to use high pressure steam for multitubular boilers.

Reference had been made to the use of 90/10 copper nickel with an iron content, and it had been said that this alloy showed promise as a condenser tube material. It had been used very largely in the United States, primarily because of the difficulty, a few years ago, of obtaining 70/30 cupronickel alloy owing to restrictions in the supply of nickel. Today nickel was readily available and was in full supply. It was only to be expected that the cost of 90/10 alloy would be lower than that of the nickel alloy. Whether or not it would prove to be its equal in service could only be determined after practical experience in ships and power stations.

Fair quantities of the 90/10 alloy tubes were now being tested in ships and, as manufacturers, his company felt that in fairness to potential users reliable experience from service trials must be obtained before offering this alloy as a substitute for 70/30 cupronickel. He agreed that whilst tin bronze, 88/12 copper-tin alloy tubes withstood excellently the effects of sand erosion, they did not have such good resistance as 70/30 cupronickel to deposit attack.

Reference was made in the paper to eight important factors which, singly or collectively, caused condenser tube troubles, but Dr. Gilbert had not brought out sufficiently strongly a factor which was often found to be a cause of trouble—water box design. There were water boxes fitted with scoops leading off cooling water to auxiliary equipment, such scoops causing turbulence and subsequent ill-effects in the tubes. Another factor affecting design was that insufficient means were sometimes provided for the escape of air from the first to the second pass.

Dr. Gilbert had referred to inefficient expanding of tubes as another fruitful cause of trouble. He might have added that where ferrules were used the tubes at the inlet end should come right up to the check on the ferrule. Otherwise the gap between tube and ferrule was a possible cause of water turbulence —and frequently was.

He had also referred to the effect of high velocity steam striking the condenser tubes and eroding them on the outside surface. The introduction of baffle plates was suggested in the paper to prevent direct impingement of the steam on the tubes. There was an alternative remedy that had been tried and found effective after the ship had been in service and time had perhaps not permitted the introduction of baffles. This was achieved by the extraction of a top row of tubes which had been subjected to steam impingement and their replacement by brass bars. These effectively took the attack and permitted the steam to follow the normal channels or lanes.

Incidentally, it had been found that another common place for trouble from attack on the outside of tubes was underneath the air ejector plates. In many instances, this had been dealt with by removing a small pocket of tubes and replacing them with brass bars in the direct stream where external corrosion was experienced.

He agreed with previous speakers about tube cleaning and the danger of using hard steel wire brushes. He would, like the previous speaker, appreciate some guidance from Dr. Gilbert on the use of chemical cleaners.

He welcomed the warning given by Dr. Gilbert and others about not allowing condenser tubes to remain flooded with polluted water. This was a fruitful cause of trouble. But he was not sure that sufficient emphasis had been placed on the danger of permitting the tubes to remain full in the fitting-out basin stage of construction.

He would like to conclude on this note: when troubles arose, tube manufacturers were often looked upon as the guilty parties. In diagnosing the causes of corrosion, one could divide the troubles into four categories: the material itself, whether in the tube, the tube plate, the ferrules, etc.; the design of the condenser; the operating conditions; the fortuitous conditions over which nobody had any control, such as the quality of the water, unless remedies such as chlorination could be introduced. That was not possible in a ship.

The point was that other factors should be taken into account in addition to the materials in diagnosing troubles.

DR. U. R. EVANS, F.R.S., congratulated Dr. Gilbert on his admirable paper. It was extremely practical and, although expressed in simple terms, it was not over-simplified. He emphasized this because there was great pressure at the present time on corrosion writers and speakers to give papers in which truth was sacrificed to simplicity. That was most dangerous in a subject such as corrosion. Dr. Gilbert had resisted the temptation and he had provided a paper with which everyone could agree.

As an example of the dangerous tendency to oversimplify, he would call attention to certain tables of "i.p.y." values which had recently been printed. They showed the alleged loss of thickness of different materials from corrosion, expressed in inches per year. At first sight, they provided just what an engineer needed: by a very simple arithmetical sum, he could calculate what would be the loss of thickness of the material in which he was interested in the environment in which he was interested over the time in which he was interested.

These i.p.y. values, however, were nearly always calculated on the assumption that corrosion was uniformly spread over the surface. If that was true in the case with which the engineer was concerned, no doubt his estimate would be approximately accurate. Fortunately, it did happen with various materials, such as steel, that under some conditions thinning was fairly uniform. But with many non-ferrous

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[*] Allen, G. B. 1920. "Service Experience with Condensers", Jnl.Inst.Metals, Vol. XXIV, No. 2, p. 285.

materials, particularly some of those which Dr. Gilbert had been discussing, corrosion was not uniform, but highly localized. Calculations made on the assumption of uniform attack would involve great error and might suggest a very much longer life than could actually be obtained. He always warned students, particularly engineering students, against using i.p.y. calculations unless they were satisfied that the conditions were such that there would be uniform attack or that the compiler of the tables had made proper provision for localization.

It was evident that what really interested the engineer was not the total corrosion but the intensity of corrosion (corrosion per unit area of the part affected). It was the distribution that was so important, and one had to consider the causes of this non-uniform attack. Dr. Gilbert had referred to one very important cause: the impingement of water bubbles, vacuum cavities, sometimes sand particles at certain points which caused a film otherwise fairly protective to break down locally and continue breaking down always in the same place. He did not propose to say more about that. It had been well discussed already.

Another important factor entered into the question; the electric currents which were passing over the surface during corrosion. These electric currents were facts. They had been measured on electrical instruments. Mr. Sherborne had emphasized that films were concrete realities, which could be handled; they were not figments of the imagination. Similarly, the electric currents were facts, not phantasies, and very important facts for the practical engineer. One could get such currents even if only one metal or alloy were involved.

The electrical currents had been measured at Cambridge by four independent methods, and it was found that they were strong enough to correspond with the corrosion rate in the sense of Faraday's law. It could be said, therefore, that the electrochemical character of certain types of corrosion had been demonstrated directly and quantitatively.

These currents were particularly dangerous when one had two dissimilar metals in contact. A principle very important to the engineer was the cathode/anode ratio. It must be remembered that every electric battery had two poles—the anode and the cathode. The anode was the one which corroded. The cathode did not generally corrode, except sometimes for secondary reasons. In the ordinary torch battery, the zinc was the anode and the carbon the cathode. In a service corrosion problem, if the cathode was big and the anode small, corrosion would generally be much more intense than if the anode was big and the cathode small. There were exceptions which he could have mentioned, with their reasons, had there been time; but this generalization was in most cases true.

Perhaps the most sensational case of intense corrosion caused by a big cathode/anode ratio concerned not the condenser but the hull of a ship. It was the case of the American yacht *Sea Call*. She was built to the order of a wealthy American who chose Monel metal, a comparatively new material then, because he knew that it was resistant to corrosion and thought he would have no corrosion troubles at all. He was warned that the boat would be very expensive but apparently that did not matter; perhaps, it was an added attraction! At any rate, this boat was designed to have Monel metal plates and rivets on the hull. That plan was duly carried out, but unfortunately a few steel rivets got mixed up with the Monel metal ones. The boat was launched and came into the basin for fitting out. After a time it was noticed that she was leaking rapidly. A diver was sent down and reported that the riveters had left out some of the rivets, the holes being found empty. The boat was condemned and broken up before ever she had made a trial voyage. It was an extraordinary affair and he would not have believed it but for the fact that it was reported in a paper by the late Professor Oliver Watts, who, as a young man, had investigated the case which he called, rather appropriately, the "Million-dollar Experiment in Corrosion".

What had happened was that there was a very big cathode, namely the whole hull of the ship, and small anodes (the few steel rivets). The big cathode had permitted a large corrosion-current and the whole of its effect was concentrated on the small steel anodes. The rivet points were rapidly corroded away, leaving nothing to hold in the stems. The pressure due to difference of level pushed the stems in, and the water soon followed. That was the cause of the trouble.

One might well ask why experiments had not been carried out to determine what would be the effect of steel and Monel metal in contact. Such experiments would not have cost a million dollars. That was the advantage of laboratory experiments; properly designed, they were cheap and saved much money. Improperly designed, they could in the end be very expensive indeed.

The answer to that question was that some experiments had been performed for a special reason: that there were certain parts of the ship (such as the rudder frame) which for technical reasons could not be produced in Monel metal. They knew, therefore, that apart from any mistakes there would be Monel metal and steel in contact and very wisely they desired to know whether there would be serious intensification of the attack on the steel. They came to the conclusion that there would be no very serious intensification of attack, the reason being that the experiments had been performed with plates of Monel metal and steel of the same size. The importance of the cathode/anode ratio had been overlooked. Although the experiments were probably accurate, they nevertheless led to the wrong conclusion.

With regard to polluted waters, Dr. Gilbert had said that some of the sulphur compounds assisted and accelerated the attack. The fact was that in some cases they produced a film which was tolerably protective and would probably prevent corrosion, provided it was not damaged. In point of fact, it usually was damaged and there was a big cathode, the film-covered part, with a small anode, the exposed metal. The film apparently acted as a more efficient cathode than the unfilmed alloy would have done, so that the relatively few discontinuities in the film were attacked rapidly. Roughly speaking, these discontinuities could be regarded as receiving the ration of corrosion which would otherwise be spread to some extent on other places. This would seem to be the view of Mr. Rogers, Dr. Gilbert's colleague, though he expressed it in different words.

If that was the right explanation (and he was speaking subject to correction), it provided another example of the disastrous cathode/anode ratio principle.

MR. L. KENWORTHY congratulated Dr. Gilbert on an excellent and informative paper. He appreciated the difficulty of including every point having a bearing on this subject, but there was one omission which he thought should be mentioned and that was the damage that might arise from too vigorous mechanical cleaning. Even with present-day condenser tube alloys, corrosion might occur on this account and one or two cases had been met with in naval practice. They were presumably due to the fact that cleaning was usually carried out in harbour, after which the condenser might remain flooded for a time with polluted water. Although normally the abraded areas would have developed a protective film, organic material in the water might prevent this by hindering the polarization of these anodes, which thus remained active and suffered attack.

With further reference to the subject of cleaning, it might be of interest to note that a certain amount of successful acid cleaning of both aluminium brass and cupronickel tubes had been carried out in H.M. ships. Subsequent examination of tubes and of cores trepanned from Naval brass tube plates, after considerable periods of service, gave no indication that any form of corrosion had been initiated by the cleaning operation.

He thought the statistics quoted concerning the tubes examined by the British Non-Ferrous Metals Research Association since 1945 might be misinterpreted. There was no indication of the relationship these bore to the total number of failures which had occurred. Whilst he appreciated that this would be difficult to establish, it might be concluded from the figures given that twice as many failures occurred in naval service as in either merchant ships or power stations. He felt fairly certain that this was not the case and that a higher percentage of failures in Naval vessels than in the other two categories had been brought to the notice of the author; he thought it would be an advantage, however, if the author were to make this clear.

The prevention of fouling in condensers as distinct from its removal, which in the case of shell fouling could best be achieved by acid cleaning, was a particularly difficult problem in ships since it involved carrying extra equipment or chemicals. Experience with systems involving less water than main condensers, such as firemain systems, indicated that intermittent injection with, for example, sodium hypochlorite, was more convenient than electrolysis. Other methods were under examination, such as electrocution and the use of a thermal barrier.

MR. W. MCCLIMONT, B.Sc. (Member) said the Chairman had omitted one point from his excellent biographical note about Dr. Gilbert. About two years ago the British Non-Ferrous Metals Research Association and the British Shipbuilding Research Association decided to get together in the sports field. They found a very excellent captain for a cricket team, which had not done too badly, in Dr. Gilbert. His paper showed all the virtues he had shown in his cricket activities. He was, though not spectacular, a sound and reliable opening bat.

The shipbuilding industry as a whole felt, he thought, that the British Non-Ferrous Metals Research Association had done very good and adequate work on the problems falling within their sphere.

Dr. Gilbert had drawn attention to the lack of precise information on the thickness of films formed on condenser tube materials in various conditions. The usual practice in the design of condensers was that a heat transfer coefficient for scale, based on experience of rates of scaling and nature of scale, was assumed and was combined with the coefficient for clean surfaces to give an overall coefficient. Investigation of the rate of scaling and of heat transfer coefficients for scale would enable the specification of such equipment to be more scientifically compiled and would possibly lead to reductions in weight.

Consideration had been given to this matter by the British Shipbuilding Research Association and a programme of experimental work had been put in hand. It was intended to measure the thermal resistance of tubes, taken after various lengths of service, from a wide range of marine condensers. The tubes would be tested under conditions approximating as closely as possible to those existing in a marine condenser. Arrangements were being made with a number of shipowners to obtain specimens after use, together with the relevant particulars concerning the route of the ship, and the load and time of operation of the condenser. It was hoped to obtain specimens from ships operating on as wide a variety of routes as possible, so that the relative importance of the various factors likely to affect the rate of fouling could be examined. These included the variation in the solid material in sea and river water, the condenser working pressure and cooling water velocity, and possibly other factors.

The co-operation of owners having tubes available, say, at a refit, was a prerequisite of the success of this investigation. It would appear necessary at first to determine whether the deposition of scale was uniform over all the tubes and the positions of the tubes in the first tests were being carefully selected to provide information on this point; it should then be possible to cut down the number of sample tubes per condenser.

Results so far obtained had indicated the suitability of the apparatus and experimental method being used, and it was hoped that results of significant value would soon be available.

MR. J. CROWTHER said that he was a comparative newcomer to condenser tubes and so had missed the period mentioned by Mr. Sherborne in which condenser tube failures were very common. The continued use of materials not suited to the service conditions did, however, provide the present-day metallurgist with examples of types of failures which were really somewhat archaic.

He had recently come across dezincification in a condenser tube from a Continental power station, which had apparently been retubed too soon after the war. The material used was not fortified with arsenic. Of two samples of tube of Admiralty brass one was badly dezincified. It was free from arsenic and phosphorus. Another which was not so badly dezincified had a substantial amount of phosphorus. Whether it was put in deliberately or just happened to be in the material, he did not know.

He had, however, been in contact with the troubles due to polluted waters and had seen attack of the type described in the case of aluminium brass. Considerable intercrystalline corrosion took place, and that was always a serious form of attack because one never knew when one would lose metal because it had been attacked round the grains. The appearance of the inside of the tube was quite different from what it was in most other cases of attack. There was often a continuous layer of sulphide-containing material, covered with an oxidized layer. It was an intensely black oxide.

Similarly, he had recently come across a case where cupro-nickel had been used in marine service without the standard fortification with iron. Pitting had occurred underneath the deposit of an extremely fine silt. That was a case where the material would have stood up reasonably well with the correct iron fortification.

DR. J. E. RICHARDS, B.Sc., Wh.Sc. (Associate Member) referred to the cathodic protection of condenser tubes by means of steel blocks. He pointed out that some recent work at the Water Pollution Research Laboratory had shown that some cupro-alloys became electronegative to steel, when immersed in water with a high sulphide concentration. Could such a reversal of polarity possibly occur in an estuary in summer and might this cause excessive corrosion of the condenser tubes?

Secondly, to what extent could the conclusions reached as a result of research on condenser tubes be applied to other components, such as propellers, which were subject to the flow of salt water over their surfaces?

COM'R(E) F. ROBERTS, O.B.E., D.S.C., R.N.(ret.) (Member) said that as a marine engineer who had sometimes had to look for leaks in condensers, often in harassing circumstances, he greatly appreciated what had been done to improve condenser tube materials.

Possible damage to condenser tubes due to cleaning them with wire brushes in order to remove obstructions had been mentioned by several speakers. Had any of them used a water jet? In his experience, it was quite effective in removing obstructions. Where the tube was badly blocked, a cane, not a brush, would usually force the obstruction through without damage.

MR. R. J. ANDERSON (Associate) regretted that neither the author in his admirable paper nor any of the contributors to the discussion had taken note of a significant event that had occurred in this memorable year, 1953. He referred to the publication by the British Standards Institution of B.S.378.

He noted that Table I on page 2 of the paper referred to an A.S.T.M. specification and he thought that it was the first time he had heard this authority quoted at a meeting of the Institute of Marine Engineers. It was understandable to find equipment in oil-refineries being built in the United Kingdom entirely to A.S.T.M. specifications, because the modern petroleum refining industry owed almost everything to American development and practice. He made a plea, however, for the indigenous British industry of marine engineering to support and use the British specifications. It should be generally known that B.S.378 covered, for the first time, every known alloy which was generally acceptable for marine condenser and heat exchanger tube utilization.

MR. H. J. HETHERINGTON (Member) said that when he first went to sea over thirty years ago, it was well known that water in the Manchester Ship Canal was polluted and that all engineers flushed out with sea water. It seemed to be a simple remedy to overcome pollution. He had had practical experience of pollution in the Thames. He had fallen into Woolwich Reach about two years ago!

Correspondence

MR. H. C. BONES had studied the above paper with great interest and thought Dr. Gilbert was to be congratulated on having covered such an enormous subject so fully and yet so concisely. He felt, however, that if Dr. Gilbert, with his great knowledge of this subject, could be persuaded to prepare papers based on each section of the present one, such papers would be invaluable. He offered this as a suggestion.

He found the paper so factual that there was little left to question or discuss; certainly there was nothing, in his experience, which could be disputed. In most of the sections he found references to, and details of, troubles which it had been his misfortune to experience. Unfortunately, the paper arrived five years too late!

In reading the paper one could not help wondering why, with all the hazards involved, engineers continued to use condenser tubes, and certainly it confirmed opinions of most engineers that the perfect tube had yet to be made, despite the tremendous strides which had been made and of which the British Non-Ferrous Metals Research Association could be justly proud.

He was particularly interested in the section devoted to the adverse effect of polluted water on aluminium brass condenser tubes. He could not more readily agree with Dr. Gilbert as to the destructive nature of a polluted estuary water. Bitter experiences of the past four years in the generating station with which he was associated confirmed the hazards, mentioned by Dr. Gilbert, which arose from using a polluted cooling water supply. In his case, two 45 M.W. turbo-generator condensers had to be retubed after 6-8 months' service, and involved the replacement of 22,000 18ft. 1in.-diameter aluminium brass condenser tubes with cupronickel.

Although not the perfect answer, cupronickel tubes had been proved to be far superior to aluminium brass when used in contact with the circulating water at this station. The water was virtually sea water contaminated with an untreated sewage farm effluent. It was sulphide bearing and often completely anærobic.

He wished to ask Dr. Gilbert if he would express an opinion as to the best method of selecting a tube alloy for a particular installation. In his case and in his experience, the normal inorganic water analysis and, indeed, the usual and well known jet impingement test was proved to be by no means infallible, since aluminium brass was recommended based on such tests taken prior to installation. Both test methods failed to detect the most insidious cause of tube failure, namely, sulphate-reducing bacteria and associated complex sulphur compounds. Evidence of such a potential source of trouble might, in fact, be destroyed by the simple procedure of taking a water sample due to the aeration of the water in the process of filling the bottle or carboy.

Dr. Gilbert mentioned impingement attack from air bubbles above a certain size. Could he give the size above which danger arose? With regard to operating conditions in which condensers were allowed to remain idle and full of polluted water, he would go further and recommend that not only was it desirable to empty the condensers, but that they should, wherever possible, be washed out with a fresh water hose. Time and trouble expended in this way was amply repaid.

He noted that Dr. Gilbert did not mention the use of plastic tube end inserts in cases where sand erosion occurred, and he would be glad if he would express an opinion as to the value of such inserts. The section devoted to protector blocks was of particular interest to him, especially the use of magnesium for this purpose.

He noted that although protector blocks were certain to be effective when they were in a satisfactory condition to function, there was a potential danger when they became exhausted. Since it was often impracticable to inspect at frequent intervals, he would like to ask Dr. Gilbert if he knew of any external indicator which would give warning when the danger point was being reached. Also, were steel blocks better than the cast iron of the water boxes themselves in providing protection and would such blocks be attacked preferentially. Further, he would like an opinion as to whether a combination of painting and protector blocks would be satisfactory and, if so, whether any economy in protector blocks would result.

Insofar as zinc blocks were concerned for this purpose, his experience with aluminium brass tubes confirmed the undesirable nature of zinc salts in condensers. In both cases mentioned earlier, where aluminium brass tubes failed after a very short life, the associated tube plates were very severely attacked, whereas those on the condenser fitted with cupronickel tubes were relatively free from corrosion. Drainage of zinc salts from the aluminium brass tubes was considered to be the cause of the more pronounced tube plate corrosion.

During the past five years he had tried various paints for water box protection and had reached the conclusion that the normal bituminous types were of little use in his case. The most satisfactory paint so far tried was "Rustodian", a calcium plumbate based paint manufactured by the Associated Lead Manufacturers, Ltd. In applying protective paint coating, however, in cases where the water was aggressive, it was dangerous to paint the cast iron work only. Both water box and tube plate should be painted.

The danger of tube losses arising from tube end stoppages was also very real. Practically every cupronickel tube failure in his station during the past three years had been due to this cause. Apart from adequate water screening, and even then some pieces seemed to get through, the only cure was frequent "tube end picking".

This paper, generally speaking, pointed to two alloys as being the most successful, aluminium brass and cupronickel, but with discretion being necessary before using the former. With this he fully agreed and would like to add that he had confirmed that it was possible to build up a protective film on aluminium brass with good water conditions early in its life, so that it would withstand a bad water condition later.

Finally, he would recommend Dr. Gilbert's summary as a basis for use in deciding which alloy to use when planning an installation, but would suggest one addition—"When in doubt use cupronickel"!

MR. R. W. CROMARTY (Member of Council) had listened with interest to Dr. Gilbert's paper and the subsequent discussion and wished to congratulate him on the excellence of both.

The paper brought back sea-going memories of condenser "drill" in the Red Sea in the early 1920's. Thinking back, it seemed to him that most of their "drills" took place in the tropics; rarely did they have them on the outward passage from the United Kingdom. Several speakers who took part in the discussion mentioned "clean sea water" and excess phosphorus in tube material was mentioned also as a cause of condenser trouble. The "clean sea water" in the Indian Ocean contained phosphorus; it made a beautiful spectacle seen from the deck of a ship at night.

Could Dr. Gilbert give his opinion as to whether this phosphorus might have been a cause of their condenser drills in the 1920's and might it be a contributor to the troubles still experienced?

MR. F. L. LAQUE regarded the paper as a welcome addition to the series of valuable contributions to our knowledge of the behaviour of condenser tube compositions that had come from Dr. Gilbert and his associates in the laboratories of the British Non-Ferrous Metals Research Association. His company had had the benefit of frequent contact with their work during the past several years and had undertaken both parallel and co-operative research in the same field. It was not surprising, therefore, that they found themselves in substantial agreement with most of Dr. Gilbert's conclusions. There were, however, a few points on which their views were either somewhat different or which might benefit from some amplification. These would be dealt with in turn.

It was indeed surprising that the commercial use of the iron modified 90/10 cupro-nickel alloy had progressed so much more rapidly* in the U.S.A. than in the United Kingdom, where much of the early research on these alloys was undertaken. The development in the U.S.A. was stimulated, of course, by governmental regulations to conserve nickel. However, this alloy had progressed considerably on its merits. In this connexion, it was significant that the first large scale commercial production was a lot of tubes for a power plant condenser for which this alloy was chosen because some experimental tubes that had been installed in the unit for test had outperformed Admiralty brass, aluminium brass and an aluminium bronze and had equalled the performance of the more costly iron modified 70/30 cupro-nickel. This first installation required about 40 tons of 90/10 tubing and represented a rather bold step in the application of a new alloy. It was gratifying, therefore, to be able to report that these 90/10 tubes had given excellent service and remained in use after some six years when the Admiralty tubes that they replaced were showing signs of distress in one to two years. They felt, therefore, that this alloy deserved a place on its merits in the list of condenser tube alloys, quite apart from any considerations of nickel conservation. For example, it had done very well in certain highly polluted waters where it had demonstrated a superiority over other compositions, including cupro-nickels of higher nickel content.

As made in the U.S.A., the 90/10 cupro-nickel alloy originally contained either about 0·8 per cent or 1·5 per cent iron, depending on the manufacturer, rather than 2 per cent iron suggested by the B.N.F.M.R.A. Concurrently, the range was from 1·0 to 1·75 per cent in line with the applicable U.S. Navy specification. The optimum iron content probably varied with the conditions of use. In the mill annealed condition, resistance to impingement attack increased with iron content up to about 1·5 per cent. To secure much advantage from more iron required that the alloy be quenched so as to retain a maximum amount of iron in solution. However, where pitting, such as might occur in sulphide polluted waters, was the principal factor, the alloys that contained iron at the lower end of the range, e.g. 0·7 to 1 per cent, had shown a higher resistance to pitting attack. Perhaps 1·25 per cent would represent a desirable level of iron for all-round performance when the actual requirements of the service were not known in advance. Detailed information on some of the metallurgical characteristics of the alloys and their behaviour in salt waters under several conditions of exposure might be found in some U.S. papers(1, 2, 3).

In several investigations of impingement attack, using various kinds of apparatus, including jet test machines which duplicated those employed by Dr. Gilbert and his associates, they had failed to demonstrate any considerable effect of air bubbles of any size. About as much attack occurred when no air bubbles were present as when they were admitted. In their laboratories located on the sea coast, there was an ample supply of sea water so that it did not have to be recirculated through the apparatus but passed through only once. Evidently this represented more vigorous testing conditions, especially with respect to the more resistant materials such as aluminium brass. This alloy did not demonstrate its expected advantage over Admiralty brass when tested under the standard jet test conditions (e.g. 15 f.p.s. jet velocity). They were convinced that if the degree of turbulence was high enough, all of the common condenser tube alloys could suffer impingement attack in the absence of air bubbles. They were also convinced that the results of the "standard" jet tests with air bubbles admitted as carried out by Dr. Gilbert and his associates were reliable in providing a qualitative rating of the several common alloys with respect to their resistance to impingement attack in service. At the same time, one must not conclude that elimination of air bubbles would serve of itself to avoid impingement attack in all or even most practical cases.

While they had not gone as far as they hoped to in studying the effects of vibration on corrosion, they had been very much impressed by the apparent ease with which severe damage could result from high frequency vibrations of small amplitude. This reached a peak, of course, in the laboratory techniques for producing cavitation erosion damage by magnetostrictive devices for generating vibration at high frequency. In practice, this was suspected as being a factor in the cavitation erosion of propellers and of the liners of Diesel engine cylinders(4). It was easy to see how vibrations could interfere with the formation of protective films or destroy them once they had formed. This was obviously something that should be kept in mind when exploring the causes of unusual failures of tubes in service.

It was too bad that they did not have more precise data on the effects of iron corrosion products in enhancing the protective qualities of the films that formed on aluminium brass and cupro-nickels in salt water. The inference from the available information was that the principal virtue of iron protector blocks was their contribution of iron corrosion products rather than any protective action of the galvanic currents that they generated. They should also know for sure that the corrosion products of zinc actually had a detrimental effect on protective films and whether magnesium corrosion products acted in a similar fashion. More precise answers to these questions were required before they could reach any final conclusion as to the desirability of installing zinc or magnesium protectors.

While there seemed to be evidence of a practical nature that iron compounds in the water were helpful to aluminium brass and cupro-nickel and that zinc compounds were detrimental to aluminium brass, they had had successes with both zinc and magnesium in improving the performance of cupro-nickel heat exchangers of the flat tube type when the salt water circulated outside the tubes. Therefore, they could not support Dr. Gilbert's recommendation that zinc slabs should in no circumstances be used in water boxes.

In their work with zinc as a galvanic anode, they had not only found that the zinc should be of extra high purity, 99·99

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* By the end of 1951 the production in the U.S.A. had amounted to over 2,500,000lb., practically all in the form of tubes, most of which were used in contact with salt water in condensers and heat exchangers.

per cent minimum zinc, but that the iron content should be especially restricted to a maximum of 0·0015 per cent.

Caution must be exercised in attempts to protect steel or iron water boxes by means of coatings. If such coatings did not in the first place completely cover the exposed surface, or if they developed discontinuities in use, their effect would be to concentrate the galvanic action in small areas where severe pitting would occur. This could be prevented by the use of auxiliary magnesium, zinc or iron anodes. Perhaps iron would be the best, especially where aluminium brass tubes were installed in view of the possible detrimental secondary effects of zinc or magnesium compounds and the beneficial secondary effects of iron corrosion products.

By very careful engineering and maintenance, it might be possible to install zinc or magnesium protectors in iron water boxes so as to hold corrosion of the iron within tolerable limits while still permitting enough corrosion to occur to provide the iron compounds needed by the tubes to form the desired protective films.

It was evident that more research was required to answer the questions that had been raised concerning the desirability of zinc and magnesium for protecting water boxes and tube ends. It was also evident that casual installations without careful attention to design and maintenance were likely to be ineffective and in extreme cases might do more harm than good.

He agreed that there was no simple answer to the choice of condenser tubes for use in polluted waters, largely because the kinds and degrees of pollution covered such a wide range and their effects were superimposed on the more common causes of tube damage, such as impingement attack and deposit attack. Apparently, the iron modified cupro-nickels were best able to cope with these several factors and were most likely to survive where pollution effects were severe. The best procedure for choosing an alloy to handle a particular polluted water was to install trial lots of promising materials and observe their performance over an extended period. For the main installation, while such trials were in progress the cupro-nickel alloys were most likely to prove suitable.

He could emphasize the importance of the corrosion products formed during the early life of tubes, especially the difference between those that developed in sulphide polluted waters as compared with clean sea water. This was illustrated by some tests in which specimens were exposed for several months in a power plant intake system where the water was badly polluted with organic waste so that these specimens acquired black sulphide films. These specimens were suspended in containers of the same water so as to preserve the films and shipped to their test station, where the sea water was free from pollution. There, these specimens were subjected to jet impingement tests in comparison with companion specimens of the same materials that had been reserved for the purpose. There was a great difference in the attack on the two groups of specimens, especially in the case of aluminium brass, where, in an extreme case, specimens 0·031 inch thick previously exposed in polluted waters were perforated in a subsequent thirty-day jet test in clean sea water. It was evident that the harmful effects of sulphide pollution might continue to aggravate impingement attack even after the pollution had been removed or in the case of a ship after it had moved into clean water. In the tests described, the cupro-nickels were less sensitive to the effects of the prior exposure to polluted water—the depth of impingement attack of 70/30 cupro-nickel specimens previously in contact with the polluted water was only 0·005 inch.

While it undoubtedly provided a convenient basis for comparison or choice, the assignment of critical or maximum tolerable velocities to the several alloys represented over-simplification of the problem. This was especially the case when an effort was made to translate the apparent jet velocity in an impingement test into equivalent average velocities of flow through the tubes in a condenser. For example, as mentioned previously, the effect of a certain jet test velocity with recirculated water was much less than that with once-through water at the same test velocity. Thus, while it was convenient to describe impingement tests by reference to the velocity of the jet in feet per second, it did not follow that these numbers had any direct relation to the rate of flow of water through condenser tubes which were also expressed in feet per second.

The relative responses of different alloys to changes in jet velocity in tests did provide a basis for rating the alloys qualitatively with respect to their probable resistance to impingement attack in service. In his company's experience with the behaviour of tubes in experimental and full size condensers as well as salt water pipe lines, they had observed a considerable superiority of both 70/30 and 90/10 cupro-nickel tubes over aluminium brass tubes, where the calculated rate of flow was as low as 10 f.p.s. Thus, they were inclined to suggest that the cupro-nickels deserved special consideration even for unpolluted waters when the nominal velocity exceeded 7 f.p.s. rather than the 9 f.p.s. figure suggested by Dr. Gilbert.

In the course of studies of chlorination of sea water to suppress growth of slimes and macro fouling organisms, they had observed incidental effects of the treatment on corrosion of some condenser tube compositions. These observations might be summarized as follows:—

1. For the control of macro fouling organisms, e.g. mussels and barnacles, continuous chlorination, e.g. 0·5 p.p.m. residual had been more effective than intermittent treatment at higher concentrations in various cycles.
2. The corrosion of Admiralty brass was likely to be accelerated by chlorination in the concentrations required for the effective control of fouling.
3. The corrosion of iron modified cupro-nickels and aluminium brass was not likely to be accelerated by effective chlorination treatments.

(1). Tracy, A. W., and Hungerford, R.L. 1945. "The Effect of Iron Content of Cupro-Nickel on Its Corrosion Resistance in Sea Water". Proc.Amer.Soc.Test.Mat., Vol. 45, pp. 591-613.

(2). Palmer, E. W., and Wilson, F. H. "Constitution and Properties of Some Iron Bearing Cupro-Nickels". Journal of Metals, January 1952, p. 55.

(3). Stewart, W. C., and LaQue, F. L. 1952. "Corrosion Resisting Characteristics of Iron Modified 90:10 Cupro-Nickel Alloy". Corrosion, Vol. 8, No. 8, pp. 259-277.

(4). Speller, F. N., and LaQue, F. L. 1950. "Water Side Deterioration of Diesel Engine Cylinder Liners". Corrosion, Vol. 6, No. 7, pp. 209-215.

Mr. B. Todd, M.Eng., was particularly interested in the statement occurring at the end of the second paragraph in the section on "Protector Blocks", which stated that chalky cathodic deposits were not protective. In view of the trouble taken to produce such coatings on certain structures, e.g. offshore oil drilling platforms,* in order to protect them from corrosion, he thought the author's statement required elucidation.

The answer to the difference between the author's statement and the generally held belief that cathodic deposits were protective might lie in an explanation of the type of corrosion which he claimed occurred in condenser tubes in way of these deposits. Was it, for instance, a type of deposit attack set up by the coating being porous a short distance from the end of the tube, where the current density was less?

Finally, he would like to ask the author whether iron salts in the cooling water were beneficial when the alloy itself contained iron.

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* Doremus, G. L. 1950. "Corrosion", Vol. 6, p. 164.

Author's Reply

The author said he would like to thank the contributors to the discussion for their kind remarks about the paper. Whatever its merits, he felt that the preparation of the paper had been amply justified by the comprehensive and valuable discussion which it had provoked. Mr. Sherborne was to be thanked for preparing and recording details of some of the earlier history of condenser tube performance, which illustrated the magnitude of the problem, and in the light of which the great progress that had been made became very clear. He had performed a service in drawing attention in such a vivid way to the vital importance of the formation of protective films on condenser tube alloys, and his remarks on the pollution of harbours and estuaries added force to points which had been made in the paper.

He greatly welcomed Professor Hutton's contribution, and his presence at the meeting was particularly gratifying in view of the leading part he played in the development of the aluminium brass condenser tube which had had such outstanding success. The main difficulty associated with a pretreatment, such as selective oxidation, was that there would be a serious risk of accidental damage to the protective film before or during installation. Severe localized attack might occur at such points of damage during service. A safer procedure would be to pretreat the tubes after assembly of the condenser, and if new condensers could always be filled initially with clean sea water, considerable advantages would probably accrue. In this connexion, the earlier results obtained by May, mentioned by Professor Hutton, had by no means been forgotten. Laboratory impingement tests had confirmed that the corrosion resistance was considerably improved by the treatments described, but had shown that even such treated specimens could be severely corroded when the sea water contained hydrogen sulphide.

Commander Sidgwick and others emphasized the difficulties of avoiding polluted waters in the early life of a ship, particularly during fitting out. He well appreciated these difficulties but, nevertheless, unless some steps were taken it was quite possible that condenser tube corrosion troubles would again assume serious proportions in the near future. Draining of the main condensers when not in use was not, in itself, sufficient, for, as Commander Sidgwick pointed out, water would remain in some tubes, and tubes partly full of polluted water were liable to corrode at least as rapidly as those completely full of polluted water. It was necessary, therefore, to flush out with fresh water after draining, a point emphasized in Mr. Bones's contribution.

He had consulted Mr. May with regard to the points raised by Commander Sidgwick on impingement attack and the conditions of flow in tubes. Mr. May commented as follows: —

"Commander Sidgwick is quite correct in suggesting that the flow pattern which he quoted would not produce impingement, nor in fact would it be expected to produce impingement attack unless it were disturbed, and then, of course, the flow pattern would be different. Disturbances of the ideal flow pattern can occur at the inlet, which is the usual site of impingement attack; at partial obstructions; or by a small particle adhering to the tube wall and projecting through the laminar boundary layer. The local increased turbulence associated with these seems to produce a repeated local and momentary breakdown of the laminar boundary layer with a corresponding impingement of more rapidly moving water, and the flattening and breaking of any air bubbles against the tube wall. It has been realized for a long time that nominal water speed is not the determining factor in impingement attack, but it does give an indication of the maximum turbulence and intensity of impingement which can arise if the ideal conditions of flow are disturbed. It is perhaps significant that a given material capable of undergoing impingement attack, exposed to disturbed conditions of flow for a given time, at a given nominal water speed, is corroded to about the same depth, whether in the form of a 2-in. diameter pipe, a ⅝-in. condenser tube, a flat strip inside a ¼-in. glass tube, or as a small specimen exposed to a 2-mm. diameter jet".

The difficulties of controlling the growth of shellfish and other marine organisms in condenser tubes were referred to by Mr. Cotton, who suggested that portable dockside chlorination units might be feasible. Another possibility, suggested by Mr. Younger, was the generation of chlorine *in situ* by electrolysis of sea water. This method had received consideration, but as indicated in the contribution by Mr. Kenworthy, other methods might be preferable. Some useful observations on the effects of chlorination were included in the contribution by Mr. LaQue. Mr. Kenworthy emphasized that chlorination would be useful for the prevention of fouling in condensers as distinct from its removal. Similarly, with scales and deposits which interfered with heat transfer, chlorination was usually found to keep clean tubes clean, but to be ineffective in cleaning dirty tubes. Mr. Younger's statement that chlorination had cleared the tubes in a condenser which fouled very rapidly was, therefore, surprising.

To remove fouling or other deposits it was usually necessary to clean mechanically or with acid. Several speakers asked whether acid cleaning was harmful when carried out in the usual way with hydrochloric acid of about 5 per cent strength with inhibitor added to prevent corrosion of ferrous parts. This question was answered by Mr. Kenworthy, who said that the use of acid cleaning in H.M. ships had led to no trouble. He believed it was general experience that acid cleaning properly carried out was perfectly safe. Protective films would normally quickly re-form after acid cleaning, but trouble could arise, of course, if polluted waters were encountered immediately after cleaning.

Several speakers referred to mechanical cleaning, and he agreed with Mr. Kenworthy that this was an occasional source of trouble. Cleaning carried out with bristle brushes, or with a water jet as mentioned by Commander Roberts, or removal of obstructions with canes, was almost always beneficial, but the use of stiff wire brushes or other over-vigorous methods was undesirable owing to damage to the protective film, which could lead to localized corrosion if the subsequent conditions of exposure were unfavourable. The answer to Mr. Younger was probably that it was better to remove a protective film completely as by acid cleaning, than to damage it locally by inappropriate mechanical cleaning methods.

He had emphasized in the paper the point made by Mr.

Cotton that protector blocks only provided protection to the extreme ends of the tubes. It was of considerable interest to learn from Mr. Wilkinson that tube ends could be rapidly attacked despite the presence of active zinc protector blocks. Although in the cases he mentioned the corrosion was initiated by mechanical damage, its continuance as impingement attack was undoubtedly electrochemical in nature, and it should, therefore, have been possible to stop it by cathodic protection. It was only possible to conclude that the zinc blocks were not active enough. Something even more active, such as magnesium, might have prevented the corrosion. He was unable to agree with Mr. Wilkinson that magnesium anodes should never be used in water boxes; he had seen convincing evidence in Canada and the U.S.A. of their effectiveness in preventing corrosion of water boxes and tube plates and as yet he had seen no evidence that they had detrimental effects on condenser tubes. He was glad to have confirmation from Mr. Wilkinson that substitution of zinc blocks by iron blocks had in a number of cases eliminated condenser tube corrosion.

He was particularly glad to have the valuable contribution from Mr. LaQue, with whom he had been in close touch on marine corrosion matters for some time. His contribution indicated that there was much yet to be learned about the effects of protector blocks, and that they could not yet tell Mr. Wilkinson why iron corrosion products were beneficial and zinc products detrimental. He thought it was true that zinc products were more harmful to aluminium brass than to cupronickel, but in view of the doubts about zinc they had preferred to recommend its complete avoidance. For naval applications and other cases where non-ferrous water boxes were used, steel protector blocks provided cathodic protection to the tube plate and tube ends and were also a source of beneficial iron corrosion products. The question of protector blocks of other materials need only arise when steel or cast iron water boxes were used, and in this case the primary purpose of the blocks was to protect the water box. For this purpose he considered that magnesium was preferable; the chief disadvantage was, of course, that the water box was no longer a source of iron corrosion products beneficial to the condenser tubes. This might not matter if the cooling water passing through the condenser contained sufficient iron corrosion products from elsewhere in the system; if not, it might be possible to arrange for a controlled amount of corrosion of the water box, as suggested by Mr. LaQue, but he feared this might be very difficult in practice. In reply to Mr. Bones, he did not think steel blocks would give any substantial amount of protection to a cast iron water box.

Mr. LaQue and Mr. Bones pointed out that difficulties arose in protecting water boxes by coatings. Both suggested that a combination of protective coating with sacrificial anode might give good results, and this method was attractive since the rate of consumption of anodes should be considerably reduced. It might not be easy to apply in practice, however, and considerable care would have to be taken in control of current density and choice of paint coating, otherwise paint stripping would occur. Mr. Bones asked whether an external indicator could be devised to show whether protector blocks were working efficiently. This should be feasible, and one possibility would be to install a silver/silver chloride reference electrode in the water box with an insulating lead coming through the box so that the potential of the water box could be measured. If this potential were sufficiently depressed, no corrosion could proceed, but if at any time it rose above the critical value, protection would be incomplete.

The point raised by Mr. Todd was an interesting one and, he believed, the discrepancy lay in different interpretations of the term "protective". A chalky cathodic deposit would be protective in the sense that it covered much of the metal surface and greatly reduced the current required to protect the metal cathodically. Such a deposit might, however, be insufficiently protective to prevent corrosion if cathodic protection ceased. Thus, in the event of protector blocks in a water box becoming inoperative, the cathodic deposit on the inlet ends of the tubes might not prevent impingement attack, or some other form of corrosion, from starting.

With regard to intercrystalline corrosion of brasses, there was a considerable amount of evidence, as Mr. Wilkinson pointed out, to show that if the arsenic content was too high there was a serious increase in susceptibility to intercrystalline attack. For this reason the upper limit of arsenic content was set at 0·06 per cent in various British Standards. The brass shown in Fig. 2 of his paper complied with standard in this respect, having an arsenic content of 0·03 per cent. The only unusual feature of the composition was the presence of 0·05 per cent phosphorus, and it was possible that this might have contributed to an unusual susceptibility to intercrystalline attack.

A number of interesting points were raised in Mr. Younger's contribution. With regard to the iron content of cupronickels, it was true that B.S. 378 required an iron content in 70/30 cupronickel of 0·4-1·0 per cent. In this country the material was usually supplied with about 0·8 per cent iron (in the U.S.A. usually about 0·5 per cent) and this was adequate for all normal purposes. For special cases, such as resistance to sand erosion, the iron content could be increased to as much as 2 per cent with advantage, and as this, as far as he knew, did not have any serious practical disadvantage, he agreed there was a case for raising the maximum iron content in the specification to 2 per cent. For the 90/10 cupronickel, more iron was usually needed for maximum corrosion resistance than in the 70/30 cupronickel. Tubes of the 90/10 alloy were supplied in the U.S.A. with iron contents ranging from about 0·75 to 1·75 per cent, and in this country the alloy was supplied with up to 2 per cent iron.

He agreed with Mr. Younger and Mr. Kenworthy that the statistics quoted concerning the failures examined by the B.N.F.M.R.A. must be interpreted with caution and must be related to (a) the total numbers of tubes of various materials in service and (b) the particular selection of service failures that had been submitted to the Association. In this connexion, the relatively high proportion of failures of aluminium brass tubes probably reflected mainly the very large amount of this material in service rather than any particular unreliability in the material. Similarly, the relatively high proportion of failures in naval ships was probably due to the fact that the Association investigated a much higher proportion of the failures that occurred in naval service than in other services.

The case, mentioned by Mr. Younger, of a Thames-side power station where 70/30 cupronickel was giving good service was an interesting one. It was true that his examination of tubes after several years' service led him to conclude that if conditions did not change materially, the life of the tubes would be of the order of twenty-five years. This was probably due mainly to two factors. First, the station in question was situated at a point where the degree of pollution was much less severe than in some parts of the Thames. Hydrogen sulphide was occasionally detectable but was not normally present. Secondly, a frequent and regular cleaning of the tubes with bristle brushes was carried out at this station and this tended to discourage pitting and led to comparatively uniform corrosion, which was much less dangerous. He agreed with Mr. Younger that where ferrules are used they should always be of aluminium brass or cupronickel rather than Admiralty brass or naval brass.

Mr. Latimer had stressed that the 90/10 cupronickel alloy could only be recommended as a substitute for 70/30 cupronickel after adequate service trials. In this connexion, the remarks of Mr. LaQue were of great interest and the data he provided appeared to confirm without doubt that the 90/10 cupronickel was a useful condenser tube alloy. Experience indicated that its behaviour in polluted waters was variable (as indeed, was that of all other condenser-tube alloys) and, as Mr. LaQue pointed out, the optimum iron content appeared to vary with the exposure conditions.

He was very grateful to Dr. Evans for his contribution, in which he had illustrated several important principles of the science of metallic corrosion in his usual lucid way. He agreed with Dr. Evans that in many cases the pitting of condenser tubes was due to attack at small anodic points in large film-covered cathodic surfaces. This was probably particularly true of service in polluted waters; investigations were in progress at the Association on the very complicated processes occurring when condenser tube alloys corroded in polluted seawater.

It was good to learn from Mr. McClimont that the British Shipbuilding Research Association had in hand investigations of the effects of films and scales on rates of heat transfer. More data on such matters were badly needed and the results of the work would be awaited with much interest. He had studied the interesting results obtained by the Water Pollution Research Laboratory mentioned by Dr. Richards, which showed that some copper alloys could become anodic to steel in water containing sulphides. He believed that in the particular experiments in question, brasses did not become anodic to steel, and cupronickels were not tested. There was thus no evidence that a steel water box could become cathodic to the condenser tubes. Even if it did, only the extreme ends of the tubes would be affected. He considered it unlikely that this was a cause of condenser tube corrosion. Certain general principles which applied to condenser tube corrosion would apply also to the corrosion of components such as propellers, but there would, of course, be many different features. In particular, the speed of the seawater past a propeller was in general much greater than the speed of flow along a condenser tube.

British Standard 378:1953 dealt with condenser tubes of copper, 70/30 brass, 70/29/1 (Admiralty) brass, aluminium brass, 70/30 cupronickel, and 7 per cent aluminium bronze. Mr. Anderson was, therefore, hardly correct in saying that it covered every known alloy generally acceptable for marine condensers and heat exchangers. Amongst the alloys not specified in B.S. 378 was the 90/10 cupronickel, and no British specification at present existed for this alloy, as stated in Table I of the paper, even though it was developed in this country. It was not inappropriate to quote an A.S.T.M. specification for the material in view of its widespread use in the U.S.A., as stated by Mr. LaQue. The data for most of the alloys in Table I were taken from B.S. 378.

He sympathized with Mr. Bones, whose experience of condenser tube behaviour had been far from happy, and who had had particularly bad trouble with aluminium brass in polluted waters. It was of interest to note that at least one instance could be quoted where aluminium brass was used in the condensers of a power station where the cooling water was extremely badly polluted, and the performance had been at least as good as that of any other condenser tube material, including cupronickels. In general, however, he agreed that 70/30 cupronickel was the safest choice when pollution of the water was suspected, as he had said in the paper. It was Mr. LaQue's view also that iron-modified cupronickels were best able, in general, to cope with contaminated waters, though he suspected Mr. LaQue included both the 10 per cent nickel and the 30 per cent nickel alloys, whereas when Mr. Bones said, "When in doubt, use cupronickel", he meant 70/30 cupronickel.

The question of the selection of the most suitable alloy for use in a polluted water was, as Mr. LaQue indicated, far from simple. He agreed with him that the best procedure was to carry out trials in the condenser in question. It would probably be unwise to use anything but cupronickel for the main installation while such trials were being conducted. It was essential, as Mr. Bones pointed out, for proper sampling techniques to be used in taking water samples which were to be analysed for dissolved oxygen, hydrogen sulphide, etc. Mr. LaQue had shown that alloys initially exposed to polluted waters might subsequently corrode abnormally rapidly in clean water, especially in the case of aluminium brass. Mr. Bones had shown that aluminium brass initially exposed in good conditions might subsequently be able to withstand bad conditions. Both observations were of the greatest significance, and on such evidence he had based the recommendation that polluted waters should at all costs be avoided during the early life of a condenser.

For a given alloy under a given set of conditions there would be a water speed, in the absence of air bubbles, below which no impingement attack would occur. If air bubbles were present, attack might occur at much lower water speeds. It was thought that bubbles would only have this effect if they were large enough to break when they hit the tube wall, since bubbles which impinge without breaking were much less liable to damage the protective film. The minimum size of bubble which would break against a tube wall would clearly depend on a number of factors, and it was, therefore, difficult to answer Mr. Bones's question. Under some conditions, bubbles of diameter less than 1 mm. might certainly be harmful.

Mr. Bones was right to draw attention to the use of plastic inserts to counter severe inlet end attack. When sand erosion was severe, some attack might occur at the inlet even with such resistant materials as high-tin bronze or 70/30 cupronickel containing 2 per cent iron. If plastic inserts were used, the tube end was protected but attack might occur instead at the end of the insert. Such attack was usually rather less intense, however, and an increased life was therefore obtained. If it could be arranged to start with inserts 3 inches long, replaced after a suitable period with 4-in. inserts, continuing to increase the length of the inserts up to, say, 6 or 9 inches, it would probably be possible to obtain lives of twenty-five or thirty years even in very adverse conditions.

In reply to Mr. Cromarty, he understood that the phosphorescence sometimes seen at sea was due to the presence of small marine organisms which emitted light, and not to phosphorus. Whether such organisms would affect condenser tubes he would hesitate to say, but they could possibly cause trouble in two ways. First, passage of suspended matter through condenser tubes might damage a protective film or hinder its formation. Secondly, a slime containing marine organisms might be deposited on tubes and this might subsequently decompose, giving products which caused local corrosion.

He had already discussed many of the points raised in Mr. LaQue's contribution. As already stated, he agreed that if the degree of turbulence was high enough, all common condenser tube alloys suffered impingement attack in the absence of air bubbles. The question of testing in the laboratory using the jet impingement apparatus was a complicated one, particularly in regard to the effects of recirculation of the water as opposed to passing it once through, and to the effects of adding air bubbles. These matters had been discussed in some detail in a paper which Mr. LaQue and the author had prepared jointly and which, it was hoped, would be published in the near future. With regard to the maximum normal water speed which aluminium brass would withstand, there was practical experience to indicate that it could be satisfactory up to at least 9ft. per sec. For unpolluted waters, he could see no necessity to limit the permissible water speed to 7ft. per sec. as suggested by Mr. LaQue. In polluted waters, of course, corrosion might occur at any nominal water speed.

Sir Gilmour Jenkins, K.C.B., K.B.E., M.C., and Lady Jenkins, Mr. and Mrs. Stewart Hogg

Lady Jenkins, Mr. R. K. Craig, Mrs. Sharp, Mr. Hogg, Mr. A. J. Sharp, Mrs. Jenkins, Mr. A. J. K. Jenkins, Sir Gilmour Jenkins, Mrs. Hogg, Mr. A. Robertson, C.C.

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Mr. Hogg, Mr. H. White, Sir Gilmour Jenkins

Mrs. Clarke, Mr. T. F. Clarke, Mrs. Hogg, and Mr. Robertson

Annual Conversazione, 1953

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Institute on Tuesday, 10th November 1953

An Ordinary Meeting was held at the Institute on Tuesday, 10th November 1953, at 5.30 p.m., when a paper by Mr. P. T. Gilbert, Ph.D., A.R.I.C., A.I.M., entitled "The Resistance to Failure of Condenser and Heat Exchanger Tubes in Marine Service" was presented and discussed. Mr. Stewart Hogg (Chairman of Council) was in the Chair. Eighty members and visitors were present and fifteen speakers took part in the discussion. A vote of thanks to the author proposed by the Chairman was enthusiastically endorsed. The meeting ended at 8.20 p.m.

Annual Conversazione

The Annual Conversazione was held at Grosvenor House on Friday, 4th December 1953. The President, Sir Gilmour Jenkins, K.C.B., K.B.E., M.C., and Lady Jenkins, received the 1,463 guests.

After dinner, Sydney Jerome's Ballroom Orchestra played for dancing until 1 a.m., and there were two interludes for cabaret when the guests were entertained by the Twelve Famous Sherman Fisher Girls with Jack Tripp, Wallace, Delyse and Jeanette, Ted and Flo Vallett, Ravic and Partner, and the Mathurins.

Local Sections

Kingston-upon-Hull and East Midlands

Junior Lecture

A lecture entitled "Stress Analysis using the Photo-elastic Method" was given by Dr. J. Ward, B.Sc. (Member) at the Kingston-upon-Hull Municipal Technical College on 3rd December 1953. The Chair was taken by the Vice-Chairman, Mr. J. G. Charlton, and the meeting was attended by one hundred senior and junior students and members of the Institute.

The speaker dealt with the construction of polariscopes and explained how the principal stresses and their directions could be obtained from the fringe pattern and the valuable data obtainable from boundary stresses. Numerous slides were shown, illustrating the method applied to determine stresses in gear teeth, keys, etc. At the end of the lecture an interesting discussion took place and numerous questions were asked.

During the evening Mr. F. C. M. Heath (Vice-President) presented the Institute of Marine Engineers' Prizes to Mr. Leslie Sharp, the best student of the year in the Heat Engines A.1 Course, and to Mr. Brian R. Sheppard (Student), the best first year student taking the Ordinary National Diploma Course in connexion with the alternative apprenticeship training scheme.

A vote of thanks to Dr. Ward was proposed and seconded respectively by a senior and junior student of the college, and carried unanimously.

Scottish

At a general meeting held on 9th December 1953, a very interesting paper on "Marine Lubrication" was read by Lieut. Com'r G. H. Clark, R.N.(ret.) (Member). In this paper, which was profusely illustrated with lantern slides, Com'r Clark dealt with the refining and testing of lubricating oils and, after a brief outline of the principles of lubrication, gave a comprehensive survey of lubrication problems of steam reciprocating engines, steam turbines and Diesel engines.

A short, lively discussion followed, then Mr. T. A. Crowe (Chairman of the Section) proposed a hearty vote of thanks to the author, which was accorded by the eighty members and visitors present.

South Wales

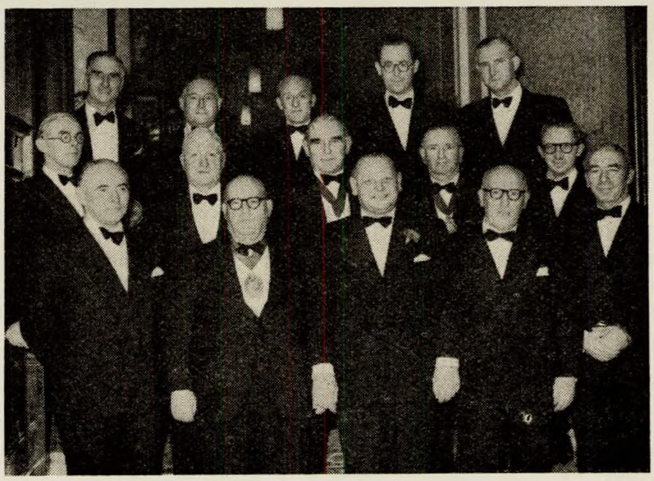
On Monday, 7th December 1953, at 7.0 p.m., the paper by J. Lamb, O.B.E. (Member) and R. M. Duggan, B.A.(Hons.) (Associate Member), on "The Operation of a Marine Gas Turbine under Sea Conditions", was presented (in the absence of Mr. Lamb) by Mr. Duggan and Mr. L. Birts, B.Sc. (Member). The meeting was held at the South Wales Institute of Engineers, Park Place, Cardiff; Mr. J. H. Evans, M.B.E. (Vice-Chairman of the Section) was in the Chair and the meeting was attended by ninety-four members and visitors.

During the discussion period, many questions were asked about this most unusual, new and interesting equipment, and these were answered by Mr. Duggan in a masterly manner.

Dinner

The Fifth Annual Dinner of the South Wales Section was held at the Royal Hotel, Cardiff, on Friday, 13th November 1953, there being 178 members and guests present.

The Chairman of the Section, Mr. J. E. Church (Member) was in the Chair, the Principal Guest was the Lord Mayor (City of Cardiff) and the following principal guests, Members



South Wales Section Annual Dinner

Back row: A. Logan, O.B.E., Eng'r Capt. G. B. Bailey, C. Tudball, J. Stuart Robinson, R. W. Cromarty.
Middle row: B. P. Ingamells, T. G. Thomas, A. M. C. Jenour, T.D., J.P., A. J. Jenkins, M.C., C. P. Harrison.
Front row: R. G. M. Street, Sir James Collins, J.P., J. E. Church, Stewart Hogg, David Skae.

of Council of the Institute, and principal Officers of the Section were present:—

Principal Guests

Councillor Sir James Collins, J.P., The Lord Mayor (City of Cardiff); A. Logan, O.B.E., Vice-President, London; A. Harvey, Ph.D., B.Sc., F.Inst.P., Principal, The City of Cardiff Technical College; A. M. C. Jenour, T.D., J.P., President, Cardiff Incorporated Chamber of Commerce; A. J. Jenkins, M.C., Chairman of Cardiff and Bristol Channel Shipowners' Association; R. G. M. Street, Managing Director of The South American Saint Line and President of the Industrial Association of Wales and Monmouthshire; C. Tudball, Past Chairman of the Cardiff Ship Brokers' Association; and Group Captain G. B. Bailey, O.B.E., D.F.C.

Members of Council

Stewart Hogg (Chairman); R. W. Cromarty; B. P. Ingamells; C. P. Harrison; and J. Stuart Robinson, M.A. (Secretary).

Principal Officers, South Wales Section

David Skae (Vice-President, Cardiff); J. E. Church (Section Chairman); J. H. Evans, M.B.E. (Section Vice-Chairman); and T. G. Thomas (Dinner Secretary).

The toast to The Queen was proposed by the Chairman. Then Mr. A. M. C. Jenour proposed The City and Port of Cardiff, and the Lord Mayor responded.

The Shipping Industry was proposed by Mr. A. J. Jenkins, and Mr. R. G. M. Street (Companion) responded.

Mr. Stewart Hogg proposed a toast to the South Wales Section of The Institute of Marine Engineers, to which Mr. John E. Church replied.

The arrangements for the Dinner were carried out most efficiently by Mr. T. G. Thomas, assisted by a small subcommittee comprising Mr. Skae, Mr. Church and Mr. G. Thomas (Honorary Treasurer). The growing popularity of the event was evidenced by the increased attendance of members and guests.

Local officials and members of the Institute, although regretting the inability of the President, Sir Gilmour Jenkins, K.C.B., K.B.E., M.C., to attend, nevertheless wished to thank Mr. Hogg and those other Members of Council already mentioned who attended and helped to make the evening such a success.

Southern Joint Branch I.N.A. and I.Mar.E.

Visit

By kind permission of the United States Lines, a party of 150 members and their ladies were entertained aboard the s.s. *United States* on Friday, 6th November 1953. Before being conducted round the ship, a film entitled "Building and Launching of the *United States*" was shown in the First Class Theatre, followed by a paper, read by Captain L. W. Akerman, R.D., R.N.R., M.I.N., "Some of the Safety Factors Incorporated in the s.s. *United States*". The Council of the Joint Branch regretted that a large number of members were disappointed by not being included in this visit; the applications were dealt with strictly in order of their receipt by the Honorary Secretary.

Meeting

A very successful meeting was held in the Polygon Hotel, Southampton, on Friday, 27th November 1953, when over 120 members and guests heard Mr. H. G. Yates, M.A., lecture on the work of Pametrada, of which he is chief designer.

Junior Section

Dinner and Dance

What has become the Junior Section Annual Dinner-Dance was held this year on Saturday, 19th December 1953, at the "Chez Auguste" Restaurant, Frith Street, when 128 members and their guests gathered together and had what really could be called a grand Christmas party.

This year's function was marked by a far greater attendance of junior members—about fifty per cent of those present—and the atmosphere was heightened by a few appearing in their new uniforms. They were very pleased to have the company of Mr. and Mrs. J. S. Robinson, and other members of the staff of the Institute. At the end of the Dinner, the Chairman, Mr. F. D. Clark, proposed a toast to the ladies and made one or two amusing comparisons between the marine engineer's interests afloat and ashore, which brought forth a very witty reply from Mrs. F. A. Everard.

Junior Section Dinner and Dance

Much hilarity was caused by the demands made by the Chairman for the privilege of winning a spot-prize and, although some extremely energetic dances were introduced, they were readily accepted and performed in true festive spirit. When hands were joined together for Auld Lang Syne just before midnight, it was unanimously agreed that this was one of the best Junior Section social functions which had been held, and that it must be repeated in the future.

Film Show

A meeting was held at the premises of Babcock and Wilcox, Ltd., Salisbury Square House, London, E.C.4, at 10.30 a.m. on the 12th December 1953. Eighty-three junior members attended, accompanied by Mr. J. McCaig (Member) and Mr. G. F. Gatward (Associate Member).

After an introductory address by Mr. R. E. Zoller (Member) and the distribution of preprints of his paper, "Babcock Marine

Boilers", which was to be presented at a meeting of students at the Institute on 12th December, four films were shown, as follows: "Steam Power for American Sea Power", "Forging", "Seamless Tube Making", and "Welding in Boiler Manufacture".

The programme arranged for them was much appreciated by those present and an appropriate vote of thanks was expressed by Mr. Gatward.

Acton

A lecture on "Marine Diesel Engines" was given by Mr. A. G. Arnold (Member) at Acton Technical College on Thursday, 10th December 1953. The Chair was taken by Mr. Spink, Head of the Mechanical Engineering Department. The audience of 160 comprised full and part time students of Ordinary and Higher National Certificate and Mechanical Engineering Diploma courses, together with second-year and first-year marine engineering apprentices.

A complete survey of Diesel development, illustrated by slides, was made by Mr. Arnold, and an excellent film was shown. Particular reference was made to indicator diagrams and their tell-tale characteristics.

The meeting concluded with a lively series of questions from the audience, followed by a vote of thanks to the author from the leading apprentice.

Mr. A. T. Lindley (Associate Member) represented the Council and outlined the advantages of membership of the Institute.

Bolton

A meeting was held at the Bolton Technical College on Thursday, 12th November 1953, when a lecture entitled "The Marine Diesel Engine" was given by Mr. A. G. Arnold (Member), to the boys studying at the college under the new scheme for training marine engineers.

Mr. G. E. Turner, Head of the Mechanical Engineering Department of the college, took the Chair, and the Institute was represented by Mr. G. Kenworthy-Neale, who also presented prizes on behalf of the Institute to the two best marine engineering students at the college, J. K. Baker and G. G. Hawksley.

The lecture, which was illustrated by slides and a short film, was followed with great interest by a large and appreciative audience. Question time provided opportunity for a lively discussion, and the vote of thanks to Mr. Arnold was passed with enthusiasm.

Falmouth

A meeting was held on Tuesday, 24th November 1953, at 7.30 p.m., in the lecture room of the Falmouth Technical School for the presentation of a lecture on "Petroleum Refining" by Dr. E. J. Boorman. There was an audience of sixty, including a large percentage of engineer apprentices and students.

Dr. Boorman's talk and a ciné film of the Fawley installation held the audience in rapt attention during the whole of this most interesting lecture. Unfortunately, the meeting ended rather late and there was no time for questions.

Liverpool

A junior meeting was held at the Liverpool City Technical College at 7.0 p.m. on Friday, 20th November 1953, when about eighty members and students attended.

Dr. R. H. Grundy, Ph.D., M.Eng., head of the marine engineering department at the college was in the Chair, and Mr. R. H. Dickinson (Associate Member), representing the Institute, introduced Mr. R. S. Hogg (Member), who read his paper entitled "Launching of Ships".

Afterwards, Mr. Hogg answered questions put to him by those present and from the variety of the questions it was obvious that the paper had aroused much interest.

A vote of thanks was proposed by Mr. K. Campion and was heartily endorsed by all present.

Salford

A meeting was held on Tuesday, 24th November 1953, at the Royal Technical College, Salford, which was attended by 102 students and visitors. The Chair was taken by Mr. W. K. Rooney, Principal of the engineering section of the college, who introduced the speaker, Mr. J. Hodge, M.A., A.M.I.Mech.E., A.R.Ae.S., M.A.S.M.E.

Mr. Hodge read a paper entitled "Gas Turbines". This covered a wide range and included a description of many interesting marine applications. At the conclusion of his paper the author answered a number of questions which showed the great interest the paper had aroused.

Mr. J. McNaught (Member) proposed a vote of thanks to Mr. Hodge, which was carried with acclamation.

South East London

A meeting was held at the South East London Technical College on 16th November 1953 at 8.0 p.m., when Mr. J. Ward, Ph.D., B.Sc. (Member) gave a lecture on "Photo-elasticity". The meeting, under the chairmanship of Mr. F. H. Reid, B.Sc. (Member), lately Principal of the college, was well attended, there being present over 150 students and members of the staff, including the head of the mechanical engineering department, Mr. H. McQueen, B.Sc. (Eng.).

The lecture was followed attentively and, as indicated by the questions which followed the lecture, aroused considerable interest. A vote of thanks, proposed by a student of the college, Mr. F. E. Heath, was carried with acclamation.

OBITUARY

JAMES CARNAGHAN

An appreciation by Mr. John Anderson (Member)

The Institute lost a dear friend, and a valued link with the past, by the death of Mr. James Carnaghan on the 17th November 1953. Although in his eighty-third year, his interest in the affairs of the Institute and the Guild of Benevolence remained unabated. He continued to represent the Institute on a number of committees of the British Standards Institution until the end.

After an apprenticeship with Messrs. Scott and Company, Greenock, Mr. Carnagham served at sea, first with Messrs. Dixon Harrison and Company, and later with Messrs. Alfred Holt and Company. Having obtained an Extra First Class Board of Trade Certificate, he joined the Wallsend Slipway and Engineering Company as senior draughtsman, but shortly afterwards returned to Messrs. Scott and Company as a leading draughtsman.

In June 1899, Mr. Carnaghan was appointed an engineer surveyor to Lloyd's Register of Shipping, and was stationed at Middlesbrough. Two years later, he was transferred to the United States, serving in Pittsburg and Philadelphia, and upon his return to the United Kingdom in 1904, he was stationed at Liverpool. In 1913 he was appointed a senior surveyor and transferred to Dundee, where he remained until 1916, when he joined the headquarters staff in London. He was appointed a principal surveyor on the chief engineer surveyor's staff in 1922, and became an assistant to the chief engineer surveyor in 1926. He retired from active service with Lloyd's Register on the 31st December 1932.

Mr. Carnaghan was a Member of Council of this Institute, either as an elected Member, Vice-President or Honorary Vice-President from 1921 until his death. He was twice Chairman of Council, and was for a long time a Member of the Finance Committee. He served continually on both the General and Executive Committees of the Guild of Benevolence from the time of its inception in 1936, as Chairman from 1939-47. He was indefatigable in his representation of the Institute on outside committees, such as the Heat Engine Trials Committee, the Engineering Joint Council and International Association for Testing Materials, and numerous Committees of the British Standards Institution.

Mr. Carnaghan endeared himself to colleagues and associates by his kindly and sympathetic manner. He was respected for his wide experience and sound judgment.

ARCHIBALD CAMERON (Member 6539) was born at Ayr in 1903 and educated at Ayr Academy. He served an apprenticeship with the Ailsa Shipbuilding and Engineering Company at Troon from 1918-23 and joined the British India Steam Navigation Company in 1924; he sailed in their ships, the *Modasa* and *Nerbudda,* until he obtained a First Class Board of Trade Steam Certificate, and then joined the Shaw, Savill and Albion Co., Ltd. During the war he served the Air Ministry on construction work, being posted to Southampton, Prestwick and Perth, and attaining the position of chief examiner. After the war he was appointed superintendent of plant and machinery and boilers with the Caribonum Company at Leyton, and from 1947 until his death he was employed by the Ministry of Works, latterly as supervisory engineer at the Victoria and Albert Museum. He died on 16th October 1953 in St. Mary Abbots Hospital, Kensington.

Mr. John Weir (Companion) writes that Mr. Cameron was very proud of his association with the Institute, to which he was introduced by the late Mr. George Adams (Vice-President); he was elected a Member in 1930. His chief interest outside his work was connected with St. Columba's, the church in Pont Street which suffered such material damage during the last war.

GEORGE STANLEY ROCH (Member 11592) was born in 1907. His apprenticeship was served with the Great Western Railway marine factory. He then went to sea, serving in steamships from 1929-38, and obtained a First Class Board of Trade Steam Certificate in 1935. For a year, until the end of 1939, he was refrigerating and air conditioning engineer with the Anglo-Iranian Oil Co., Ltd., in Abadan. At the beginning of the war, he joined the Royal Naval Volunteer Reserve as Sub-Lieutenant(E), but from October 1940 until October 1946 he was a Lieutenant(E) in the Royal Navy. Mr. Roch joined the dredging section of the Basrah Port Directorate in 1947 as a relief engineer and was promoted chief engineer (dredger section) in July 1950, a position he held until his death on 2nd October 1953, when he was accidentally drowned.