Some Corrosion Problems in Naval Marine Engineering

L. KENWORTHY, M.Sc., A.R.C.S., F.R.I.C., F.I.M.*

An account is given of a few of the problems investigated by the Navy Department Committee for the Prevention of Corrosion and Fouling, chosen mainly for their general interest and for the experimental work they have involved in Navy Department laboratories.

The major part of the paper is devoted to sea water cooling and circulating systems, and describes the isolated condenser tube failures encountered in recent years, especially of aluminium brass in polluted water and the examination of inhibitory treatments against this attack; the policy regarding cathodic protection in condensers; the reasons for standardizing on 70/30 cupro-nickel condenser tubes and the introduction of 90/10 copper/nickel/iron piping in place of the 95/5 alloy.

Other problems deal with corrosion in engine cooling systems; fungal growths in hydraulic and cooling systems; investigation of aluminium bronzes in place of H.T. brass; use of stainless steels and titanium; choice of silver brazing alloys; study of cavitation damage; seizure of nuts and bolts; protection of propeller shafts; and protection of machinery during building.

Reference is made to steps being taken to ensure the better use of existing knowledge, and towards making the whole Service conscious of the importance of corrosion prevention.

INTRODUCTION

Since 1943, the investigation of corrosion problems and the dissemination of advice on corrosion prevention in the Naval Service have been the responsibility of the Admiralty Corrosion Committee (recently renamed the Navy Department Committee for the Prevention of Corrosion and Fouling). The detailed work of the committee is delegated to a number of sub-committees, one of which deals with machinery corrosion, and it is the activities of this sub-committee which form the basis of the present paper.

In planning the scope of the paper, it was thought inappropriate to attempt a comprehensive survey of the work carried out by the sub-committee since its formation, as this would have included much of historical interest only and many instances of failures by corrosion due to faulty practices which would have added little to existing knowledge. Instead, a selection has been made from recent problems which seemed of more general interest and which illustrate important principles. Preference has also been given to describing problems that have involved experimental work by Navy Department laboratories, yielding information on the behaviour of metals and alloys of wide applicability to marine engineering practice.

In spite of restricting the scope of the paper in this way, so many problems have qualified for inclusion that in most instances the treatment has, for space reasons, been more superficial than the author would have preferred. More details will, however, be found in the original papers to which reference has been made and, it is hoped, in future papers on some of the work yet unpublished.

PROBLEMS IN SEA WATER COOLING AND CIRCULATING SYSTEMS

Condensers and Heat Exchangers

Condensers and heat exchangers have figured prominently in the history of corrosion troubles encountered in naval ships. For many years now, however, the number of these units that have suffered significant corrosion has been statistically small. Nevertheless, because of the vital importance of the equipment, much attention has been given to the problems that have occurred, and for this reason a substantial part of the present paper has been devoted to these items. Moreover, it has been thought advisable to explain in some detail the steps that have been taken to overcome the problems encountered, since some of these may otherwise give the impression of inconsistencies in policy, whereas in fact they have been dictated by the emergence of successive problems which have been tackled in the light of the knowledge available at the time.

Tubes

Since 1935, main condensers of all but the smaller ships have employed 70/30 cupro-nickel tubes complying with the composition subsequently adopted in B.S.378:1953 (main constituents—nickel 30-32 per cent; iron 0·4-1·0 per cent; manganese 0·5-1·5 per cent; copper remainder). These have given excellent service and the only serious corrosion encountered has been confined to a few ships used as accommodation ships while in reserve. Under these conditions water circulation was very sluggish allowing the settlement of mud, the water itself was often polluted, and intermittent overheating occurred, especially in the top rows of tubes as a result of exhaust steam being fed into the condensers at atmospheric pressure. In some of the failed tubes, soft plugs of redeposited copper were present whilst the outer layers of mud were found to contain a high proportion of nickel. Other tubes exhibited scales of calcium carbonate and calcium sulphate together with black cupric oxide, indicative of overheating. Corrosion was attributed to the presence of shielded areas under scale and mud giving rise to a deposit type of attack, accelerated by the high temperature and polluted conditions. The trouble has been overcome by providing more rapid circulation of water through condensers of ships employed under these conditions and by draining condensers when not required, followed if possible by flushing with clean water before being closed.

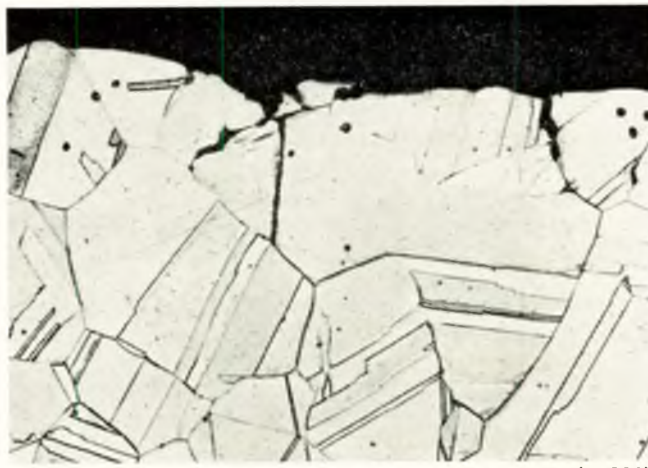
*Royal Naval Scientific Service.

This type of attack, referred to as "hot-spot" corrosion, has also been encountered in the Merchant Navy, and an investigation by Breckon and Gilbert[1] and by Bem and Campbell[2] showed that 70/30 cupro-nickel is particularly prone to suffer in this way. Pollution of the water, whilst assisting attack, does not appear to be an essential requirement. The latter authors consider that thermo-galvanic effects play an important part in the attack, whilst Breckon and Gilbert incline to favour differential aeration beneath the heavy scales deposited in the locally hot zones, as a major factor. All agree that further investigation is necessary before a full understanding of the mechanism of this attack can be elucidated.

Auxiliary condensers and heat exchangers (and main condensers of smaller ships such as *Whitby* Class frigates), have been fitted for many years with expanded and sealed, and more latterly rolled-in, aluminium brass tubes (main constituents—copper 76-78 per cent; aluminium 1·8-2·3 per cent; arsenic 0·02-0·05 per cent; zinc remainder). Until recently, these have given little trouble apart from impingement attack at inlet ends, caused by the turbulence often found in multi-pass condensers. Over the past year or so, however, transcrystalline cracking of the stress corrosion type, together with pitting and intercrystalline attack have caused extensive failures of tubes in some ships shortly after commissioning. The seriousness of this can be judged by the fact that in one ship no fewer than 16 heat exchangers needed substantial re-tubing.

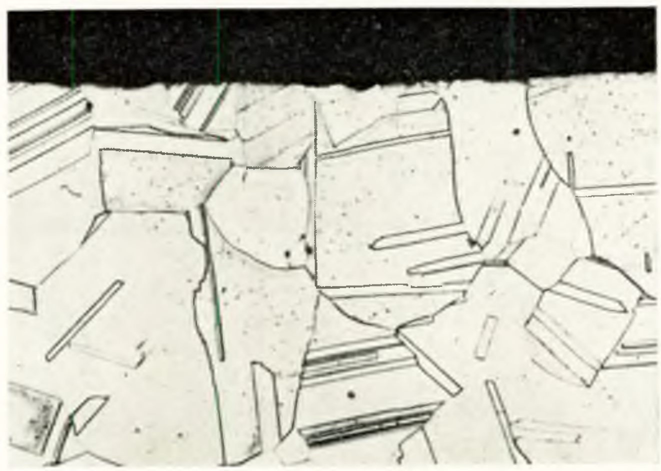
The mechanism of these failures is attributed to the formation of a complex cuprous sulphide film which was always present on affected tubes. With aluminium brass exposed to sea water containing cystine (a sulphur compound produced by bacterial action and commonly present in polluted water[3]), it was found at the Central Dockyard Laboratory[4] that the filmed surface was up to 50 mV more noble than that formed in clean sea water. Since the sulphide film must be extensively formed to provide the necessary current density for severe attack to take place at discontinuities, this is most likely to occur in new construction ships where a clean metal surface is exposed to sulphide polluted water from the fitting-out basin. The vulnerability of aluminium brass to this form of attack, especially in its early life before a resistant film has had time to form, is well known to be its Achilles heel, as pointed out by Gilbert[5] and others, and many instances of failure from this cause have been reported[5, 6].

In a search for a method of overcoming the trouble, recent work[7, 8] on the inhibition of copper and its alloys by benzotriazole suggested that this or other compounds which form chelates with copper might be worth investigating. Tests were therefore carried out[9], using various methods of assessment including a potentiostatic stress corrosion technique that had been found to reproduce in the laboratory the type of attack occurring in service, and these showed that benzotriazole and other substituted derivatives of dithiocarbamic acid, at a concentration of 0·01 per cent w/v, were extremely effective in preventing attack in polluted sea water, not only of aluminium brass but of other alloys containing more than 50 per cent of copper. The effect of this type of inhibitor in suppressing intercrystalline corrosion of aluminium brass is illustrated in Fig. 1.



(× 200)

(a)



(× 200)

(b)

a) Without inhibitor, showing intercrystalline corrosion.
b) With 0·01 per cent sodium dimethyl dithiocarbamate in the water, showing surface roughening only.

FIG. 1—*Aluminium brass after three months' immersion in polluted sea water*

As a result of these tests, ship trials have been instituted using sodium dimethyl dithiocarbamate which was as effective as any of the inhibitors tried and was also the cheapest, its cost being only one-sixth of that of benzotriazole. The inhibitor is injected into the system on first flooding and allowed to stand for 24 hours, followed by occasional dosage during service. Judging by the laboratory results, the treatment would be applicable to other copper-based alloy condenser tubes and for combating the attack of copper/nickel/iron sea water piping in polluted water, a problem referred to in the section on "Sea Water Carrying Pipes".

Another method of water treatment is undergoing trials by the Central Electricity Generating Board[10] to prevent the corrosion of tubes caused or aggravated by the deposition of mud which can contain free sulphides, instances of which in H.M. Ships have been mentioned earlier. The treatment consists of the occasional injection of one p.p.m. of a poly-electrolyte which coagulates the colloidal mud and prevents its settlement.

Yet a further treatment, that has met with success in the U.S.A. and which is being tried in this country, is injection with ferrous sulphate. This results in the deposition of a protective iron oxide film on the tubes, a matter referred to again under "Further Observations on Protector Blocks and Other Protective Measures".

An attempt has been made by Belgian workers[11] to improve the resistance of aluminium brass tubes to sulphide attack by suitable heat treatment, but experiments at the Central Dockyard Laboratory[9] have failed to reproduce the degree of protection reported, and no treatment was found to be as effective as inhibitor injection.

In spite, however, of the possibility of measures being introduced to combat the effects of pollution, it has been decided to replace aluminium brass by 70/30 cupro-nickel for new construction ships and for re-tubing existing heat exchangers that have suffered as a result of pollution. This decision, which was a difficult one to make in view of the many merits of aluminium brass as a condenser tube material (including good corrosion resistance in other respects, reliability at high temperatures, good heat conductivity and relative cheap-ness), was largely influenced by the overriding importance of dependability and by the tendency for pollution to increase in many of our rivers, estuaries and in-shore waters. Although the rival claims of 90/10 copper/nickel/iron were given due consideration, cupro-nickel was chosen partly because of its known reliability in R.N. service and partly for the convenience of standardizing on one tube material for all condensers and heat exchangers.

At the same time, interest is being taken in the development of other condenser tube materials, particularly those designed to resist polluted conditions. For instance, ship trials sponsored by the British Non-Ferrous Metals Research Association, of two compositions of tin brass tubes containing 16 per cent zinc and 6 per cent tin, and 10 per cent zinc and 8 per cent tin, respectively, are being carried out in a drain cooler, a turbo-generator condenser and a main condenser. After five years' service, all the tubes appeared to be in perfect condition, although it cannot be said that the trials have seriously tested the resistance of the materials to polluted conditions. Tin bronze (10-12 per cent tin) tubes are also under trial in the condensers of a number of H.M. Ships, but here again although no deterioration has been observed after four years, the conditions have not been very searching. This material is particularly resistant to sand abrasion[12, 13] but is stated to be less resistant than 70/30 cupro-nickel to deposit attack[12]. More information on the merits of these three materials is expected to be obtained as a result of the installation of sample tubes in certain C.E.G.B. stations operating on highly polluted water.

Another type of tube being developed by industry, primarily for use in power stations operating on polluted water, consists of 70/30 cupro-nickel clad internally with 88/10/2 copper/nickel/iron. The idea behind this type of tube is that as the cladding is anodic to the basis metal, any perforation of the former will not be likely to lead to perforation of the tube. Trial tubes are to be installed in one or two ships under construction where they will encounter the polluted conditions during fitting out which can prove so disastrous to aluminium brass.

Tube Plates

The rolled Naval brass (copper 61-63 per cent; tin 1·0-1·5 per cent; zinc remainder) formerly used exclusively for tube plates of all condensers and heat exchangers, has for many years been free from trouble, following improvements in design which reduced the turbulent conditions of flow responsible for impingement attack. More recently, however, dezincification of main condenser (and some heat exchanger) outlet tube plates in some ships has given rise to concern. So far as is known, serious attack (up to ¾ in. deep), has again been confined to ships used as accommodation ships in reserve. On the other hand, the Royal Australian Navy has experienced similar severe trouble in ships that have neither been in reserve nor used as accommodation ships, whereas a survey of Royal Canadian Navy ships revealed that dezincification was fairly common but never serious.

The major factor responsible is undoubtedly the cathodic nature of the gunmetal doors and the cupro-nickel tubes, coupled with the fact that this was not offset by the provision of protector blocks. It seems likely also that temperature is a contributory factor since only the outlet tube plates were involved and the worst affected condensers were in Royal Navy ships that had been used as accommodation ships and in R.A.N. ships which operate in warmer waters, with the R.C.N. ships operating in colder waters experiencing less trouble. The more fundamental aspects of the problem have been studied by Rowlands[14], who found that in addition to the factors well recognized as promoting dezincification, a continuous network of beta-phase was especially harmful, particularly if it comprised less than ten per cent of the micro-structure.

The solution appeared to be either to provide cathodic protection to the plates, or to change the material. As regards the former, this had previously been provided by mild steel protector blocks which for many years had been fitted to both inlet and outlet plates. In 1939, however, it was decided to dispense with blocks on the outlet plates, in order to concentrate maintenance effort in ensuring that those fitted to the inlet plates were kept in good working order, for reasons that will be explained later.

In re-introducing cathodic protection to the outlet plates, consideration was given to the use of mild steel blocks, zinc alloy (containing ½ per cent aluminium and ⅛ per cent silicon) blocks or impressed current. It was decided, however, that the last named would have to be ruled out since, although theoretically attractive, its practical application, including the need for careful maintenance, could present considerable difficulties. The choice between mild steel and zinc alloy was made as the result of the work of a number of investigators. Crennell and Sawyer[15], for example, at the Central Dockyard Laboratory, showed that a potential of −600 mV (relative to silver-silver chloride) completely prevented dezincification, and arrested its progress beneath an already dezincified layer. Similar work at the Australian Defence Standards Laboratories, Marybrynong, described by Knuckey[16], indicated that −500 mV would prevent dezincification, whilst practical trials in an R.A.N. ship showed that dezincification was prevented with mild steel blocks giving a potential of −590 mV while stagnant. At the Canadian Department of National Defence Pacific Naval Laboratory, Esquimalt, experiments indicated that zinc alloy anodes were needed to bring active dezincification under control, after which mild steel was adequate. To be on the safe side, therefore, zinc alloy anodes were chosen, which have the added advantage of better throwing power, and these are being fitted on the basis of one 18lb. anode for each eight square feet of exposed tube plate area. Provision has also been made for fitting a reference electrode for trial purposes to determine whether or not protection is being provided at the right level.

Some slight apprehension has been expressed that the application of cathodic protection to outlet plates might increase the danger of impingement attack in the tubes at a point where the cathodic protection becomes ineffective. So far, however, no evidence has been found to indicate that this is of significance. In any event, in most condensers to which cathodic protection has been applied to the outer plates, the tubes would already have been in service for some time and should have developed a protective scale.

With regard to alternative tube plate materials, several single-phase copper alloys have been examined in the laboratory and by immersion tests from the Navy Department's exposure raft in Langston Harbour, to assess their resistance to galvanic, crevice and stress corrosion, and to impingement attack. The material found to possess the best combination of properties was an aluminium bronze complying with A.S.T.M. Specification D171-55, Alloy D (main constituents—aluminium 6·0-8·0 per cent; iron 1·5-3·5 per cent; copper remainder), and this composition has been chosen as the standard tube plate material for all condensers (including auxiliary condensers and heat exchangers) for new construction ships and for replacement of R.N.B. plates requiring renewal. Additional support for the choice of this alloy was afforded by its excellent performance as a tube plate material in oil refinery equipment[13].

Further Observations on Protector Blocks and Other Protective Measures

Mention has already been made of the recently introduced practice of fitting zinc alloy anodes to R.N.B. outlet plates in main condensers. As regards inlet plates, the general practice has been to fit mild steel protector blocks to the inlet tube plates of all main condensers and to the inlet paths of auxiliary condensers and heat exchangers. Their function is not only to give cathodic protection to the plates, ferrules and tube ends, but to provide a supply of iron corrosion products to the tubes which has been shown[17, 18] to be beneficial in the early formation of a protective film. The beneficial effect of iron salts has also been demonstrated in certain power stations by the injection of ferrous sulphate[18], as previously mentioned in the section on "Tubes".

Protector blocks, however, unless correctly designed, fitted and maintained can do more harm than good. For example, their action, especially if they are fitted too generously so as to give over-protection, tends to prevent the small amount of initial corrosion which gives the characteristic protective film on many alloys, and to produce instead a film of cathodically deposited substances. This is satisfactory provided the blocks remain active, but if they cease to function, particularly if this happens fairly suddenly, the cathodic film then becomes unstable; areas formerly protected may then suffer severe attack by becoming anodic to adjacent areas carrying a naturally formed film.

The most common cause of this happening is the insulation of the blocks from the tube plates by the growth of iron corrosion products. In order to minimize this danger, a special fitting was devised in which the blocks were cast into a non-ferrous boss which is attached to the tube plate with brass washers on either side.

A second drawback to protector blocks is their tendency to break up the smooth flow of water through the condenser. This has been reduced by fitting blocks edgewise rather than parallel to the tube plate, which was the original practice, but even this arrangement may cause some interference in certain cases.

Partly with a view to overcoming these objections and partly with the object of removing at its source the cathodic stimulation caused by the gunmetal doors, the practice was adopted for a time of dispensing with protector blocks and spraying the doors with mild steel as an alternative. It was considered that as the mild steel coating would fail slowly, the tubes would receive maximum protection both cathodically and from the point of view of iron corrosion products in their early life when these were most wanted, and that the gradual reduction of both these effects would not be likely to lead to the possible corrosion caused by sudden failure of protector blocks.

Although evidence does not point to this practice having been harmful, subsequent consideration led to its discontinuance on the grounds that :

a) there was little to be gained by providing iron corrosion products in main condensers as these are fitted with cupro-nickel tubes and as severe pollution is rarely encountered;
b) the mild steel spray may have been exerting little cathodic protection (apart from masking the cathodic stimulation caused by the gunmetal doors) since the particles of the sprayed coating may well have been electrically insulated from the box by an oxide film.

In auxiliary condensers and heat exchangers there is a stronger case for mild steel protector pieces because the vast majority still have aluminium brass tubes, and the turbulence and liability to impingement attack are much greater than in main condensers. Mild steel protector pieces are therefore fitted in the inlet passes, and secured to the door in such a way as to cause least interference with the water flow. Their area is approximately equal to half the developed area of the inlet pass. In many small heat exchangers, however, it is impossible to fit protector blocks, and in these cases a 12-in. long tubular corrosion length is fitted immediately adjacent to the inlet door, of the same bore as the inlet pipe. The outside of these corrosion lengths is covered with glass reinforced epoxy resin so that perforation of the steel will not result in leakage. Tubular corrosion pieces are not fitted in submarines.

Doors

Although gunmetal doors, either of the 88/10/2 or the 86/7/5/2 composition, have never suffered deterioration in service, they are not ideal since they are highly cathodic to the other metals in the condenser, as well as being expensive, heavy and difficult to manufacture. New doors may also be coated with graphite which may have been used as a mould separator, and this can be a further source of trouble unless removed. To avoid these disadvantages consideration has been given to the development of glass fibre epoxy resin doors. At present these are being tried on an experimental basis for turbo-generators, but if they are successful, it is probable that their use could be considerably extended.

Experimental Systems for Studying Condenser Corrosion

Whilst much of the development of condenser practice has resulted from ship trials and service experience, consideration has been given to studying experimentally under controlled conditions the degree to which tube plates, inlet ferrules and tubes are affected by condenser design and increase in water speed. Factors thought to be of special importance were the approach water velocity to the tube plate, the angle of entry to water boxes, methods of fitting tubes, and the amount and distribution of air in the water stream. Two experimental recirculation systems were designed for such a study by the Yarrow Admiralty Research Department and installed at the Central Metallurgical Laboratory, Emsworth. In one of these, sea water, thermostatically controlled, was circulated via 6-in. bore copper piping through the 35 tubes in a quadrant of a drain cooler, at speeds up to 30 ft./sec. The other system was constructed of 4-in. bore ceramic piping (thereby eliminating contamination of the water apart from that derived from the test specimens) and was designed primarily to provide information on the resistance of different condenser tube materials to high speed water flow at speeds up to 100 ft./sec. through a small number of tubes fitted in "Perspex" tube plates.

Unfortunately, only a limited number of results were obtained owing to the closure of the Central Metallurgical Laboratory, and by the time the equipment had been dismantled and reassembled, a greater need had arisen for information on the behaviour of materials for sea water piping, particularly in relation to the design of systems. Some of the work being carried out at the Admiralty Materials Laboratory with the equipment modified and extended for this purpose is mentioned in the following section—"Sea Water Carrying Pipes".

Finally, on the subject of testing equipment, two points call for mention. The first of these is the possibility that results obtained from recirculation systems may differ from those obtained where the water passes once only through the equipment, as pointed out by Gilbert and LaQue[19], in the case of jet impingement tests. The author has for many years advocated the desirability of installing "once-through" equipment so as to bridge the gap between recirculation plants and service conditions. Fortunately, the difficulties of finding a suitable site have at last been overcome and facilities are to be provided in the Portland area. The second point, which has been made by Breckon and Gilbert[1], is that in investigating the corrosion resistance of condenser tube alloys, true simulation of service conditions cannot be achieved without heat transfer through the tubes.

Sea Water Carrying Pipes

As a result of disastrous failures of copper sea water carrying pipes by impingement attack, which immobilized many ships in the early part of the Second World War, extensive use was made during the later stages of the war of a copper/nickel/iron alloy containing 5 per cent nickel and 1 per cent iron (now complying with B.S.2871 : 1957—CN101 :—nickel 5-6 per cent; iron 1·05-1·35 per cent; manganese 0·3-0·8 per cent; copper remainder), one of a series of alloys developed by the British Non-Ferrous Metals Research Association[20]. The choice of this alloy was a compromise between a material giving improved resistance to impingement attack and one which was amenable to coppersmithing operations with little, if any, change in dockyard techniques. The latter feature was particularly desirable at the time because of the urgency of the problem and the high proportion of dilutee labour then being employed.

The new material was a great improvement over copper, but when post-war designs allowed mass flows to increase from 5½ ft./sec. to 10 ft./sec., failures again became frequent. Although this speed is one which 95/5 copper/nickel/iron is capable of withstanding under ideal conditions of smooth flow, it does not leave sufficient margin for resisting the local turbulence frequently met with in ships' systems. This turbulence commonly arises at flange joints (for example, by badly aligned flanges allowing a step in adjacent bores, by pipes not finishing flush with the flange face, and by protruding jointing material), on the down-stream side of reducing valves (particularly screw-down globe type) and pumps, and where there are sharp changes of direction and section.

Much more attention should therefore be given to the layout of systems and to close supervision during fabrication and installation. In one ship where this was done, a striking improvement has been shown, no failures having occurred to date after more than two years' service, whereas similar ships have suffered numerous failures in a much shorter time. With a view to giving wider publicity and advice in these matters, a Code of Practice is at present being drafted by the Navy Department. This idea is also being followed in Germany for the Merchant Navy where a specification for copper pipelines has so far been produced[21]. It is understood that similar action for other materials is being considered.

Two other points deserve mention in discussing the corrosion resistance of 95/5 copper/nickel/iron. The first concerns the fact that if the alloy has been heated to about 600 deg. C. (1,112 deg. F.) its corrosion resistance is somewhat impaired. This inevitably occurs as a result of many coppersmithing operations, but, as the heat-affected zones coincide with the areas of excessive turbulence previously mentioned, there has been a tendency in some quarters to place undue emphasis on the effect of heating. It is, in fact, of quite secondary importance compared with the effect of turbulence.

The other point concerns instances of attack of the alloy by polluted water which have occurred in stagnant portions of systems. To guard against this, systems are flushed with clean shore or sea water immediately after basin trials and "blind" systems are also flushed periodically during service.

Even by taking all reasonable precautions, however, 95/5 copper/nickel/iron is clearly being subjected to conditions close to the limit of its capabilities in many H.M. Ships, and bearing in mind that future requirements might demand yet more arduous conditions, it seemed advisable to change to a more resistant pipe material. Accordingly, copper/nickel/iron alloy containing 10 per cent nickel (complying with B.S.2871: 1957 —CN102:— nickel 10-11 per cent; iron 1·0-2·0 per cent; manganese 0·5-1·0 per cent; copper remainder) is now being fitted in all new surface ships and for the replacement of failed lengths of the 95/5 alloy in ships in service. This material was considered when the 95/5 alloy was originally chosen, but was not adopted because of anticipated coppersmithing difficulties at that time. It has been extensively and successfully used in the U.S.A. for some years[17, 22] including the U.S. Navy[17]. For submarines, 70/30 cupro-nickel is replacing 95/5 copper/nickel/iron.

With regard to coppersmithing, trials recently carried out on 90/10 copper/nickel/iron alloy, 90/10 copper/nickel/iron alloy containing 0·2 per cent zirconium, and 70/30 cupro-nickel, by the Constructive and Engineering Departments of Portsmouth Dockyard in collaboration with the Central Dockyard Laboratory, showed that bending of these alloys presents no difficulties provided piping is in the annealed condition and is machine bent cold (filling being unnecessary) to a radius not less than 3 D. If machine bending is impossible or a sharper radius than 2 D is desired, hypo-filling is advised. For hot bending which, however, is not recommended, pipes are sand filled and bent to as large a radius as possible. The tendency for intergranular attack to take place on hot bending, particularly with 70/30 cupro-nickel, may be remedied by the zirconium addition. Some observations on brazing and soldering are given in the section—"Brazing and Soldering Alloys".

The installation of recirculation pipe testing facilities at the Admiralty Materials Laboratory, mention of which has been made in the previous section, is proving a great help in investigating corrosion problems arising in piping systems and, in addition, is furnishing data which will be useful in compiling the Code of Practice to which reference has been made. Although it is hoped that a full description of the equipment and some of the investigations carried out will eventually be published, it is relevant to make brief reference to the results of some of the early tests[23]. For these, a system was installed duplicating the salt water supply system to the a.c. motor generating plant of an aircraft carrier, which had given considerable trouble. It was found that with 95/5 copper/nickel/iron piping, impingement attack occurred at a number of localities downstream of turbulence raisers such as orifice plates, valves, T-pieces, sharp bends and protruding (especially eccentrically protruding) flange material. In subsequent tests with 95/5 and 90/10 copper/nickel/iron and 70/30 cupro-nickel, it was gratifying to find, in view of the recent decision regarding the materials to be used for piping systems, that, after 5,000 hours, the 95/5 alloy had suffered several perforations and widespread attack downstream of the turbulence raisers, whereas no perforation and very little attack of the other two alloys had taken place.

The use of plastic piping in H.M. Ships is also constantly under review; at present, however, such piping is not fitted in machinery spaces because of the fire hazard (with which is associated the risk of toxic fumes in the case of some materials) and the fact that, under closed conditions, ambient temperatures could be critical for such materials as PVC or polythene. There is, however, a special application of plastic piping in the ballast system of Assault Ships, in which about 1,000ft. of 20-in. bore piping is needed to carry water at a speed of 30 ft./sec. The material chosen comprises a core of multi-wrap epoxy resin impregnated glass cloth, clad on both sides with a wrap of acrylic fibre similarly impregnated to give impact resistance. Tests at the Admiralty Materials Laboratory have indicated that this will withstand a water speed of 30 ft./sec. for a prolonged period with only negligible deterioration. Moreover this material is only one third the weight of mild steel of equal strength and only one third the cost of copper/nickel/iron piping, and when lagged with conventional rope lagging is as fire resistant as metallic piping. With these attractive properties it is possible that this piping could find extensive application in ships in the future, if standard bends and elbows were to be developed.

PROBLEMS IN COOLING AND HYDRAULIC SYSTEMS USING MISCELLANEOUS FLUIDS

Engine Cooling Systems

Apart from the older types of submarine main engines employing "one-through" sea water cooling, there is a variety of Diesel engines in naval service varying in size, materials of construction, and service use. For most of these an anti-freeze coolant is required, and the one at present employed is 20 per cent ethylene glycol solution inhibited with sodium mercaptobenzothiazole (NaMBT) and triethanolamine phosphate (TEP) and complying with D.T.D.779 and B.S.3150: 1959, Type A.

Whilst this coolant has on the whole been satisfactory, instances of severe water-side attack of cylinder liners have occurred, sometimes resulting in perforation, and this has led to a comprehensive study of the problem by Barton[24, 25], at the Admiralty Engineering Laboratory. The attack, which usually has the characteristic appearance of cavitation damage, has been found to be associated with liner vibration. This would appear to account for the fact that instances of trouble have been more frequent in recent years because of the introduction of more highly powered, higher speed engines of lighter construction.

Since cavitation damage is due to a combination of mechanical and electrochemical factors, as described under "Cavitation Damage", remedial action is to be found either in reducing the vibration of the liners, in the use of a liner material or a coating less susceptible to mechanical damage, or in providing a coolant with good and lasting corrosion inhibitive properties.

As regards the former, work at the Admiralty Engineering Laboratory has shown the vibration to be principally due to piston slap and, as a result of a study of this aspect by Fearon [26, 27] at the Admiralty Research Laboratory, an oil cushion type piston that provides viscous damping of the transverse motion has been developed which shows promise.

Increasing the rigidity of the liner is also a possible method of decreasing vibration.

Little choice is economically possible in the material of the liner, but a wide range of coatings has been tested at the Admiralty Engineering Laboratory. Most of these proved unsuccessful because of failure to withstand mechanical damage, either by being too soft (e.g. tin/zinc, cadmium and nickel) or too brittle (alumina), and the only completely successful coating was nickel plus hard chromium, with nickel phosphorus plating being partially successful.

Much work has also been carried out by Barton [24, 25] on the coolant problem. Tests with the present coolant (i.e. to D.T.D.779) have confirmed some of the findings of Collins and Higgins[28] and of Squires[29] as regards depletion of the inhibitors, although Barton[25] has established that this is more a function of the engine running hours than the overall time in the engine. Depletion was found to be more rapid in engines mainly of ferrous construction than in aluminium alloy engines. Loss of inhibitor may result not only in cavitation damage asserting itself but also, since glycol solutions become acidic after a time as a result of oxidation, in severe corrosion of some of the metals in the system with consequent trouble through blockages by sludge. It would seem very desirable, therefore, to have a simple service test for checking the inhibitor concentration.

With this in view, a proprietary test kit was examined by means of which a standard volume of mercuric chloride solution is added to a standard volume of coolant, using diphenyl carbazide as indicator to show excess mercuric chloride when the NaMBT falls below 0·01 per cent. Unfortunately, this proved unsuitable for use at sea for a number of reasons, the chief of which was the instability of the indicator. At the same time it was discovered that, although the NaMBT depleted very rapidly, the coolant did not necessarily become corrosive for some considerable time thereafter, and a test for NaMBT content is therefore not necessarily a criterion of the corrosivity of the coolant.

Consideration of other possible coolants has led to the conclusion that the coolant at present employed is, in general, more satisfactory than ethylene glycol solution inhibited with sodium nitrite/sodium benzoate (to B.S.3151 : 1959—Type B), with sodium borate (to B.S.3152 : 1959—Type C) or with soluble oil. The two former are both liable to attack certain materials of the system, whilst the last named, although used in the U.S. Navy[30] and widely in the Merchant Navy, has the disadvantage of giving an alkaline coolant which is not advisable for aluminium alloy engines.

In spite of this there is still a feeling that it might be possible to develop or adopt a coolant more satisfactory than D.T.D.779, both from the point of view of remaining noncorrosive for a longer period and also of being readily checked in this respect by a simple service test. Work with this in view is currently proceeding at the Admiralty Engineering Laboratory.

Fungal Problems

Fungal growths in naval ships can cause much trouble for three reasons. In the first place, fungi exude enzymes for converting many organic substances into soluble products which can be absorbed as food; in the process, a wide range of materials supporting the growth of fungi can suffer deterioration, including cotton, canvas, rope, paints, oils and timber. Secondly, the waste products of their metabolism which commonly include citric and oxalic acids can be corrosive towards many metals; cadmium plating, which is used extensively in electronic equipment, is particularly vulnerable to this form of attack. Thirdly, fungi merely by their presence can result in mal-functioning of equipment, for example by causing electrical leakage in electronic gear; moreover, when present in quantity, which can occur if they are growing in a nutrient medium, they can cause blockages in piping systems, valves and gauges.

A study of the fungal problems met with in naval service which is being carried out by Hendey[31] at the Admiralty Materials Laboratory, involves the isolation, identification and preparation of pure cultures of the fungi concerned, and the subsequent use of these cultures in laboratory tests to assess the value of various possible fungicidal techniques. This is not so simple as it may appear in that most fungicides are not only specific to a particular species, but are often effective only in certain media. Moreover, the choice is further restricted since any fungicide used must be non-toxic to human beings (a matter of special importance in the confined spaces of ships), and must have no interaction with the medium into which it is introduced.

Most of the problems encountered in naval ships and stores fall outside the scope of the present paper but a few may be referred to which are relevant. The first of these concerns hydraulic systems which operate lifts, arrester gear and miscellaneous services in aircraft carriers. The hydraulic fluid used in these is a 40/60 glycerine/water mixture containing disodium hydrogen phosphate and sodium nitrite as corrosion inhibitors. This is an ideal nutrient medium for fungi and if fungal contamination occurs, massive growths (mainly species of *Aspergillus*) quickly develop. These usually accumulate in the header tanks and when the system is operated the growths are broken up and carried to all parts of the system causing blockages in pipes, valves and pumps to such a degree that some systems have failed to operate. Laboratory tests also showed that the corrosion of mild steel in the system was enhanced by these growths. The loss in weight (after cleaning) of mild steel strips after three months' immersion in hydraulic fluid with and without fungus present was 58 mgm./sq. dm. and 0·4 mgm./sq. dm. respectively. Of a number of fungicides examined it was found that "Panacide" sodium (the sodium salt of 5 : 5-dichloro 2 : 2 dihydroxy diphenyl methane) was the most effective and this is now being added at a concentration of 100 p.p.m. to the hydraulic fluid.

Other systems that have suffered from the accumulation of fungal growths have been cooling systems employing a 50 per cent solution of inhibited ethylene glycol (complying with D.T.D.779 and containing sodium mercaptobenzothiazole and triethanolamine phosphate as corrosion inhibitors); this is also a highly nutrient medium and supports the growth of fungi similar to those found in the glycerine/water medium. One instance concerned a lubricating oil cooling system which, on examination, was found to be completely blocked for a length of 18 inches. Another occurred in a radar cooling system and this resulted in overheating and breakdown of the magnetron electro-magnets. As a result of laboratory tests, the addition of cetyl trimethyl ammonium bromide was found successful in preventing fungal growths in this medium. In both these instances there was evidence that the fungi had caused corrosion.

It will be clear from the foregoing that fungal growths can be of the greatest significance in naval ships and equipment, and that every effort should be made to prevent such growths both for economic and operational reasons. It should not, however, be assumed that the greater number of fungal problems examined and reported on within recent years represents a genuine increase in their incidence; in the author's opinion it is probably to be attributed to more accurate diagnosis.

USE AND DEVELOPMENT OF SOME ALLOYS FOR MARINE SERVICE

Alternative Materials to High Tensile Brasses

Following the many cases of dezincification and stress corrosion of high tensile brasses (typical composition—copper 57 per cent; tin 1 per cent; iron 1 per cent; manganese 1 per cent; zinc remainder) in naval machinery (and other components in ships), there has been a gradual tendency to avoid this type of alloy and recently its use in the Service has been banned, apart from a few specialized applications in the weapons field and for large propellers. The materials that have been used in their place until recently have been medium strength aluminium bronzes complying with B.S.2032 : 1953 (main constituents—aluminium 8·8-10 per cent; iron plus nickel 3 per cent maximum; manganese 0·5 per cent maximum; copper remainder) for wrought alloys and with B.S.1400:1961—AB1-C (main constituents—aluminium 8·5-10·5 per cent; iron 1·5-3·5 per cent; manganese 1 per cent maximum; nickel 1 per cent maximum; zinc 0·5 per cent maximum; copper remainder) for cast alloys.

The micro-structure of alloys complying with these specifications, however, is a function of their manufacturing history and is not controlled by a heat-treatment clause. In consequence, whilst this class of material has in general given satisfactory service, there have been cases of severe preferential attack, and these have been associated with a continuous network of gamma$_2$ phase in the micro-structure. Since little information appeared to exist regarding the relationship between chemical composition, thermal treatment, micro-structure, and behaviour in sea water of these alloys, an investigation was carried out at the Central Dockyard Laboratory, as described by Upton[32].

It was confirmed that a continuous network of gamma$_2$ phase was detrimental from a corrosion point of view and resulted in de-aluminification, but that its formation could be restricted to a non-continuous form or avoided altogether by limiting the aluminium content to the range 8·4-9·1 per cent, or by quenching from 600 deg. C. (1,112 deg. F.) respectively. Since the latter is not always practicable and since in any event its effect may be nullified by subsequent welding or brazing, or by components operating at elevated temperature, a Navy Department Specification has been drawn up with a modified aluminium content, but specifying a heat treatment as applicable. Alloys to this specification, which combine good ductility with dependable corrosion resistance, including resistance to crevice attack, are expected to find wide application in the Service.

A range of aluminium silicon/bronzes as possible alternatives has also been examined at the Central Dockyard Laboratory[33]. The most promising alloy contained 6·5 per cent aluminium, 2 per cent silicon and 1 per cent iron, and possessed good corrosion resistance irrespective of heat treatment, excellent weldability and low magnetic permeability. This alloy is at present undergoing service trials.

There is, however, a demand for corrosion resistant nonferrous alloys with higher strength than the 34 tons/sq. in. (and with better mechanical properties generally) that can be obtained from these substitutes for alloys of the B.S.2032 type. With this in mind investigations were undertaken by Bradley[33] at the Central Metallurgical Laboratory, and later at the Central Dockyard Laboratory, on wrought and cast nickel/aluminium bronzes complying respectively with B.S.2033:1953 (typical composition—aluminium 10 per cent; nickel 5 per cent; iron 5 per cent; copper remainder) and B.S.1400:1961—AB2-C (similar to B.S.2033 with a maximum of 3 per cent manganese); on a few precipitation hardenable copper base alloys (e.g. to D.T.D. Spec. 498: typical composition—nickel 2·5 per cent; silicon 0·5 per cent; copper remainder) and on a high manganese/aluminium bronze alloy complying with B.S.1400:1961 CMA1-C (typical composition—aluminium 8 per cent; manganese 12 per cent; iron 3 per cent; nickel 2 per cent; copper remainder). Sea water corrosion tests were conducted in Chichester and Langston Harbours and, through the cooperation of the Parsons Marine Engineering Turbine Research and Development Association, in an area of brackish polluted water in the River Tyne. These included galvanic couples with a number of other alloys in various anode/cathode ratios, as well as tests to assess the effect of welds and crevices.

It was found that no nickel/aluminium bronze possessed better all-round corrosion resistance than alloys complying with an existing Navy Department Specification (typical composition— aluminium 10 per cent; nickel 5 per cent; iron 5 per cent; manganese 2·5 per cent maximum; copper remainder). The precipitation hardenable alloys (essentially all alpha in structure) had good corrosion resistance and possess attractive mechanical properties, but are considered unsuitable for general Service application, especially in the form of castings. The high manganese alloy, although possessing superior mechanical properties to the nickel/aluminium bronzes, proved more liable to crevice attack, particularly in the heat-affected zones of welds, and to be less compatible with the other alloys used in marine engineering.

It is clear therefore that a requirement still exists for an alloy of high strength and ductility with good all-round corrosion resistance under marine conditions. With this end in view, work is proceeding at the Central Dockyard Laboratory directed at a more complete understanding of the factors controlling the corrosion of nickel/aluminium bronzes.

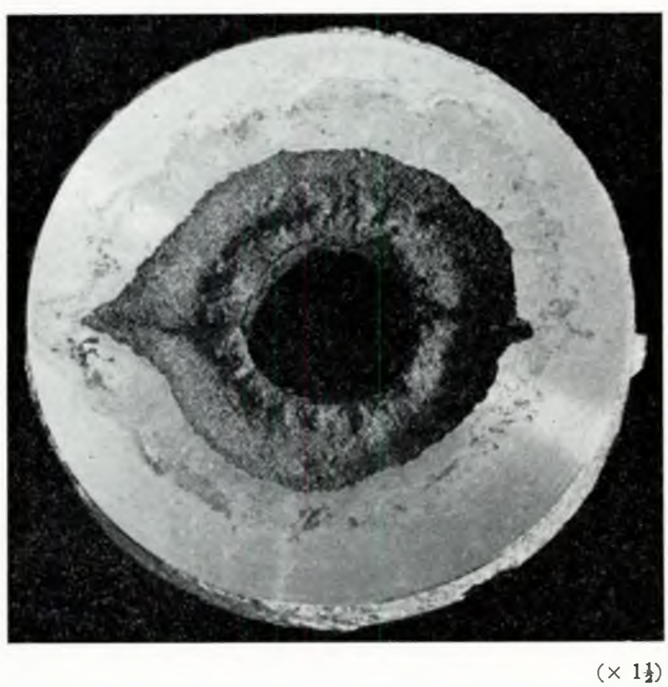
Stainless Steels

A certain amount of trouble has been caused in H.M. Ships by the use of stainless steels, stainless irons and certain high nickel alloys, largely through the susceptibility of these materials to fail by crevice corrosion in the presence of sea water.

Typical examples have been stainless steel shafts, propellers, underwater detection gear and sanitary services; and 13 per cent chromium iron turbine blading[34] and pump gearing. The corrosion of steam valve spindles made of 13 per cent chromium iron, 18/2 stainless steel or chromium-plated 18/2 stainless steel, which frequently takes place where the spindle is in contact with the packing, has been particularly troublesome. Not unexpectedly, in view of the nature of the attack, ships that have been laid up have suffered more severely in this respect.

In order to demonstrate more clearly the properties of these alloys, several series of tests were conducted on a range of martensitic, ferritic and austenitic stainless steels, on precipitation hardenable stainless steels and on high nickel alloys exposed under full immersion, half-tide and crevice conditions at the Corrosion Committee's exposure sites in Chichester and Langston Harbours. Crevice corrosion and galvanic corrosion tests were included under the full immersion conditions, and accelerated laboratory tests for assessing resistance to crevice corrosion were also carried out.

Space does not permit giving details either of the experimental work or of the results obtained, but the main points that emerged were as follows: crevices formed between closely fitting components or as a result of the settlement of marine fouling, both of which give rise to oxygen concentration gradients, resulted in severe local attack of all the alloys tested.



(× 1½)

FIG. 2—*Crevice attack around periphery of bolt hole in 17/10 austenitic precipitation hardened stainless steel*

The 18/8 austenitic stainless steel containing 3 per cent molybdenum (B.S.970: 1955 En 58J) was the alloy least affected. The precipitation hardenable stainless steels (range of compositions tested—chromium 16-18 per cent; nickel 3-11 per cent; copper 0-5 per cent; molybdenum 0-2 per cent; carbon 0·05-0·14 per cent) which are of interest because of their high strength, proved to be little better from the point of view of resisting crevice corrosion than the 18/2 type martensitic stainless steel (see Fig. 2). In addition, the crevice corrosion resistance of the alloys varied significantly with structure, a point which was investigated in more detail in the case of 18/2 type steel (to B.S.970: 1955 En 57) by Newcombe[35]. Coupling to an equal area of copper accelerated the attack whereas, with galvanic protection given by an equal area of mild steel, all materials behaved satisfactorily, crevice attack being suppressed.

It was concluded that none of the materials tested is suitable for service in marine environments involving immersion in sea water where there is any tendency for oxygen concentration gradients to develop, unless given some form of cathodic protection. Their good intrinsic corrosion resistance in well aerated sea water must always be overshadowed by their liability to severe local corrosion at crevices, which are impossible to avoid in practice. The reason for the attack is explained by the breakdown of passivity at areas locally deprived of oxygen, with the fully exposed and still passive areas acting as cathodes. The latter will usually be much larger than the crevices where corrosion is concentrated, with the result that deep pitting may occur.

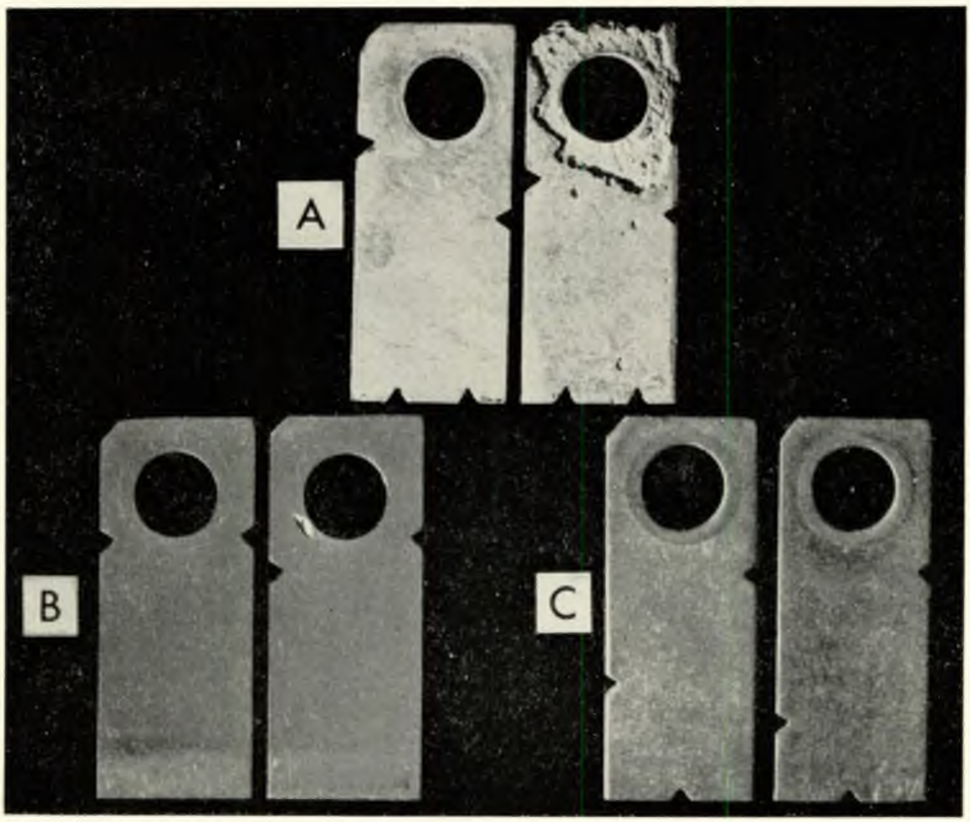
With regard to the protection necessary to render these alloys immune from crevice attack in sea water it was shown by Crennell[36] in laboratory tests that cathodic protection at a potential of −0·8 volts (relative to silver-silver chloride) is completely effective. This explains the suppression of crevice attack by coupling to mild steel in the exposure tests, described earlier.

Coupling to more anodic metals, however, whilst suppressing crevice attack of the stainless steels, will, of course, result in accelerated attack of the coupled metal, and this constitutes a further precaution to be observed when using stainless steels in marine environments. With some metals this may not be serious provided the anode/cathode area ratio is favourable. Rogers[37] states that brasses are appreciably affected only if the area of the stainless steel is large in comparison, whilst cast iron, steel and aluminium alloys do not suffer accelerated attack if their area is at least 4 times that of stainless steel. He does, however, comment that the use of stainless steels in sea water should, in general, be avoided[38].

Titanium

Because of the outstanding resistance of titanium to impingement attack, cavitation damage and especially to crevice corrosion[39], the possibility of its being used for special applications in naval engineering has frequently been under review. With the reduction in price over the last few years, this has seemed to become more and more an economic proposition, bearing in mind that the initial expense would be offset by freedom from maintenance costs and by greater reliability.

Up to the present, although several applications have been considered, its adoption has been confined to components of certain weapons where extreme reliability is vital, to tests in a submarine muffler tank, and for platinized anodes for cathodic protection. In the case of the muffler tank where the environ-



(× ¾)

A)—Aluminium alloy (99 per cent);
B)—18/8 (2.5 per cent molybdenum) stainless steel;
C)—Naval brass

FIG. 3—*Appearance of cleaned specimens after 13 months in the sea. The right-hand specimen of each pair was coupled to a similar sized specimen of titanium, the left-hand specimen to one of the same material*

ment consists of a mixture of hot sea water and Diesel engine exhaust gases, titanium test specimens were completely unaffected after a year's service.

Apart from economic considerations, however, doubts have been expressed as to the possible adverse galvanic effect that titanium might have on other metals and alloys to which it might be coupled in naval engineering practice. Accordingly an investigation was carried out at the Central Metallurgical Laboratory and subsequently at the Central Dockyard Laboratory, in which specimens of titanium sheet of commercial purity were coupled to some thirty alloys currently used in the Service. The two members of each couple were of equal area and were joined by insulated bolts to give an overlap of 1in. Controls of each material, self-coupled in a similar manner, were also included in the tests.

Examination of the specimens after one year's exposure in Chichester Harbour confirmed that titanium is a highly corrosion-resistant material for marine applications. It is, however, cathodic to most materials and for sea water immersion care must therefore be taken both in selecting the alloys to which it is coupled (see Fig. 3) (in general the more anodic the material the greater the increased attack) and also with regard to the relative exposed areas of titanium and coupled metal. In comparing the results obtained with those given by Cotton and Downing[39] for tests carried out at anode/cathode ratios of 1 : 10 and 10 : 1, it appears that with equal or more favourable anode/cathode ratios the attack in practice is likely to be relatively small except for highly anodic materials such as mild steel, zinc and aluminium alloys, which should never be coupled to titanium for exposure under marine conditions.

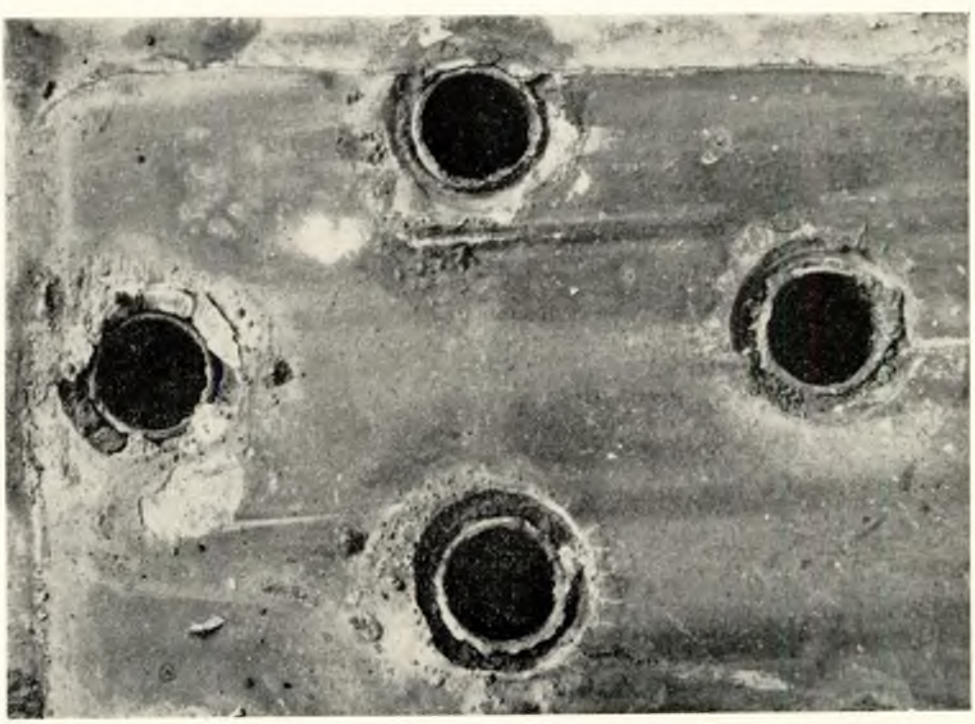
As a result of the evidence that has now been accumulated regarding the enormous benefits to be obtained from the correct use of titanium in marine engineering the Navy Department has recently placed a contract for the development of a titanium heat exchanger. It is planned to use this for all auxiliary systems, which could then be operated on closed fresh water systems, thereby eliminating the ever-present danger of contamination with sea water which now exists.

Brazing and Soldering Alloys

Brazing and soldering alloys need to be chosen with care in marine engineering where there is any risk of contact with sea water. Some alloys corrode under these conditions whilst others can cause accelerated attack of the metals with which they are in contact, leading in either case to the possibility of a leaking joint. Thus, copper/zinc brazing brasses have caused much trouble because of their tendency to undergo dezincification. The high cadmium alloys have also shown poor resistance in service when in contact with sea water. For example, an alloy of 80 per cent cadmium, 5 per cent silver and 10 per cent zinc which was used for sealing the copper tubes of an air/sea water heat exchanger into Naval brass tube plates, suffered rapid and complete disintegration, as shown in Fig. 4.

It was therefore thought desirable to assess which jointing alloys were most suitable from a corrosion standpoint and to this end an investigation was carried out on a comprehensive range of alloys by the Central Dockyard Laboratory[40] in which specimens consisting of a copper strip with a groove filled with the alloy under test (giving a surface area ratio of copper to alloy of 35 : 1) were immersed in the sea from a raft in Langston Harbour. After two years, the only higher melting point alloys that had proved completely satisfactory were the silver-containing alloys to B.S.1845 : 1952—Type 3 (average composition—silver 50 per cent; copper 15 per cent; zinc 16 per cent; cadium 19 per cent) and Type 5 (average composition—silver 43 per cent; copper 37 per cent; zinc 20 per cent). The phosphorus-containing alloy Type 6 (average composition—silver 15 per cent; phosphorus 5 per cent; copper 80 per cent) caused some attack of the adjacent copper, whilst the tin-containing brazing brass Type 12 (average composition—copper 60 per cent; tin 1 per cent; zinc 39 per cent) showed extensive dezincification.

Of the low melting point solders, the tin-rich types to B.S.219 : 1959 gave the best results, and especially the antimonial solders Grade B (average composition—tin 50 per cent; antimony 2·7 per cent; lead remainder) and Grade D (average composition—tin 30 per cent; antimony 1·4 per cent; lead remainder), although these are not suitable for soldering zinc and zinc coatings (nor possibly for some zinc-containing alloys) because of difficulties in soldering caused by the formation of a zinc-antimony compound. Of the antimony-free solders tested, Grade K (average composition—tin 60 per cent; lead 40 per



($\times 1\frac{1}{4}$)

FIG. 4—*Air cooler tube plate showing attack of high cadmium solder*

cent) performed well and appeared suitable for naval service. The rapid attack suffered by a high cadmium solder (cadmium 80 per cent; silver 5 per cent; zinc 15 per cent) confirmed the service behaviour of this alloy referred to earlier.

A somewhat similar series of tests was subsequently carried out on 70/30 cupro-nickel specimens brazed with three silver brazing alloys with a ratio of cupro-nickel to brazing alloy of 15:1. After one year's immersion the B.S.1845 Types 3 and 5 alloys again showed the best results and suffered only slight attack with minor pitting of the adjacent cupro-nickel. The joint made with the phosphorus containing alloy Type 6 on the other hand suffered severe interfacial attack which appeared to be stimulated by the presence of nickel phosphide in the diffusion zone. Since this zone can build up rapidly at brazing temperatures above 800 deg. C. (1,472 deg. F.) this type of alloy is inadvisable for brazing cupro-nickel to be used in naval service.

More recently, doubt has been expressed regarding the effect of the cadmium content of silver brazing alloys and a further investigation is in hand at the Central Dockyard Laboratory[41]. For this work, various alloys were brazed with a number of silver brazing alloys. It was found that with B.S.1845—Type 3 alloy (containing 19 per cent cadmium) and more particularly with a proprietary alloy (containing 26 per cent cadmium), joints made to 7 per cent aluminium bronze formed a corrodible zone round the joint due to diffusion from the brazing alloy; with the higher cadmium alloy, this zone completely dezincified in one year when immersed in sea water.

These brazing alloys are also unlikely to be suitable for aluminium brass, silicon bronze and two-phase brasses. For such materials it is necessary to use a cadmium-free alloy such as that complying with B.S.1845—Type 5, or a proprietary alloy containing 3 per cent nickel in addition to 50 per cent silver and 15 per cent cadmium, which appears to inhibit diffusion. The drawback to the use of the former in some circumstances, however, is its high melting range, 700-775 deg. C. (1,292-1,427 deg. F.). Type 3 brazing alloy can safely be used on copper, 70/30 brass, copper/nickel/iron alloys and gunmetals.

In addition to the avoidance of unsuitable brazing and soldering alloys, it should be emphasized that the danger of corrosion at joints can often be overcome or minimized, as for example in the case of pipe flanges, by designing so that the jointing alloy makes little contact with sea water. Even in such cases, however, it is desirable, as a second line of defence, to use jointing alloys acceptable from the corrosion standpoint. Present advice for naval practice based on the investigations just described, is to use B.S.1845—Type 3 or Type 5, or the alloy containing 50 per cent silver, 15 per cent cadmium and 3 per cent nickel (as appropriate) where a higher melting point alloy is required, and one of the high tin alloys for low melting point solder.

MISCELLANEOUS PROBLEMS

Cavitation Damage

Cavitation damage is a problem that is apt to be encountered in marine practice under conditions where metals are subjected to sea water moving at high speed with turbulent flow. Typical situations giving rise to cavitating conditions are low pressures, caused by a flow restriction such as a valve, or an obstacle such as a propeller blade; intense flow rotation that may result from a sharp bend in a piping system, or reduction in pressure, as in a pump working with a high suction lift. Propeller damage is perhaps the best known example, although, in naval service, serious cases of this are exceptional and more trouble is encountered in valves in sea water circulating systems, in engine cooling systems, as described under that heading, and on underwater fittings, such as rudders and shaft brackets.

It would be inappropriate, in the present paper, to discuss in detail the mechanism of this type of attack, for which various theories have been advanced as described in a comprehensive review of the subject by Godfrey[42]. In the case of most metals and alloys, however, it can be said that cavitation damage is the result of a combination of mechanical and electrochemical factors, the relative importance of which depends on the particular alloy and the environmental conditions. Corrosion fatigue may sometimes assist in the removal of particles of metal by initiating surface cracking.

The most satisfactory solution to the prevention of cavitation damage is to redesign the system so as to minimize the cavitating conditions, but when this is not practicable, the only palliative, unless the system is a closed one, is to use a material as resistant as possible to cavitation damage. To be able to do this, however, it is necessary to have some method of assessing resistance to cavitation damage and of studying the whole problem with a view to developing more resistant materials. Although several methods have been proposed and used for this purpose[43], consideration of these led Godfrey to the conclusion that none was entirely satisfactory and he has developed, at the Admiralty Materials Laboratory, an apparatus of the constricted tube type which is proving very promising[44]. From the limited amount of work so far carried out with this apparatus, titanium, austenitic stainless steel and nickel/aluminium bronze (complying with B.S.1400:1948—AB2-C) have been the least attacked of the metal specimens tested. Of the non-metallic materials, "Perspex" showed particularly poor resistance, P.T.F.E. and glass-reinforced epoxide were significantly attacked, whilst nylon appeared to be outstandingly good.

Seizure of Nuts and Bolts

The seizure of steel nuts and bolts in naval machinery was at one time a common occurrence, and was costly, both in manpower and material. It was particularly troublesome in steam lines, where the marine environment and the condensation that occurs under shut-down conditions aggravated the problem by corrosion. Moreover, the prevention of seizure under these conditions is especially difficult to achieve, since any treatment must be capable of withstanding prolonged heating at temperatures to 950 deg. F. (510 deg. C.).

Several possible remedies such as copper plating, electrolytic de-rusting and the use of various anti-seize compounds were tried in service, but were found to be either too costly or cumbersome for general application, or of only limited value. In collaboration with the Parsons Marine Engineering Turbine Research and Development Association, it was therefore decided to carry out a laboratory investigation of the problem. For this, assemblies were prepared consisting of sleeved ⅝-in. B.S.F. studs fitted with a nut and washer at each end, made from either B.S.970:1955—En 15(R) steel (1·3-1·7 per cent manganese) with nuts of En 6 steel (0·5 per cent manganese) or from 1 per cent chromium (plus molybdenum and vanadium) steel with nuts of 0·5 per cent molybdenum steel.

The treatments under test were applied either to the threads of the studs or to the threads of the nuts, after which the nuts were tightened to give a stress of approximately 20 tons/sq. in. in the studs. (A clearance of four to six mils was allowed between the studs and nuts, appropriately undersized bolts being used as necessary to obtain the same clearances on all specimens.). The assemblies were then subjected to a 1,000-hr. test by heating in air at 650 deg. or 950 deg. F. (343 deg. or 510 deg. C.), or by alternate heating and exposure in a salt spray cabinet, followed by unloosening torque measurements.

The best results were obtained with the molybdenum disulphide greases, followed by graphite greases, sulphocyanide treatment, phosphorus nickel plating, copper plating and phosphating, all treatments giving some improvement except phosphating. The untreated controls were so badly seized that several broke during the attempt to unscrew them.

As a result of these tests the better of the two molybdenum disulphide greases was introduced as a standard treatment in the Service and this has proved very effective. Similar tests at lower temperatures than those previously investigated are now in progress on other possible treatments such as P.T.F.E. tape.

Protection of Propeller Shafts

Considerable trouble has been experienced in the past with the corrosion, including deep pitting, of steel propeller shafts. A succession of different coatings was experimented with, but although some, such as zinc-rich type paints, gave excellent protection against corrosion, none was sufficiently resistant to mechanical damage. Rubber coatings were superior in this respect, but failed by settlement of barnacles, the shells of which penetrated the rubber and allowed corrosion to take place underneath. Eventually a solution was found by the use of epoxy resin reinforced with glass cloth and this is now the standard procedure. This coating has the advantage of possessing great resistance to mechanical damage and to the penetration of barnacles. It is, moreover, comparatively cheap and can be applied and repaired without specialist labour. The introduction of this coating caused a temporary problem by concentrating attack on a bare area of the shaft between the "A" bracket and the propeller, but this was overcome by extending the gunmetal liner into the propeller boss.

A further problem has been the deep circumferential pitting of steel shafts running in white metal bearings, particularly in way of the after stern tube bearings. Various theories have been advanced to explain this, but it is now thought to be due to lack of lubrication as a result of hardening of the grease in contact with sea water. It is hoped that the problem will be overcome by the substitution of an emulsifiable grease.

Preservation of Ferrous Parts of Machinery During Shipbuilding

During the fitting out period, which can extend up to 18 months, it is necessary to prevent superficial rusting taking place on ferrous parts of machinery, since rust particles can cause serious trouble and damage, for example where bearing clearances are small, when the machinery is put into operation. In many instances this can be achieved by the use of temporary protectives. Gearcases, however, present a special problem since any temporary protective applied must be compatible with the oil subsequently used. The practice at one time adopted was to pickle and degrease, followed by phosphating and finally an application of sprayed-on preservative, soluble in oil.

It was found, however, that for gearboxes it was impracticable to comply with that part of the phosphating specification which called for a fresh water rinse. Additionally, the preservative proposed as a final coating, proved to have an adverse effect on the lubricating oil. It was finally decided that an acceptable inhibiting treatment could be carried out by the use of a five per cent phosphoric acid solution in distilled water and that the final preservative should consist of the application of a coating of mineral oil.

FUTURE REQUIREMENTS FOR CORROSION PREVENTION OF NAVAL MACHINERY

Much has been accomplished in the past few years in preventing corrosion in naval machinery, the examples described in the present paper being but a few of the many problems investigated. No relaxation in this field can yet be contemplated, however, and success in the future will require much effort to be devoted both to technical and educational aspects.

On the technical side, it is to be expected that for some time to come there will continue to be a demand for greater power and higher power/size and power/weight ratios in naval machinery which, judging by past experience, will create conditions of increasing severity, more and more difficult to cope with from a corrosion point of view. It is of course true that the frontiers of knowledge of corrosion science and technology are also advancing, but it is unlikely that information will be available to provide the immediate answer to every future naval corrosion problem as it arises; there will still remain a need for experimental work both of an *ad hoc* and of a longer term planned nature to investigate the problems peculiar to naval service. Since such work is often time consuming, it is desirable that design authorities should consult corrosion specialists on probable future trends as soon as possible, so that there is a better chance when the necessity arises of recommending materials which, while fulfilling the many other requirements, will not be likely to fail by corrosion.

Educational aspects of future work are concerned with ensuring that better use is made of the vast fund of knowledge on corrosion that already exists. The first essential in tackling this problem is to engender throughout the Service an appreciation of the importance of corrosion prevention, which is still not as widespread as it should be. Secondly, much thought and effort are required to provide, at the appropriate level, information and guidance on the subject for naval and civilian personnel of all ranks and grades who are concerned with the design, operation and maintenance of machinery. This aspect, like the previous one has by no means been neglected to date, but certain shortcomings are apparent and further steps are being taken which include the preparation of a general handbook on corrosion at a fairly elementary level, guidance to designers in the form of data sheets giving the corrosion characteristics of alloys, as well as their mechanical and physical properties, and consideration of the appointment of full time corrosion officers in H.M. Dockyards, a scheme already in existence in Royal Australian Naval Dockyards.

Finally, it should be emphasized that the efficiency with which corrosion prevention in the Royal Navy can be tackled in the future will depend very much on the continued co-operation of organizations outside the Service, which has proved so valuable in the past. Great importance is attached to the assistance that can be rendered at home by the D.S.I.R. Research Associations and by certain sections of industry, and abroad, by the corrosion committees of the Commonwealth Navies, and by the U.S. Navy Department's Bureau of Ships.

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Discussion

DR. U. R. EVANS, F.R.S. said that Mr. Kenworthy was to be congratulated on a masterly paper of great practical importance. He had no particular points of criticism to offer, in contrast to his experience during the 75 years of his life, for he had often at the end of a corrosion paper felt a great desire to quarrel with the lecturer, and sometimes to murder him. There were two reasons why he had no criticisms to offer; first, it was a very admirable paper, and, secondly, Mr. Kenworthy had dealt with a large number of matters on which he, Dr. Evans, was quite unqualified to express an opinion. However, there were three points on which he would like to make suggestions.

The first concerned the so-called hot-spot corrosion. No doubt numerous factors, such as differential aeration, played a part, but the determining condition seemed to be non-uniformity of temperature, in time as well as in space. The simple notion of a small hot spot suffering intense anodic attack, with the large cool area around it as the cathode, did not accord with the observed facts; nor was it scientifically acceptable, since electrochemical considerations, which he would not discuss, would lead one to expect that normally the hot area would be the cathode. If, however, there was violent fluctuation of temperature with time, the sudden expansion or contraction of the metal would probably rupture the protective film, which had different mechanical properties, and repair might not keep pace with rupture; in that event, the small bare area would be the anode, and the cathodic reduction of oxygen on the large film-covered area around would direct a large current upon it, causing intense attack. If the cooling or heating was slow, healing might occur and prevent that effect. Everyone would agree that further experimental work was needed, but he suggested, it should include not only experiments introducing different hot-spot temperatures but also experiments with different heating rates and cooling rates. If it was found that rapid temperature fluctuation in time was important in causing the attack, the practical recommendation was obvious. No doubt for active ships it would be unrealistic to suggest that changes should never be made in a hurry, but for accommodation ships it might be easier to foresee requirements, and presumably sudden changes were generally avoidable. If new work should establish the fact that film cracking, due to sudden temperature changes, was important in causing the localized corrosion, it would help also to explain why laboratory experiments, as commonly conducted, often failed to reproduce service failures produced under conditions where heat passed through the tube walls.

His second suggestion concerned the steel-spraying of gunmetal doors. Would it not be possible to electro-deposit iron on the doors? That would avoid the risk of the sprayed coating being insulated from the gunmetal by an oxide film, and also avoid the passage, into the tubes, of cementite and manganese sulphide particles, released from steel by the anodic attack upon the iron phase. Such particles were a potential source of danger. The electro-deposition of iron was no more difficult than the plating of nickel, provided that continuous filtration was carried out.

The third point concerned steel protector blocks. There also, one of the relatively pure forms of iron would seem preferable to steel. The difficulty arising from loss of contact could probably be overcome by filling crevices with a suitable jointing compound. The insulation of the blocks from plates experienced at one time did not, he suggested, arise from corrosion product formed on the area where the block was pressed against the plate, since no water could have penetrated to that area, but at the area around where the block was separated from the plate by a narrow crevice. The corrosion product, occupying bigger volume than the metal destroyed in producing it, would lever the block away from the plate. Those levering forces due to voluminous corrosion products often played havoc with land structures, in the days of riveted construction, leading to the snapping of rivets on bridges. They also caused distortion of steel railings built from designs which involved crevices; the remedy was to fill the crevices with a suitable paste, usually containing a mixture of red and white lead. On aircraft, other mixtures containing zinc, barium or strontium chromate were used in rather analogous situations. It was suggested that a paste could be found suitable for application to both the surfaces before they were brought together; it would be pressed out from the actual area of contact, but would fill the crevices around. There might be reluctance to apply an insulating mixture to areas where contact was required, but the jointing compound was no better an insulator than air, and, if suitably chosen, should be pressed out from the contact areas. It was believed that some of the problems of crevice corrosion on stainless steel could also be solved by filling up the crevices.

CAPTAIN J. SIDGWICK, R.N., said that he regretted to admit that his first impression on superficially reading the paper was that not a great deal had changed during the last ten years since he was intimately connected with the author on the Admiralty Corrosion Committee. However, a more careful reading had indicated to him that he was wrong and that a great deal had changed. He thought that his misleading impression arose from the fact that some of the examples quoted had been successfully dealt with some years ago, and also the fact that the tests that one had to conduct to prove cures to corrosion problems had to be carried out over a number of years.

There was one field which was new to him, and he thought that advances in that field were the particular achievement of the author. The field concerned the growing problem of corrosion by fungi. Another field in which progress had been made was that of making people corrosion conscious. Corrosion prevention was not a matter which could be left to the few experts, however knowledgeable they were. As shown in the paper, the man in the drawing office, the factory, the shops or on the slips of the shipyard and the man in the machinery spaces at sea all had their parts to play, and they could, in their ignorance, wreck the best efforts of the experts. It was essential to disseminate, in language understandable to the non-expert engineer, the hard-won experience and knowledge of the experts. The paper was an excellent example of meeting that need.

To his list of those involved he might add storekeepers. Mr. Kenworthy might remember that there had been an occasion when a small number of plain brass tubes became mixed up with a stock of aluminium brass tubes, and he might remember the trouble they had in sorting the sheep from the visually-indistinguishable goats. An isolated case of such a mix-up had been found recently in a heat exchanger at the Admiralty Engineering Laboratory.

Since the author had mentioned work done at the Admiralty Engineering Laboratory on inhibitors, the following points might be of interest. Mr. Kenworthy had mentioned the widespread use of soluble oil as an inhibitor in internal combustion engine coolants in the Merchant Navy. He believed that it was used as an inhibitor in fresh water, not in anti-freeze. It had been hoped that it might make a useful inhibitor in glycol solutions, but it had been found by the Admiralty Engineering Laboratory that the subsequent breakdown of glycol to acidic products occurred more rapidly. At the Admiralty Engineering Laboratory they were now evaluating a proprietary anti-freeze formulation which used benzotriazole as the copper inhibitor. The results so far were promising and showed that the inhibitor depleted more slowly than NaMBT.

MR. S. H. FREDERICK said that he wished to ask three questions. First, with reference to the dezincification of the outlet tube plates in some ships and the re-introduction of cathodic protection, the author stated that zinc alloy anodes were chosen in preference to mild steel. As the wastage of such anodes was generally high when used to protect the inlet tube plates, he wished to know whether that was also the case at the outlet tube plates. Would the author tell them what the average life of the zinc anodes was and what the recommended periods between inspections were.

On the subject of condensers, had the author any experience of the use of sprayed plastic coatings on doors? There would appear to be considerable promise in such an application, provided that the bond strength was adequate and reliable. With regard to glass fibre epoxy resin doors, could they be made strong enough for main condensers in large tankers where they might be installed 30ft. or more below the water line?

Reference was made to the investigation of the problem of the seizure of steel nuts and bolts which was carried out in collaboration with the Parsons Marine Engineering Turbine Research and Development Association, and it was interesting to note the success of the molybdenum disulphide greases in the Service. Pametrada had also found them very effective in preventing the seizure of ferritic steel turbine cylinder joint bolts operating at temperatures up to 950 deg. F. (510 deg. C.). In the case of threaded assemblies, made in austenitic stainless steels, however, the problem of seizure was a much more difficult one. At ambient temperature, there was some benefit to be gained by the use of different austenitic steels for the mating parts, but under conditions where the operating temperature was in the region of 1,200 deg. F. (649 deg. C.), that practice, together with the use of thread lubricants, and a very large number had been tried, could rarely be relied upon to give complete protection against seizure. Aluminizing of bolt threads had given good results, but cases of serious thread embrittlement had been encountered following that treatment. The author's experience and comment on this problem would be welcomed.

MR. C. BRECKON, B.Sc. (Member) said that he wished first to congratulate Mr. Kenworthy on an excellent paper covering a very wide field indeed, and he was sure that the paper would be used as a reference by many people interested in corrosion problems in a marine environment. One of the main reasons why he wished to comment was to give a few additional observations on some of the points made in the paper which might be of value because of that "reference" aspect.

His first point arose in the second paragraph on page 150, where Mr. Kenworthy referred to the occasional trouble with aluminium brass tubes due to impingement attack at the inlet end, and again, on page 152, there was a reference to impingement attack and the beneficial effect of "mild steel protector pieces" in the case of aluminium brass tubes. He very srongly endorsed the statement that where aluminium brass tubes were fitted there should be steel protector blocks or a properly controlled system of cathodic protection.

The whole of his working life had been with a company concerned with the manufacture and supply of non-ferrous tubes for condensers, heat exchangers and the like, and he was quite certain that the most serious cause of corrosion in condensers at the present time and in recent years had been impingement attack at the inlet ends where fully protected water boxes were in use. There were innumerable cases of that, but his point was that that by no means applied to aluminium brass in isolation. It was equally important in the case of 70/30 cupro-nickel, and if there was no corroding iron in the water box or no adequate electrolytic protection, then there was liable to be corrosion by impingement attack at the inlet ends of tubes in any of the alloys likely to be used with sea or estuarine water. That attack was confined to the tube ends, and the cure was to ensure that there was an adequate area of corroding iron, electrolytic protection or, in some instances, mechanical protection by sleeves or inserts at the inlet ends. Many instances were known where trouble had occurred and had been corrected by those various techniques in isolation and in some instances in combination.

The second point on which he wished to comment was the performance of the experimental copper/zinc/tin alloys tested in naval vessels. In one of those trials, the experimental tube had been in service in a drain cooler, in comparison with the standard aluminium brass alloy used in those drain coolers. For trial purposes, 12 groups of tubes were installed, and they were all removed after approximately 4½ years' service. The condition of the tubes, on a recent examination, did not quite accord with what had been stated in the paper, and he had

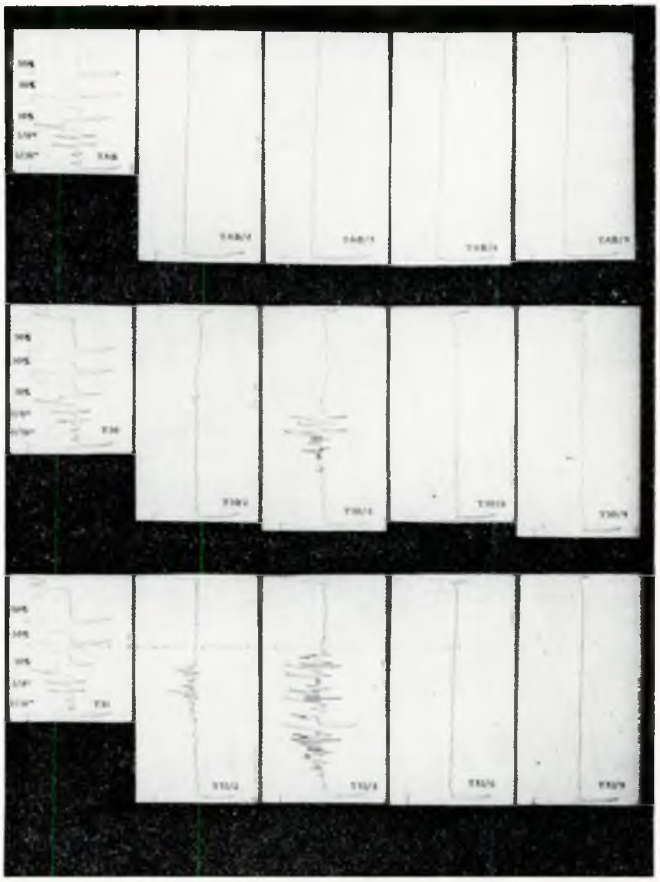

FIG. 5—*Representative "Corrodograph" traces of drain cooler tubes of aluminium brass (YAB), copper/16 per cent zinc/6 per cent tin (Y30) and copper/10 per cent zinc/8 per cent tin (Y31)*

suggested to Mr. Kenworthy that they should refer to that investigation in the discussion, which Mr. Kenworthy had welcomed. Although the trials showed that the standard Yorcalbro and some of the tubes in both of the special tin-brasses were free from any significant corrosion throughout their length, several of the tin-brass alloy tubes were locally very severely corroded, the pits penetrating to a depth of up to 60 per cent of the tube wall. Fig. 5 showed "Corrodograph" traces of all three alloys from four of the groups.

The tin-brass alloys most severely affected were those nearer to the steam inlet or to which incoming steam had direct access, and the cause of the corrosion was hot-spot attack. The present was not the time to go into greater detail on that subject, but the evidence showed that in that respect the tin-brasses suffered from the same shortcomings as 70/30 cupro-nickel in the case of hot-spot corrosion in plant such as drain coolers or any other plants where there was a possibility of high local temperatures, whereas standard Yorcalbro had behaved very much better than those alloys in those particular circumstances.

With regard to polluted waters, he had recently examined similar tubes from a condenser of an estuarine power station, and in that case, where high temperatures did not occur—"high" meant higher than the normal vacuum in that context—the tin-brasses were not as severely attacked. They were, however, marginally inferior to both the 70/30 cupro-nickel and aluminium brass, the performance of the two latter alloys being similar.

He did not think, therefore, that any glowing future for tin-brasses had yet been demonstrated. It had been claimed that they were particularly resistant to badly polluted waters, but, although several trials had been carried out, there was as yet no substantiation from practical experience of the claims made. It was felt that complete testing in a variety of circumstances would show that the situations in which the tin-brasses were better than, or in many cases as good as, currently available standard alloys would be very few.

His third comment was in connexion with the duplex 30 per cent nickel and 10 per cent nickel tubes referred to on page 151 of the paper. One should bear in mind that it was rather different from the normal duplex tube frequently used in heat exchangers where there were substantially different products on each side of the tube. The tubes were normally made by manufacturing each of the constituent tubes separately and then drawing them together during one of the final operations. In the case of the 30 per cent and 10 per cent nickel duplex tubes, the constituents were, in fact, extruded as one from a composite billet and subsequently processed as a single tube so that there was a complete metallurgical bond across the interface, and the interface itself was somewhat irregular and diffused. No experimental service results were yet available, but trials were in hand, and it seemed that they might prove to be a very useful development for certain rather special circumstances.

With regard to the data sheet shown for Admiralty brass, the impingement resistance was given as 10ft./sec. He wondered whether the Admiralty had any particular way of interpreting that, because he suspected that if it were interpreted by engineers as meaning that condenser tubes could be used with seawater at an average speed of 10ft./sec.—if the sheet was right—there would have been no need to have had aluminium brass and cupro-nickel way back in the thirties. However, he suspected that the sheet was wrong and that a much lower figure would be safer. He thought that there would be very few Admiralty brass condenser tubes which would stand more than a few months' operation at that speed due to impingement attack.

With regard to the comment by Dr. Evans on steel protector blocks, one of the most interesting cases of the effect of impurities in pure iron that he had come across, was where someone had used ground shot of cast iron to clean water boxes for rubber coating. Some of the pieces had got into the tubes, and the pieces had rusted on the tubes. None was bigger than a match head. Some of the tubes had failed. Around the nodules of chocolate coloured rust there were areas where there was a chocolate brown film, and around some of these there was a horseshoe shaped impingement pit. If one had to put a partial obstruction in a tube to cause local turbulence, one would pick iron to do it, and yet there were pieces of iron apparently causing that trouble. The explanation was that when they cut through the nodules, in all cases where there was still some of the cast iron left there was no corrosion around the area. There was just the small chocolate brown area. In those cases where there was corrosion, all the iron had gone and there was just a graphite skeleton left, and it was the graphite which had stimulated the corrosion. The turbulence was very small, but the area around was corroded because of the galvanic effect of the graphite. They had advised people not to use cast iron protector plates for that reason. They had recommended—and it had been very satisfactory—the use of a low carbon, the purest iron that one could get commercially, but not cast iron.

Captain A. H. Little, R.N. said that he had been associated with Mr. Kenworthy and with the Admiralty Corrosion Committee over the past three years. Those parts of the subject with which he himself had been concerned seemed to him to have been very well dealt with in the paper.

However, he suggested that there were one or two places where a little more emphasis might have been added to Mr. Kenworthy's remarks. In particular, he referred to Mr. Kenworthy's dezincification problems with rolled Naval brass tubes and plates. Perhaps the troubles had not been quite so sparse as the wording of the paper might lead one to believe. It was probable that the cases had never been reported and certainly had never been investigated thoroughly by a corrosion engineer, as some of the more recent land examples had been, until comparatively recently.

One facet of the problem which occurred to him was whether they should not make a rather greater differentiation between main condensers and small heat exchangers. The conditions under which these operated were quite different. It was possible that they might be leading themselves into a trap. If one thought of the main condenser system as large, there was a certain scale effect, and it was designed for a known water speed which could probably be adhered to in service. However, he was not sure that that was true of the conglomeration of small heat exchangers which existed in some ships at the present time. While it was true that water speeds in those small heat exchangers were at the design speed at full speed, he was not certain that that was always the case when the ship was getting under way or shutting down. More attention should be given to some form of balancing in the cooling water system to supply the large number of small heat exchangers under all conditions when the ship was operating. He wondered whether everything possible had been done to iron out the turbulent conditions which he sometimes thought occurred inside some of the small heat exchanger boxes.

Finally, with regard to the remarks about protection in certain instances, he was left with the impression that nothing was safe unless it was protected. He would hesitate to enter into any discussion as to which was the right protector to use. It seemed to be agreed these days that even small differences in potential in metals, or within metals, could lead to corrosion, particularly if no steps were taken to match them or to protect them. It seemed possible that protection might be necessary in every system in which they were interested.

Dr. J. T. Harrison spoke of the experience of the Central Electricity Generating Board in the use of ferrous sulphate as an inhibitor for preventing corrosion of condensers. He said that the author mentioned this treatment on pages 150 and 151 of his paper. It was first used in America, with considerable success, and he understood that it had been enlarged upon there, and it was now being used both by the Central Electricity Generating Board and the South of Scotland Electricity Board.

At one Scottish power station there had been corrosion of the aluminium brass condenser tubes in the first three 120mW units, resulting in many failures during the first few years of operation. Injection of ferrous sulphate into the cooling water was commenced on the first set in February 1962, and on the second and third sets later in the same year. On all those units there had been a dramatic cessation of tube failures since that time.

In England similar treatment had been used at two power stations, at one using aluminium brass condenser tubes where it had met with success, and at one using cupro-nickel condenser tubes. At the latter, Tilbury, there was not yet sufficient evidence to determine whether the treatment had been successful. He would be interested to hear from Mr. Kenworthy whether he had had any experience of that treatment.

Mr. H. S. Campbell, B.Sc. (Associate) said that the high tin-brasses were not really materials likely to be much used in naval or marine service. They had been developed by the British Non-Ferrous Metals Research Association as experimental alloys for possible use in place of 70/30 cupro-nickel in the condensers of power stations on exceptionally polluted estuaries. Under these conditions 70/30 cupro-nickel sometimes failed by localized impingement attack.

The tin-brasses had been tested as far as possible in the laboratory, in jet impingement tests using sea water polluted with hydrogen sulphide, and had behaved exceptionally well. Experimental condenser tubes had then been produced and had been installed in three of H.M. Ships, as mentioned by Mr. Kenworthy, and at Tilbury Power Station. The ship trials had revealed susceptibility to hot-spot corrosion, as had already been mentioned, but 70/30 cupro-nickel was also prone to this type of attack.

At the beginning of the tests, the cooling water at Tilbury had been highly polluted, but conditions had since improved and, as mentioned by Dr. Harrison, ferrous sulphate dosing had been introduced. The conditions were therefore no longer those under which the high tin-brasses would be expected to show superiority over other materials and it appeared from a recent eddy current probe examination of the tubes at Tilbury (upon which, he believed, Mr. Breckon had partly based his remarks) that even aluminium brass was now satisfactory.

Tests were continuing at Tilbury and at another station, where conditions were believed still to be bad, but, for the present, the value of the high tin-brasses, for use under the exceptionally polluted conditions for which they were intended, remained unproven.

Dr. P. T. Gilbert, B.Sc. (Member) said that he had been associated in one way or another for some 20 years with the work that Mr. Kenworthy had described, and he could say from his own knowledge that the problems involved were extremely complex.

He thought that no one but Mr. Kenworthy could have provided such an excellent summary of such a large amount of corrosion experience in the naval marine engineering field.

He had selected two topics for discussion. The first was the corrosion known as hot-spot attack, namely a localized attack occurring on the cooling water side of a tube in positions corresponding to local high temperatures on the vapour side. As Dr. Evans had said, earlier attempts to understand the mechanism had not been entirely successful and, indeed, some of the electrochemical measurements made had given potential differences that were the reverse of those required to explain the hot-spot effect. A recently published thesis entitled "Thermogalvanic Corrosion of Copper and Copper Alloys" by Dr. P. J. Boden, of the Central Electricity Generating Board, showed, however, that when heat was passing through the metal the hot spot was normally anodic to the surrounding metal. Another interesting observation was that considerable corrosion occurred as a result of current flow between local anodes and cathodes within the hot-spot area. Dr. Evans might well be right in saying that cracking of the surface films as a result of temperature differences could lead to initiation of hot-spot corrosion. However, once attack had started, conditions might well be relatively steady with local hot spots continuously present. Subsequently, therefore, the progress of attack would presumably depend on factors other than the breaking of the protective film that might have initiated the attack.

Whatever the precise mechanism of the phenomenon was, it had been established that some copper alloys were more susceptible than others to corrosion under the influence of local high temperatures and, in the cupro-nickel range of materials, both laboratory and practical experience showed that the 10 per cent nickel alloy was superior in that respect to the 30 per cent alloy. In view of the excellent behaviour in sea water of both these materials under normal temperature conditions, one was tempted to ask whether the decision to standardize on 70/30 cupro-nickel for all re-tubing and for all new condensers and heat exchangers (including units such as drain coolers operating at relatively high temperatures) ought not to have gone in favour of the 90/10 copper/nickel/iron alloy.

The second subject that he wished to mention was the pitting corrosion of condenser and heat exchanger tubes, associated with pollution of the cooling water. Mr. Kenworthy had mentioned the formation, on the tubes, of complex cuprous sulphide films and there was no doubt that, under extreme conditions, hydrogen sulphide in the water could give rise to the formation of copper sulphide deposits that appeared to stimulate pitting, often violently. Mr. Kenworthy had also mentioned experiments in which cathodic films containing the organic sulphur compound cystine were produced.

It was perhaps not widely known that abnormal films could sometimes develop on condenser tube alloys in fully aerated waters that were not polluted in the normal sense, namely by sewage or industrial effluents. The nature of the films concerned was unknown, though it was possible that sulphur compounds were again involved. Their characteristic was that they were highly cathodic, but apparently not self-healing. When they were locally damaged, therefore, severe impingement attack set in, and rapid failure could occur. That type of trouble had occurred at several sea coast or estuarine power stations in the United Kingdom and abroad and, with aluminium brass tubes, potentials between 80 and 280 mV, cathodic to the value for a tube with a normal protective film, had been measured. There was, therefore, a considerable driving force stimulating local corrosion if the film broke down.

A successful remedial measure, which had been applied in such cases, was that mentioned by Dr. Harrison—the adoption of ferrous sulphate treatment of the cooling water. There were documented histories of a number of cases where such treatment had proved successful. Laboratory tests showed that the addition to the water of a small amount of ferrous sulphate —a few parts per million—resulted almost intantaneously in a reduction of the highly cathodic potential of the filmed surface to about the normal value for a good protective film. Hydrated iron oxide films formed all over the tube surfaces, including areas that were previously corroding actively, and attack was stifled. The treatment had been applied successfully on board ship, and, whilst the circumstances demanding its use might be infrequent in marine service, the results quoted served to emphasize the benefits, referred to several times in Mr. Kenworthy's paper, of having iron salts or corrosion products present in the cooling water used in heat exchangers containing copper alloy tubes.

He also wished to emphasize a point raised by Mr. Breckon, namely the importance of the provision of some measure of cathodic protection in condenser and heat exchanger water boxes. Under conditions of impingement and turbulence such as occurred at the inlet ends of condensers and heat exchangers, even very small differences of potential between different components could significantly increase attack. In the absence of cathodic protection severe tube end corrosion could occur both with aluminium brass and with cupro-nickel tubes, and the tube plates could also suffer severe impingement attack. Small local differences of potential could be swamped by cathodically protecting the entire system. In the past, cast iron water boxes had provided such protection but, with the adoption of effective coatings, such as rubber linings, tube end and tube plate trouble could be avoided only by suitable measures such as fitting sacrificial soft iron blocks or properly designed, operated and maintained systems of applied current cathodic protection.

COMMANDER J. S. L. STEEDMAN, R.N. said that Mr. Kenworthy's admirable paper presented with great clarity a concise and most informative survey of a wide and complicated attack field.

There was a small addition that he would like to make on the subject of polluted waters. Following the rather serious tubing trouble mentioned on page 150 of the paper, the Ministry of Defence had written to the appropriate authority and was gratified to find that it was fully aware of the problem and was acting vigorously. While some amelioration could be hoped for in future, there was no doubt that, however actively the authority pursued the matter, they would still have to deal with that sort of problem.

MR. J. B. COTTON referred to hot-spot corrosion. He did not think that anything like enough work was being done on corrosion under heat transfer conditions. It had been seen by his company that, particularly in the case of chemical plant corrosion where they were dealing with heat transfer surfaces and heating coils in the newer metals, such as titanium, one could not get the remedy for a heat transfer problem unless one did actual heat transfer corrosion tests. In experimental work it was nearly always essential to arrange also for replenishment of the corrodent fairly frequently. Failure to do this could lead to false results.

He could not let discussion on titanium go without comment. He could endorse everything that Mr. Kenworthy had said about it. It was a pity that it had been necessary to wait seven or eight years to see the first significant British titanium marine installation using sea water. About eight years ago they had managed to get a few titanium tubes into a power station in the United Kingdom, and they had done extremely well under very arduous conditions. One had to be careful about the cathodic part that titanium could play in any bi-metal construction. That was not dangerous if there was a large area of the other metal to the titanium, but when one was getting down to areas of equal proportions one should start to insulate the titanium from the other metal.

Next, there was the aspect of inhibition. People in the condenser field and the heat exchanger field had long known that if one gave a condenser tube a good start in life that was half the battle in producing protective surface films. The treatment with sodium dimethyl dithiocarbamate followed from some work that he and his colleagues were doing for a completely different purpose in the laboratory at Witton. He had two samples to show what the organic inhibitors could do. One was a piece of copper which had been washed in water and exposed to three per cent salt mist, and had become badly stained. The other was a piece of the same copper sheet treated with benzotriazole for about one minute at about 140 deg. F. (60 deg. C.) and, irrigated with water for nearly a day and which had remained bright when exposed to the same conditions as the other. Such organic inhibitors opened up a new field in pre-treatment of metal surfaces and there was a strong possibility that pre-treatment of this sort could give condenser tubes a good start in life. He looked forward to the results of the experiments now going on.

He wondered whether Mr. Kenworthy could express any opinion about the plate type heat exchangers which were now being used for cooling water. He would like to know what the experience was in the Admiralty, of those plate type heat exchangers.

MR. A. MCCONNELL said that Mr. Kenworthy had mentioned, in passing, that very little trouble had been experienced in the use of gunmetal castings for doors. He thought that was true, but it was not true for gunmetal castings used in pump casings, particularly where they were installed in ships operating in tropical waters, and especially on inshore work. His company had for a number of years felt that the performance of the cast components depended a great deal on the alloy chosen, and he thought that this conclusion was borne out by the work done by the British Non-Ferrous Metals Research Association in recent years.

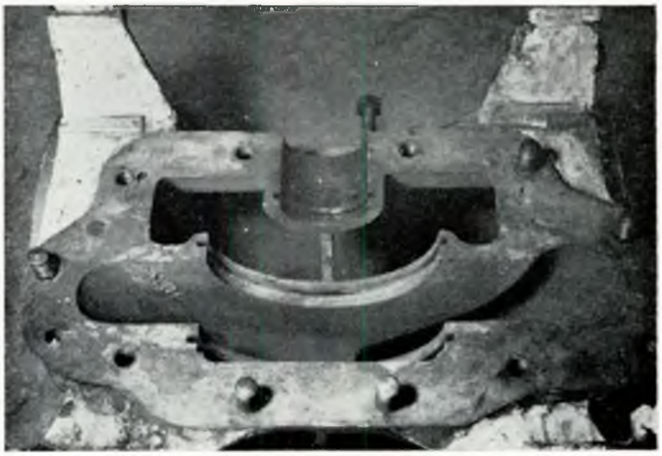

FIG. 6—*Back half of pump casing—LG4 type*

It was not always easy to show that improvements made on the basis of laboratory work could be substantiated on full-size equipment because of the great number of variables involved. For this reason, they were very interested recently when a split casing pump was made available to them for examination. One half of the casing of this pump had been made in one type of gunmetal, and the other half in a different gunmetal.

The pump was operating in sea water under very bad conditions, and the aluminium bronze impeller had suffered severely from cavitation troubles. Fig. 6 showed the half of the pump which had been made in a gunmetal similar to B.S. 1400 LG4 with about eight per cent tin, two per cent lead, two per cent zinc and three per cent nickel. There was only a slight area of cavitation-erosion wastage, just at the split in the casing.

Fig. 7 showed the second half of the same casing, which had been made in a typical LG2 composition, with five per cent each of tin, zinc and lead. Severe wastage had occurred on all surfaces of the casting exposed to fast-flowing sea water, indicating the poor properties of LG2 relative to LG4 gunmetal, in these particular conditions.

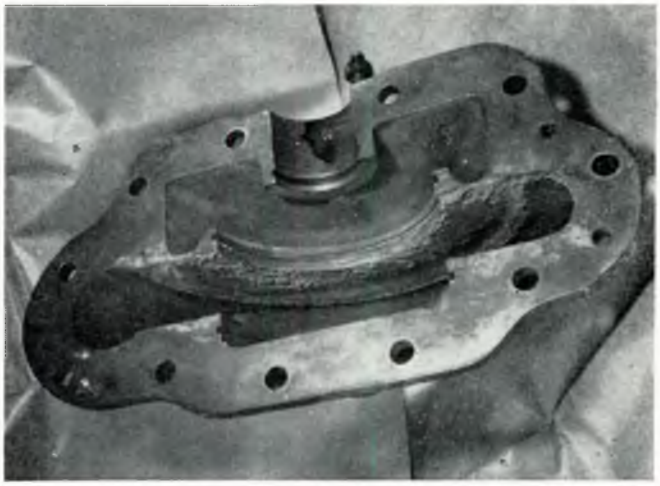

FIG. 7—*Front half of pump casing—LG2 type*

MR. S. G. CHRISTENSEN (Associate Member of Council) said that his remarks concerned what was referred to in the paper as impingement attack in condensers.

In reading this paper and referring to other papers on this subject and noting the nature of the troubles experienced, one found that, in certain circumstances, materials used in construction of condensers, tubes, etc. might be similar, their physical characteristics identical, designed cooling water velocities similar, hot side and cold side temperatures similar, yet one system would give considerable trouble and the other none.

This must lead one to think that there was some hidden factor at work in one system causing damage. He felt that this hidden factor was somewhat variable, and it was this that he wished to speak about.

Two experiences in his career had shown that a considerable amount of air in the form of a stream of air bubbles might pass into the sea intakes on the bottom of a vessel. The first experience was whilst serving as an engineer officer, and concerned some echo-sounding equipment. The second experience concerned the performance of a small evaporating plant, which functioned well whilst the vessel was in port and at anchor, but fell away to a small proportion of its rated output when the vessel was under way.

In the case of the first experience, use of the air leak-off cocks connected to the transmitter and receiver bells put matters in order, and modifications made to water inlet boxes corrected the working of the evaporator plant.

However, both experiences indicated, and the action taken confirmed, that considerable amounts of air passed under the bottom of a vessel whilst steaming at sea.

Whether this air passed into a sea inlet connexion would depend on many factors, which might be readily envisaged.

From this experience he felt that air passing under the bottom of a vessel and into a sea inlet might be the hidden factor or variable.

Had the Admiralty research establishments carried out any research into this matter of air passing along the bottom of a vessel at sea, with a view to establishing an optimum position for fitting sea inlet valves.

If any research had been done then it would please him to know of when and where it was published.

MR. H. CAPPER, B.Sc. added his appreciation of Mr. Kenworthy's effort in gathering all the information together and presenting it in such readable form. He thought he was not exaggerating when he said that the Navy Department's materials organization as a whole probably knew more about ships material than any other in the world.

His company had used aluminium brass tubes for main condensers with fair success in the past, the chief trouble being due to interpolers of naval brass about twelve years ago. They had, however, now changed to 70/30 cupro-nickel for all sea water cooled heat exchangers because of its thorough reliability. He recollected that a galley drain cooler, tubed with 12 per cent tin bronze had been installed in a cruiser, which he thought was H.M.S. *Cumberland*. If it still existed, the cooler should now have had ten or twelve years' service. He believed that he had read that the ship had gone aground, and it would be a normal occurrence in trials in ships, if the point of impact had been exactly in way of the particular drain cooler. Perhaps Mr. Kenworthy would say whether he had any information about that cooler.

With regard to tube plates and protector blocks, normally his company did not have much trouble with inlet end erosion or tube plate erosion, although they did not use protector blocks. However, they had recently had some very slight inlet end erosion and tube plate erosion in a mail ship, and some protector blocks were put in to see whether they would have the desired effect. Those concerned had not put in as many as he had wanted them to do, but four slabs, each 6in. square, were attached to the stay bar cap nuts and with an inlet tube plate area of 44 sq. ft., they represented an area ratio of 1:22. That pointed to what Dr. Gilbert had mentioned about the very small potential differences which were probably necessary to overcome erosion of this sort. After one voyage the erosion had been cured, but he was not sure whether it would continue to be so.

On heat exchangers with rubber covered or non-ferrous water boxes, his company normally metal-sprayed with iron, the bores of inlet pipes up to 18in. from the flange, which seemed to be quite successful. He was interested in what Dr. Evans had had to say about the necessary purity of the iron. It was essential to sand or shot blast before metal spraying in order to obtain a good electrical bond between the sprayed coating and the basis metal.

There was still a need for a satisfactory condenser door material. Cast iron was not very satisfactory because, apart from the necessary renewals, when the iron graphitized pieces of graphite might become dislodged and stick in the tubes. Graphite was, of course, highly cathodic to the tube material. His company had had an option in its new building specification for some years for the provision of moulded plastic doors, but manufacturers did not seem to regard those as an economic proposition as yet. He hoped that the Admiralty had success with the glass fibre epoxy resin mouldings for doors.

There was no doubt that aluminium brass was a satisfactory material for sea water pipes, provided that all the necessary precautions were taken in fabrication procedure and assembly. In one of their mail ships, where that care was taken in building, not a single failure had occurred in the 4½ years of service so far. On the other hand, they had had too many failures in other ships due to stress corrosion cracking, the stress being imposed externally due to faulty pipe assembly or internally due to failure to anneal after cold bending. Because of the apparent inability of marine coppersmiths to comply with the specified fabrication procedure, they were seriously considering the 90/10 cupro-nickel for future construction.

They were very interested in Fearon's work at the Admiralty Engineering Laboratory on the viscous damping method of reducing water-side erosion of cylinder liners. That seemed to be tackling the problem at its source, but they would like to know what the increased oil consumption was with the positive pressure of oil between the piston and cylinder wall.

The disadvantage of soluble oil as a coolant, due to its alkalinity, had been mentioned and he would like to know whether any other disadvantages of soluble oil were known, as, in the cooling systems of most merchant marine engines, aluminium alloys were not commonplace.

With regard to high tensile brass, the decision to eliminate except for propellers was made some years ago by the Admiralty, and he was associated with this decision. He was glad to see that that material was very little used now in marine practice. Considering the alternative aluminium bronze to B.S. 1400-AB1, he rather thought that its castability would be poor even compared with the AB2 alloy which many non-ferrous founders found difficult enough. He wondered whether Mr. Kenworthy could enlarge upon that aspect of AB1.

He would endorse all the points made concerning the liability of stainless steels to differential aeration corrosion, and he thought that the point about the relative area of aluminium alloy to stainless steel of 4:1 was important. That meant that stainless steel bolts, usually the 18/8 variety, could safely be used for fastening aluminium alloys. On the other hand, he had seen many instances of galvanized mild steel bolts corroding preferentially when used for joining aluminium, and he presumed that that was due to the aluminium oxide film formed on the alloy being cathodic to mild steel and, of course, to the zinc. He wondered whether Mr. Kenworthy could tell them anything about that.

His company had used titanium sheet for covering soot collector cones which had to resist salt water spray and sulphur bearing furnace gases, perhaps one of the most vicious corroding media in a ship. They had also used the 18/8 stainless steel with three per cent molybdenum and bare mild steel. The mild steel lasted about two years, the stainless steel barely lasted one year, and the titanium covering was still in very good condition after 4½ years.

He had one point to make on brazing. It appeared that the B.S.1845-Type 3 alloy was suspect for joining aluminium brass and alpha-beta brasses, but it was still advised for use. He wondered whether Mr. Kenworthy could say how serious the corrosion in joints with aluminium brass might be and how much better the three per cent nickel addition to the alloy made it.

With regard to the seizure of nuts and bolts, his company had used for some years now with great success MoS_2 grease for all steam joint nuts up to 950 deg. F. (510 deg. C.). He would like to know what the difference was between the two greases tried which led the Admiralty to choose one. Was it the particle size of the MoS_2 or the medium or something else?

The paper showed particularly that much of the work by the Admiralty laboratories was also of great value to merchant marine engineering in general, and it was to be hoped that more papers of the kind, perhaps dealing with one or two problems in greater detail would be forthcoming. In the context of dissemination of information, it was worth noting that out of the 44 references in the paper, as many as 12 were either of unpublished work or published in a classified journal. The paper also showed what metallurgical laboratory facilities could achieve in examining existing materials and testing new ones. Such facilities were practically non-existent in the marine industry outside the Navy Department organization. He could not say that, however, without mentioning the excellent, though naturally limited, assistance given in that direction by Lloyd's laboratories. It seemed to him that a central laboratory could be set up to serve the marine industry as a whole, which would be of great assistance in solving the short-term problems with which it was constantly confronted.

Mr. J. N. Bradley, B.Sc., said that he had been associated with some of the work on the nickel aluminium bronzes. These had not proved completely satisfactory because they suffered from pitting. At the Central Dockyard Laboratory in Portsmouth, they were looking into the pitting corrosion of these metals, and recent work showed that it was linked to the structure of the alloy, in particular to the form of one of the phases in the alloy. Present indications from exposure tests suggested that if they were to obtain improved corrosion resistance they must reduce the nickel content which could result in a slight loss of mechanical strength.

Another point concerned the present position of the silver solders. It was now known that quaternary silver solders containing cadmium could cause corrodible diffusion zones in certain single-phase alloys near the two-phase border composition. This was due to zinc diffusion across the joint and was a function of time and temperature. It was interesting to note that cadmium must be present in a silver brazing alloy in a certain quantity for this to happen. It was not a very high hazard with B.S.1845 Type 3 alloy, but it was with other proprietary silver brazing alloys of lower silver content.

With regard to Mr. Breckon's comments on the data sheets, the impingement resistance figures quoted were typical for straight 3-in. diameter pipes. Hydrodynamic factors in relation to tube diameter and bends had to be considered. That aspect was made clear in the introduction to the data sheets; there had not been time for Mr. Kenworthy to refer to this matter in detail.

Mr. G. P. Smedley, B.Eng., B.Met., said that it was pleasing to find recommendations on the avoidance of corrosion in a wide range of marine engineering applications summarized in simple and concise terms.

For several years Lloyd's Register had advised against the use of stainless steels for screwshafts and some other underwater parts. The name given to these steels was unfortunate as many firmly believed that they were fully resistant to corrosion under marine conditions. In fact these steels could suffer severe local or general corrosion. The worst cases had involved service in polluted harbour and estuary waters. Some tailshafts had had to be withdrawn from service after a few months. The austenitic stainless steels had been particularly bad.

Mr. Cotton had drawn attention to plate type condensers and coolers. There was some increased interest in these coolers for marine applications. However, the design and choice of materials had to be appropriate for marine practice. He understood that in some cases austenitic stainless steels were used. These metals might not give the best service, especially where the ships operated for fair periods in estuaries.

With reference to the martensitic types of stainless steel, some metallurgists claimed that an addition of about one per cent molybdenum decreased the tendency of the steels to pitting and crevice corrosion. As he could find no reliable evidence, he would be pleased to have the opinion of the author on the matter.

Occasionally austenitic stainless steels were used for parts of valves and fittings of steam lines. There had been a few cases where severe stress corrosion cracking had occurred in the steam which was inevitably contaminated with some chloride. He considered that these steels should not be used and were unnecessary in these applications.

He agreed with Mr. Kenworthy's remarks on "alternative materials to high tensile brasses". However he was surprised that no reference was made to K Monel. It was a good, high strength, wrought material and was particularly suitable for bolts and studs. For example it had proved particularly good for the studs of built propellers.

On occasion, he had been referred to the practice of the Royal Navy to repair by welding, mild steel tailshafts that suffered grooving by corrosion during service in small ships. He would be pleased if Mr. Kenworthy would give details of the practice and experience. In particular was there any restriction on either shafts repaired in this way or on the ships concerned?

Under the heading "cavitation damage", no reference was made in the paper to centrifugal pumps handling sea water. These could be troublesome due to either the selection of an unsuitable material for the casing or impeller (e.g. cast iron) or to design fault, involving excessive turbulence or velocity. Did similar troubles arise in naval applications and had any steps been taken to specify materials and limiting speeds? An earlier speaker had shown an example of the loss of metal from a pump casing due to cavitation erosion damage. Other speakers had drawn attention to local corrosion in condenser tubes and pipes as a result of deposition of particles of a foreign metal that was cathodic to that of the tube or pipe. It occurred to him that debris, from pumps and as a result of cavitation erosion of the metal, was a likely source of such foreign particles.

In the section on the protection of propeller shafts, reference was made to certain deficiencies of rubber coatings. Tests had shown that a coating of silicone rubber offered excellent protection of steel against corrosion fatigue. Such coating could be of value in some cases. What type of rubber was found unsatisfactory in the trials reported in the paper?

Finally, he endorsed the closing remarks of Mr. Capper.

Correspondence

MR. W. MATTHEWMAN wrote that the impressed current system had been ruled out because "its practical application, including the need for careful maintenance could present considerable difficulties". In his experience within the power generation industry, the sacrificial anode, by its very nature raised immense maintenance problems when used on a large scale. In view of Mr. Kenworthy's comment regarding the dangers of poor maintenance on protector blocks (last paragraph on page 151), would it not be prudent to re-examine the decision in the light of present-day technical advances in anode materials and automatic controls. In this context the use of impressed current anodes would enable small coolers to be fully protected, instead of relying on the sacrificial properties of the "tubular corrosion length". The cost was an obvious factor, but possibly the same reason held as that advanced to justify the change of tube material from aluminium brass to 70/30 cupro-nickel, i.e. "overriding importance of dependability".

Mention was made of a reference electrode being fitted by the Canadian Naval Laboratory in conjunction with zinc anodes. The Central Electricity Generating Board required reference electrodes to be incorporated in all cathodically-protected equipment as they considered this to be the only acceptable criterion of performance. The author gave the impression that the Royal Navy did not use half-cells. Was this the case, and if so how was performance of cathodic protection judged in the short term?

His final comment was to endorse the view expressed by the author regarding the advisability of using "once through" systems for test plant. At the Sea Water Corrosion Laboratory of the Generating Board, at Brighton, very significant differences occurred between results obtained on trials where the only ostensible difference was that between recirculated and "once through" water. These differences referred to the amount of corrosion (reflected by the exchange current), the potentials exhibited by the specimens when cathodically polarized and the current density required to achieve this. In all cases so far examined, the worst condition occurred in the once through system which accorded with the observation of Gilbert and LaQue.[19]

CAPTAIN H. D. NIXON, M.V.O., R.N. (Member) wrote that he had felt for a long time and had found no reason to change his view, that the metallurgical changes which were made as knowledge progressed, only cured part of the problem in sea water circulating systems. There was a long way to go in eliminating turbulence raisers in branches, valves and coolers, in these systems, to minimize erosion.

Because the effects of erosion and corrosion often appeared to be similar, engineers had for a long time been able to pass the buck to the metallurgists and chemists for solution. He believed that the engineers must now accept a greater responsbility for many of the so-called corrosion problems and must concentrate their component design and installation design teams on to the problem of removing turbulence raisers in systems.

He recommended that senior designers from the leading component manufacturers and ship building firms should be associated more closely with the studies which the Admiralty Materials Laboratory was making with its pipe test rig.

MR. A. M. PATTON, in a written contribution drew attention to two points in the paper. The first concerned the use of 90/10 cupro-nickel pipes.

Whilst it was realized that, for naval service, cost considerations—although important—must be secondary to dependability, many shipowners were forced to look more closely at their costs. First thoughts on the cost of 90/10 cupro-nickel pipe work might be misleading, but if one designed to make full use of the properties of this material, the installed cost of 90/10 cupro-nickel might well be lower than that of other copper-based alloys. Since 90/10 could withstand roughly double the velocity tolerated for 95/5, he thought that Mr. Kenworthy would agree that one could use not only smaller pipes, but also smaller valves, pumps, etc., with an overall decrease in installed cost.

It was possibly worth noting as well that, whilst naval practice was to use copper-base flanges, joining them to the pipe by silver brazing, it was possible to use flanges cut from mild steel plate. These could readily be welded to the 90/10 cupro-nickel pipe, which might again reduce material cost. This method provided stronger joints, which could also be easily inspected.

The second point that he wished to raise dealt with the author's reference to the effect of microstructure on the corrosion resistance of medium strength aluminium bronzes. Some work done by colleagues some years ago, indicated just how important this could be.

The number of castings corresponding to B.S. 1400; 1961-AB1 and AB2, which had been exposed to a chloride environment, were examined. It was found that the AB1 castings had suffered severe de-aluminification, and that the phase preferentially attacked was gamma 2. It was only possible to eliminate this phase by reducing the aluminium content below nine per cent and this caused loss in mechanical properties.

Examination of the AB2 castings showed that some had suffered pitting corrosion, but that others were substantially unattacked. Those attacked were found to have a structure which included areas of gamma 2, and this was always associated with the areas of preferential attack. The others were found to have fully alpha-kappa structure.

Subsequent laboratory work showed that the presence of retained gamma 2 was due to too rapid cooling after casting. If sufficient care was taken to avoid this, then the breakdown of the gamma 2 phase to give the more desirable alpha-kappa structure could be achieved.

MR. H. S. CAMPBELL (Associate) in a subsequent written contribution, said that he had later examined some of the tubes on test at Tilbury and it was apparent that the aluminium brass had suffered moderately severe inlet end impingement attack, presumably during the early stages of the test when the water conditions were bad. Some highly localized areas of impingement attack were also present in the inlet end of the 70/30 cupro-nickel tube. This attack had not been revealed by the eddy current probe examination because it was within the region where the surrounding tube plate interfered with the eddy current test.

The two high tin-brass tubes examined did not show inlet end impingement attack. This was an encouraging result, but further results from the service trials still in progress were needed before the true possible value of these alloys could be assessed.

It might well be that, with the general cleaning-up of estuarine water and the better understanding of other factors that had led to the use of ferrous sulphate dosing and the adoption of cathodic protection for condensers with coated water boxes, one or other of the well-established condenser tube materials could now be used completely satisfactorily in generating stations that had given trouble in the past. If this proved to be so, there would be no call for the high tin-brasses or other alloys specifically intended for service in highly polluted waters.

Author's Reply

The author said that, when he was writing the paper, he had had some doubts as to whether it would prove of much interest, but it seemed from the discussion it had stimulated that his fears had been groundless. He was delighted that it provided a forum for the expression of views of so many leading experts and he was grateful for the numerous valuable and helpful comments that had been made. The way in which the paper had been received, and the kind and generous remarks of contributors both outside and within the Navy Department had been most encouraging. He felt particularly honoured that Dr. Evans had been asked to open the discussion.

In replying to the many points raised, he would attempt to deal with them in relation to the subjects as they were presented in the paper. Starting, therefore, with condensers and heat exchangers, one important topic in this field which had received attention from several contributors was the prevention of corrosion of tubes under polluted conditions. He recalled that, with regard to the attack of aluminium brass tubes during the fitting out period under such conditions, Dr. Gilbert had predicted in the course of his reply to the discussion on his well-known and authoritative paper on condenser and heat exchanger tubes presented to the Institute eleven years ago(5), that "unless some steps were taken it was quite possible that condenser tube corrosion troubles would again assume serious proportions in the near future". Fortunately, the Royal Navy had suffered comparatively little from this cause, but sufficient trouble had been experienced to show how right Dr. Gilbert had been.

The Navy Department's answer to this problem, as stated in the paper, had been to change to 70/30 cupro-nickel for all heat exchangers in which aluminium brass had formerly been fitted, and it was interesting to hear from Mr. Capper that his company had recently made a similar change. Dr. Gilbert, however, had expressed some doubt in the present discussion as to whether it would not have been wiser to change to 90/10 copper/nickel/iron, because of the latter's superiority in resisting high temperature conditions. Whilst he welcomed this observation, it would be appreciated that the choice of 70/30 cupro-nickel was dictated by the necessity to take some immediate action, and approval would not have been given to the large scale introduction of a tube material previously untried in H.M. Ships. It was clear, however, from what had been said, that a close watch would need to be kept on the possibility of hot-spot corrosion occurring now that the material was being used in components liable to operate at higher temperatures.

He was grateful both to Dr. Evans and to Dr. Gilbert for their comments on the mechanism of hot-spot corrosion. Dr. Bowden's recent work, which Dr. Gilbert had quoted, had considerably advanced our knowledge of this phenomenon and had served to explain some of the anomalies pointed out by Dr. Evans. The importance of heat transfer in laboratory experiments on problems of this kind, in order to simulate practical conditions, had also been pointed out by Dr. Evans, while Mr. Cotton had specially emphasized this need, thus supporting Mr. Breckon and Dr. Gilbert's contention referred to by the author(1).

Referring to the injection of inhibitors as a method of tackling the problem of the contamination of aluminium brass tubes during fitting out, he was very pleased that Mr. Cotton had been present and had contributed to the discussion on this subject, as it was his original work that had led to the trials described in the paper. The samples Mr. Cotton had exhibited had been most convincing.

On the subject of alternative tube materials, the author welcomed the detailed comments of Mr. Breckon and Mr. Campbell on the performance of the high tin-brass tubes developed by the British Non-Ferrous Metals Research Association for polluted conditions. He agreed with Mr. Breckon that the tubes removed for close examination from the drain cooler of a frigate since the paper was written were in a worse condition than had appeared from inspection *in situ*. It would certainly seem from this trial that the resistance of these alloys to hot-spot corrosion in the absence of heavy pollution was inferior to that of aluminium brass. At the same time, and without in any way detracting from the force of this observation, it was only fair to state that the conditions in this particular drain cooler had been abnormal, owing to the failure of a steam baffle plate. An interesting situation had therefore arisen; on the one hand, although, as Mr. Campbell had pointed out, and as had been appreciated when the tubes were installed by the Admiralty, these alloys were not designed with marine applications in mind, a ship trial had in fact fortuitously served a most useful purpose in demonstrating an unsuspected weakness in these alloys; on the other hand, trials specially chosen to test the property for which the alloys were designed had so far, for various reasons, proved to a large extent abortive. He still considered, in spite of modern techniques and possibly changed conditions, that it would be wise not to dismiss the high tin-brasses without knowing more about their performance under a wide range of conditions. He thought perhaps Mr. Campbell was a little sanguine in his remarks about the general cleaning-up of estuarine waters, and that, as indicated by Commander Steedman, we should probably be faced with this problem for some time to come.

With regard to the trials of 12 per cent tin bronze tubes, Mr. Capper was quite right in believing that these had been installed in a galley drain cooler of H.M.S. *Cumberland* in 1951. Unfortunately, the tubes had been withdrawn for examination after less than two years' service under fairly innocuous conditions, and, although they were in perfect condition, obviously no conclusion could be drawn from this trial. Also, unfortunately, four other ships in which tin bronze tubes had been installed went into reserve shortly afterwards. One of these was now on the active list again and steps were being taken to make an examination of the trial tubes at an early opportunity.

The other tube material mentioned in the paper was the duplex 70/30 cupro-nickel internally clad with 90/10 copper/nickel/iron, and the author thanked Mr. Breckon for the information he had given on its method of manufacture and structure. He had recently received information from the U.S. Bureau of Ships that this material, which formed the subject of U.S. Patent No. 3,053,511, had been used in merchant ships for coolers consisting of flat strut tubes fabricated from strip by copper brazing. The thickness of the 90/10 cladding was about $\frac{1}{3}$ of the total strip thickness. Besides affording galvanic protection to the cupro-nickel, the cladding was said to have less galvanic attack on the copper brazing than cupro-nickel. In oil coolers with very turbulent water flowing on the outside of the tubes a greatly increased life had been obtained by the use of the clad material.

The author thanked Mr. Breckon for drawing attention to the value for the impingement resistance of Admiralty brass given on the data sheet that he had shown in presenting the paper, which could have been misleading. Mr. Bradley had explained in his contribution to the discussion how this value should be interpreted. He was interested to learn from Mr. Breckon's vast experience in these matters of the importance he attached to the presence of iron corrosion products (a matter which he [the author] had also advocated as a part author of a previous paper* dealing with Naval corrosion problems); and to the use of cathodic protection in preventing the attack of both cupro-nickel and aluminium brass tubes, especially at inlet ends where severe conditions were met with. The view had been strongly supported by Dr. Gilbert, who had also emphasized the beneficial effect of cathodic protection in preventing attack of tube plates as well as tubes, by swamping small differences of potential—a point also made by Captain Little. In this connexion, it had been reported, since writing the paper, that attack on some of the new aluminium bronze tube plates being fitted in H.M. Ships was taking place, apparently stimulated by contact with the cupro-nickel tubes. Zinc alloy sacrificial anodes were to be fitted and an investigation was also in hand in an attempt to minimize this trouble by modifying the structure of the alloy.

Mr. Matthewman had argued the case for impressed current systems of cathodic protection in preference to sacrificial protection pieces, and the author agreed with him that the relative merits of the two systems should perhaps be re-examined in the light of modern equipment. At the same time, the author was not at all sure that the relative dependability, on which Mr. Matthewman's argument had been partly based, did not still rest with protector blocks when it came to their use in naval vessels, where vibration and risk of damage to equipment were serious problems. Space considerations had also to be borne in mind.

The author wished to correct the impression gained by Mr. Matthewman that the Royal Navy did not use half-cells. The provision mentioned in the paper for fitting reference electrodes did, in fact, specifically refer to H.M. Ships in which zinc alloy anodes had been attached to R.N.B. main condenser outlet tube plates. Reference electrodes had shown that these anodes were providing adequate protection. In reply to Mr. Frederick, the author stated that, with regard to the life of the anodes, it was not yet possible to say, but that it was hoped that this might be two years.The anodes were being examined every four months as part of the routine inspection of condensers. Concerning the extent to which the R.N.B. tube plates were being subjected to dezincification, the author was inclined to agree with Captain Little that there could well be more instances than might be inferred from the paper. Apart from fallability in reporting, the severity and even the mere presence of dezincification of tube plates were often very difficult to establish.

The author agreed with Mr. Matthewman that tubular corrosion lengths were an unsatisfactory arrangement, and in fact, it had been found necessary since writing the paper to redesign the doors of small heat exchangers so as to allow the conventional arrangement of protection pieces to be fitted. On the other hand, Mr. Capper had reported favourably on the practice adopted by his company of spraying with iron the bores of inlet piping of heat exchangers up to 18in. from the flange.

Both Dr. Evans and Mr. Matthewman had referred to the problem of maintaining good electrical contact when using ferrous protector blocks, but, as mentioned in the paper, provided these were properly fitted, experience had shown that this trouble should not arise, and no maintenance should be required other than for renewals. Dr. Evans was undoubtedly right, however, in pointing out that unless some special steps were taken, insulation could occur by the formation of corrosion products as a result of water penetrating into crevices at the edges of the blocks where they were not in perfect contact with the securing studs. His suggestion of using a jointing compound seemed a simpler alternative method than the one adopted in H.M. Ships, and he recollected that this idea had been followed in principle by the U.S. Navy during the last war by the use of red lead paint. A paste suitably formulated for the purpose (as suggested by Dr. Evans) would, of course, be much more effective, although care would be needed after tightening up to remove all extraneous paste, which could be harmful if it were to lodge in the tubes. Dr. Evans was also to be thanked for suggesting the extension of this principle to prevent certain problems of crevice corrosion.

The importance of the composition of ferrous protector blocks had been pointed out by Dr. Evans and Mr. Breckon and that it was desirable to use the purest low carbon iron commercially available, to avoid the possible lodgement in the tubes of highly cathodic particles. Uncoated cast iron, cast steel or mild steel water boxes could presumably give similar trouble, as pointed out by Mr. Capper. Dr. Evans' suggestion for avoiding the same hazard that might arise from the steel spraying of gunmetal doors was to electroplate, which, as he pointed out, would have the further advantage of ensuring good electrical contact with the door. Whilst this might be practicable for small heat exchanger doors, larger doors which at present could have an overall size of 10ft. × 5ft. × 4ft. deep, and might in some future ships be as large as 12ft. × 8ft. × 4ft. deep and weigh some four tons, would present a difficult problem in plating and in prior surface preparation. In addition, judging by the rate of wastage of a 6-mils thick sprayed coating of mild steel (possibly not in electrical contact with the door), a fairly thick electroplated coating would be needed, and this might not possess the degree of adhesion necessary to withstand the mechanical shocks suffered during transport and fitting out.

With further reference to the possibility of poor electrical contact between metal sprayed coatings and their substrate, whilst he agreed with Mr. Capper as to the necessity for grit blasting prior to metal spraying, the reason for this was to obtain a good mechanical bond rather than an electrical bond. In fact, Mr. Capper's statement that the iron lasted a "surprisingly long time" rather pointed to the fact that there was not good electrical contact between the iron and non-ferrous parts of the system.

With regard to other methods of preventing the attack of tubes, especially under polluted conditions, ferrous sulphate dosage had been mentioned in the paper and he was grateful to Dr. Harrison for giving details of the experience of British electricity boards with this treatment, which had proved so successful in overcoming the corrosion of aluminium brass tubes; and also to Dr. Gilbert for reporting similar evidence both from practice and from laboratory tests, and for his explanation of the mechanism involved. He would, however, have liked more precise information on the effectiveness of the treatment for cupro-nickel tubes. Although its success for this purpose might with some justification be anticipated, it did not appear to the author to be clear that this was the case from what had been said. It was a pitty that owing to the changed environment mentioned by Mr. Campbell, the Tilbury tests of the C.E.G.B. might not now provide as convincing data on this point as were hoped for. In reply to Dr. Harrison, the author mentioned that ferrous sulphate injection had not been tried by the Navy Department, since the conditions encountered in H.M. Ships did not appear to warrant the use of this method, except perhaps as a possible pre-treatment for aluminium brass tubes.

On the subject of condenser doors, he agreed with Mr. Capper that all the materials in normal use for this purpose had their drawbacks. As regards the use of glass fibre epoxy resin doors, about which Mr. Frederick and Mr. Capper had enquired, it seemed possible (judging by tests at Admiralty Materials Laboratory which had included an assessment of loss of strength after prolonged immersion in sea water) that

* Slater, I. G., Kenworthy, L., and May, R. 1950. "Corrosion and Related Problems in Sea-water Cooling and Pipe Systems of H.M. Ships". *J. Inst. Metals,* Vol. 77, p. 309.

these could be made sufficiently strong for condensers installed at considerable depths below the water line. The operating temperature, however, was probably the more important factor to consider. If there was any question of water starvation occurring, with consequent rise in temperature, then it appeared that the material might suffer serious deterioration by delamination. At present, therefore, it seemed that doors made from this material were best suited to heat exchangers where this damaging condition could not arise.

The author had practically no experience of the behaviour of sprayed plastic coatings on doors, in which Mr. Frederick was interested, mainly because at the time when steel doors were in common use in H.M. Ships, the state of the art as regards sprayed plastics appeared to offer little hope of success. Sprayed "Thiokol" was one such coating experimented with during the last war; although this type of coating had behaved well in certain applications, on the condenser doors of H.M. Ships it never achieved a life of more than three months even when applied under the close supervision of U.S. technicians from the firm responsible for developing the process. Various paints, chosen as giving the best performance in the C.R.L. rotor test from a wide range of products, were also tried, but with no better success, some, in fact, showed flaking even during the fitting-out period. Since the rapid breakdown of the coatings was partly due to galvanic attack, consideration was given at one time to insulating the doors from the tube plate by rubber jointing and insulating sleeves and washers for the studs, but the idea was abandoned as being too formidable a proposition during wartime conditions.

It was probable that the situation had changed, however, and that nowadays more reliable plastic and paint coatings were available for this exacting duty. Nevertheless, it must be emphasized that coatings for this application (except those anodic to the basis metal) could do more harm than good unless they remained intact, since local breakdown could result in severe pitting instead of more uniform attack. Moreover, depending on the type of coating involved, local repair of coatings *in situ* was not always satisfactory because of the difficulty of ensuring adequate surface preparation, especially if pitting had taken place.

The final solution adopted by the Admiralty at the time, before reverting to gunmetal, was the application of sheet rubber which could be applied and cured *in situ*. Many doors were treated in this way, varying in size from those in destroyers to the larger doors of H.M.S. *Vanguard*, with very satisfactory results. Many years before this there had been experience with rubber coatings bonded to steel boxes by a vulcanized ebonite coating. Some of the old *County* class cruisers were treated in this way and although the rubber sheeting itself was not an unqualified success, especially in those cases where it parted company in its entirety with the door, the underlying ebonite coating gave a remarkably good performance. For example, in H.M.S.*Norfolk*, which was commissioned in 1930, and which had the rubber coating cut away some years after service because of showing signs of damage, the ebonite coating (which was about $\frac{1}{32}$in. thick) was in perfect condition when he had inspected it in 1947. In some cases the rubber coating itself also lasted very well, as in H.M.S. *Dreadnought*, where it remained intact for 14 years until damaged by protector blocks that had come adrift. Whatever its merits, however, this method of protection could not be applied *in situ* and it was therefore not a possible solution to the problem of the many unprotected steel condenser doors in existence in H.M. Ships during the last war.

With regard to sea water piping systems, the author was pleased that the importance of layout, fabrication and assembly had been stressed by Captain Nixon and by Mr. Capper. It was gratifying to hear from Mr. Capper that when special attention had been paid to these matters in one of his company's ships, it had been attended with the same success as is in the case of the example quoted in the paper. There were of course special problems associated with aluminium brass due to its susceptibility to corrosion cracking when subject to various types of stresses; at the same time, it should be mentioned that 90/10 copper/nickel/iron, though possessing the advantage of better all-round corrosion resistance was not quite such an easy material to coppersmith, although it presented no real difficulty if the correct techniques as described in the paper were used.

It could not be too strongly emphasized, however, that the change to a more corrosion resistant material should not be considered as an opportunity for taking less trouble over design and assembly. Relaxation in these matters could readily increase the severity of the operating conditions and so dissipate the extra margin of safety from the corrosion point of view, which was the whole object of using more resistant materials. For the same reason, he thought that the use of 90/10 copper/nickel/iron instead of the 95/5 alloy as suggested by Mr. Patton did not justify a reduction in pipe sizes, since this would offset the advantage of using the more resistant alloy. Moreover, he was not sure whether smaller pipes would, in fact, necessarily result in a substantial reduction in the size of all components, since the increased friction in smaller pipes might need an increased pump capacity.

It seemed that the only way in which the various factors connected with the design of piping systems and their conditions of operation could be considered of less significance from the corrosion point of view, would be to use fresh water instead of sea water, and this would also overcome the problem of balancing auxiliary systems referred to by Captain Little. This might become feasible in auxiliary systems if it were possible to provide a completely reliable and virtually non-corrodible condenser unit. These requirements were most likely to be met by the use of titanium, as stated in the paper, and he was particularly glad to be assured on this point by Mr. Cotton, in view of his wealth of specialized knowledge of the subject.

Captain Nixon and Captain Little had referred to other design problems in sea water systems and especially to the design of small heat exchangers and components such as valves. Although a good deal of work in the past had been devoted to the design of small multi-pass heat exchangers, he agreed that improvements could probably still be made in the light of modern knowledge. Valve design was currently being studied both by the Navy Department and by the Commonwealth Navies.

It would also be appropriate while on the subject of design of heat exchangers to comment on the plate type, referred to by Mr. Cotton and Mr. Smedley. The little experience which the Navy Department had had with these was not very happy, partly, as Mr. Smedley had suggested, because those in use were probably not designed for ship application. In any event the author thought their weight and size were drawbacks to their development for Naval use. He would certainly share Mr. Smedley's apprehension concerning the use of austenitic stainless steels in plate type heat exchangers using sea water cooling.

He thanked Mr. Patton for his suggestion of using mild steel flanges in pipe system, which he thought should be satisfactory, except that in most compartments they would need to be painted and this would present an additional maintenance problem.

Among the points raised that were relevant both to condensers and piping systems, Mr. Christensen had referred to the role of air in sea water cooling systems and to the influence of the disposition of inlets on the amount of air entrained. So far as he was aware, nothing had been published specifically on the subject of where inlets should be positioned from this point of view. Some mention of this matter had, however, been made in a paper* describing a comprehensive investigation of corrosion in salt water systems carried out by the Admiralty during the last war. An extract from this paper read as follows: "The location of sea water inlets in the ship's hull can have a large effect on the entry of air bubbles, but other considerations usually decide where the inlets are actually placed. It is not uncommon to find auxiliary inlets immediately below the bilge

* Slater, I. G., Kenworthy, L., and May, R. 1950. "Corrosion and Related Problems in Sea-water Cooling and Pipe Systems of H.M. Ships". *J. Inst. Metals*, Vol. 77, p. 309.

keels, which is almost the worst possible location as regards entangled air bubbles. Even some main inlets are poorly placed in this respect". It was not, of course, possible to eliminate all air even with ideally positioned inlets because of the turbulent layer near the hull, but further reduction in the amount entering the system could be achieved by the use of air escape pipes, as Mr. Christensen had noted.

Probably of even greater significance than the amount of air present was its distribution and this was influenced by the shape of the inlets rather than their positioning, although their shape in relation to their position was also possibly of some importance. This had been shown by the investigation already mentioned and had been based on the examination of very many ships' sea water cooling systems and on a wind tunnel study at the National Physical Laboratory. It was particularly important to avoid imparting a rotational motion to the water stream as this resulted in the development of large vortices with very high local speeds and with air at the centre which could give rise to severe impingement attack at some part of the system.

He was glad that both Mr. Cotton and Mr. Matthewman had produced further evidence to show the need for "once-through" tests. His limited experience with this type of test had similarly indicated that it was more severe than the recirculating test, and since the former simulated service conditions more closely it followed that great care was necessary in the interpretation of the results obtained from recirculating systems. Not only might the degree of attack that took place in the recirculating system in a given time be less than that experienced in practice, but it was just conceivable that there might be instances in which, however long a recirculating test was run, breakdown might not take place, in contrast with what occurred in practice under otherwise identical conditions.

He thanked Captain Sidgwick for his contribution on the subject of inhibitors for engine cooling systems and for pointing out that soluble oil as an inhibitor was mainly used by the Merchant Navy in fresh water and not in ethylene glycol anti-freeze mixtures. This partially answered Mr. Capper's query as to the limitations of soluble oil as an inhibitor. He was not aware of any drawback other than alkalinity, as mentioned in the paper, when soluble oil was used in fresh water. Captain Sidgwick had subsequently told him that the mechanism of breakdown of glycol solutions when using soluble oil was associated with slight attack of copper and copper alloys in the system, and although this was not in itself serious, the resultant copper picked up by the solution catalysed the oxidation of the glycol. It was interesting to know that tests were being carried out with an anti-freeze liquid containing benzotriazole for copper inhibition, in view of what had been stated in the paper and in the discussion. Referring to the rapid depletion of NaMBT, this had recently been demonstrated in a rather unusual way when investigating fungal growths in inhibited ethylene glycol lubricating oil cooling systems, owing to the fact that NaMBT possessed some fungicidal action. In an experimental rig containing the metals present in the cooler and with surface to volume ratios of the metals to the glycol solution approximating to those in practice, no fungicidal properties remained after a 3-day test during which the solution was heated to 140 deg. F. (60 deg. C.) for eight hours each day.

As to the viscous damping of pistons for reducing the water-side attack of cylinder liners, Mr. Capper had raised an issue regarding oil consumption which seemed to go beyond the scope of the present paper. He suggested that a direct approach to the Admiralty Engineering Laboratory or the Admiralty Research Laboratory might be the most appropriate way of obtaining this information.

The author thanked Mr. Bradley for supplementing the information given in the paper concerning his work on nickel aluminium bronzes. Mr. Patton was also to be thanked for describing work illustrating the effect of microstructure on the corrosion resistance of aluminium bronzes complying with B.S. 1400-AB1 and AB2, which was largely in agreement with the findings of Mr. Bradley and his colleagues.

Mr. Capper's question, as to whether aluminium bronze to B.S. 1400-AB1 was not more difficult to cast than B.S. 1400-AB2, was perhaps a little outside the scope of the paper and all the author would say was that neither alloy was easy to cast but that, in any event, the AB2 composition was preferable from a corrosion point of view because of the liability of the AB1 alloy to form corrosion-susceptible phases. Mr. Smedley had asked why K Monel was not mentioned as one of the possible alternatives to H.T. brass. The Navy Department experience with this alloy had been that it tended to suffer from crevice attack unless galvanically protected, which however quite frequently occurred, and was probably the case in the example quoted by Mr. Smedley.

The author was pleased to have confirmation from Mr. Smedley on the behaviour of stainless steels when immersed in sea water and also his experience of these alloys in steam lines. The effect of one per cent molybdenum on martensitic steels, a matter also raised by Mr. Smedley, might thought the author, be slightly beneficial, but he did not believe it would overcome the basic weakness of this type of alloy as regards sea water immersion. Regarding the Navy Department investigations on the corrosion behaviour of stainless steels and related alloys in marine environments outlined in the paper, the author apologized for his oversight in omitting a reference to a paper by Rowlands* describing some of this work in detail.

Mr. Capper's experience with materials for resisting severe conditions to which soot collector cones were subjected was of considerable interest to the Navy Department as the same problem was met with in inner funnels. Here again, it was significant that for the soot collector cones titanium or titanium clad material appeared to be the answer and would probably be more economical in the long run. The author was not surprised that stainless steel had behaved rather worse than mild steel under these conditions and he thought perhaps one of the low alloy steels would have been preferable; alternatively, aluminium sprayed mild steel would possibly offer a somewhat better life.

Since the sections in the paper devoted to stainless steels and titanium dealt with the effects of contact with other metals, it seemed appropriate to refer next to Mr. Capper's observation concerning the preferential corrosion of galvanized mild steel when used for joining aluminium. This behaviour was to be expected, as aluminium alloys were generally cathodic to zinc. If, however, this sacrificial attack was allowed to proceed to such an extent that the underlying steel was exposed, then the reverse could happen and the bolts could cause galvanic attack of the aluminium alloy. Corrosion products streaming from mild steel on to aluminium alloys could also have a detrimental effect on the latter.

The author thanked Mr. Bradley for describing his latest findings on the subject of cadmium-containing silver solders, which were of considerable interest. Mr. Capper had remarked that B.S. 1845-Type 3 silver solder had been advised for aluminium brass and alpha-beta brasses, in spite of its being suspect for these alloys. This advice was certainly not given in the paper, however, where it was stated that three silver solders were advised "as appropriate", the field of use of each having been described. Aluminium brass was, in fact, a border line case, and although to be on the safe side it was listed as an unsuitable alloy for brazing with B.S. 1845-Type 3 alloy Mr. Bradley had advised that no harm would result from this practice unless a combination of unfavourable circumstances was encountered, such as an aluminium content on the high side, and a prolonged time of brazing at a high temperature. On the other hand, the 3 per cent nickel alloy could safely be used for aluminium brass whatever the conditions.

In reply to Mr. Smedley's query regarding the materials used in centrifugal pumps handling sea water, the Navy Department specified gunmetal casings and nowadays either Monel or aluminium bronze complying with B.S. 1400-AB2 for the impellers. As regards speed of operation, no limits were

* Rowlands, J. S. 1959. "Stainless Steels and Related Alloys versus Marine Environments". *Corrosion Technology*, Vol. 6, p. 359.

specified except that for main pumps instructions stated that these should not be run faster than necessary to maintain the desired vacuum, because of the damage that might otherwise be caused by impingement attack in the system due to excessive speeds. As far as the author was aware, pieces detached from pump components had not caused any trouble and were presumably usually small enough to be swept through the system.

The performance of gunmetal pump casings described by Mr. McConnell was certainly an excellent example of a service trial of two different alloys carried out under identical conditions, which was usually so difficult to obtain. He agreed that the results substantiated the laboratory investigations of the impingement resistance of these alloys carried out by the British Non-Ferrous Metals Research Association. In H.M. Ships, the 88/10/2 alloy (B.S. 1400-G1) had proved superior to other gunmetals as regards resistance to impingement attack. When it came to true cavitation conditions, however, he did not think that the various compositions of gunmetal would show a significant difference.

It was interesting to hear that Mr. Capper's company was using molybdenum disulphide grease with success for all steam joints up to 950 deg. F. (510 deg. C.); and from Mr. Frederick, who had collaborated in the tests described in the paper, that the Parsons Marine Engineering Turbine and Development Association had also found this type of compound effective for ferritic steel turbine cylinder joint bolts operating up to the same temperature. He was unfortunately unable to give Mr. Capper any details of the composition of the two molybdenum disulphide greases tested, as the investigation terminated with the decision to introduce the more successful of the two greases into Service use, a decision happily reached with no difficulty since the better grease was also the cheaper. He was sorry that he could not quote any Navy Department experience that would help to answer Mr. Frederick's problem of preventing seizure at temperatures in the region of 1,200 deg. F. (649 deg. C.). Among the thread lubricants that Mr. Frederick had tried he wondered whether he had included "Vermiculite", which was reported* to be very effective at these temperatures. He would have thought, however, that the heat-resisting austenitic stainless steels should have been satisfactory.

He thanked Mr. Smedley for pointing out the value of silicone rubber for protecting steel against corrosion fatigue, but, judging by experience, he thought that no type of rubber coating was likely to be satisfactory for propeller shafts, because of the liability to mechanical damage, as could occur, for example, from loose rope guards. Neoprene was the rubber used for the coatings reported in the paper. With regard to naval practice for the repair of mild steel tailshafts by welding, also raised by Mr. Smedley, he would suggest that this was a subject slightly outside the scope of the paper, but full details could be found in a paper by Tribe.†

Concerning comments of a more general nature, the author was pleased to hear from Mr. Capper that some of the work carried out by the Navy Department Laboratories was also of interest to the Merchant Navy, and he was certain that it was in the national interest that this should continue to be the case. With regard to Mr. Capper's plea, endorsed by Mr. Smedley, for a central laboratory to serve the marine industry as a whole, he drew attention to the facilities offered by the British Ship Research Association. He felt sure that if the industry made known its problems to the Association, steps would be taken to provide the answers, and the more the Association was consulted in this way, the more likely it would be that its existing facilities could be expanded, if these were found inadequate in any particular sphere.

Finally, he would like to thank Captain Sidgwick and Captain Nixon for their support in emphasizing the need for devoting more effort to ensuring that the importance of corrosion prevention was more generally appreciated, and that the knowledge which already existed on the subject was more fully utilized. Captain Sidgwick had pertinently drawn attention to one particular aspect of this as regards storekeeping, an often neglected part of the organization which performed an important function in the long and complicated process of putting design into practice. Besides the involuntary errors incurred through mixing stores, referred to by Captain Sidgwick, he would add the deliberate issue of items in different materials from those demanded, because of failure to hold the necessary stocks. These shortcomings, which incidentally he believed were not peculiar to naval service, resulted in much trouble and expense, not only by failure of the items themselves, but by causing galvanic attack of components to which they were coupled.

* Black, D. A. 1960. "Vermiculite: its Present and Potential Value to Engineers". *The Engineer*, Vol. 209, p. 1,015.

† Tribe, F. J. 1962. "Reclamation of Propeller Shafts by Submerged Arc Welding". *The Welder"*, Vol. XXXI, No. 152, p. 74.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Memorial Building on Tuesday, 12th January 1965

An Ordinary Meeting was held by the Institute on Tuesday, 12th January 1965, at 5.30 p.m., when a paper entitled "Some Corrosion Problems in Naval Marine Engineering" by L. Kenworthy, M.Sc., A.R.C.S., F.R.I.C., F.I.M., was presented by the author and discussed.

Mr. W. Young, C.B.E. (Chairman of Council) was in the Chair and one hundred and twelve members and guests were present.

Fifteen speakers took part in the discussion which followed.

The Chairman proposed a vote of thanks to the author which was greeted with acclaim.

The meeting closed at 7.55 p.m.

Summer Golf Meeting

The Summer Golf Meeting of the Institute was held at the Burhill Golf Club, Walton-on-Thames, on Thursday, 20th May, 1965. In fine sunny weather thirty-two members took part in a Stroke Competition in the morning for the Institute of Marine Engineers Silver Cup and a Greensome Bogey Competition in the afternoon. The leading scores for both competitions were as follows:

Morning Competition

1st Prize	G. Y. Stein	(7)	66
2nd Prize	G. Dunk	(15)	67
	J. F. Watson	(2)	71
	J. White	(13)	72
	H. Armstrong	(14)	73
	A. Simpson	(16)	76
	R. G. Goodley	(15)	76
	M. MacDermott	(22)	77
	C. J. Probett	(3)	77
	E. F. J. Baugh	(10)	78
	F. C. Bown	(20)	78
	K. R. Billinge	(24)	79

Afternoon Competition

1st Prize	C. J. Probett	(3)	
	J. E. Bowell	(18)	6-up
2nd Prize	F. C. Bown	(20)	
	J. F. Watson	(2)	3-up
	J. White	(13)	
	A. Fowler	(16)	2-up
	D. G. Welton	(10)	
	W. J. L. Foreman	(18)	1-up
	R. D. Fielder	(14)	
	E. F. J. Baugh	(10)	1-up
	N. C. Marr	(16)	
	G. Dunk	(15)	1-down
	L. E. Smith	(18)	
	C. A. Larking	(7)	1-down

Commander J. White, D.S.C., R.N. (Member) presented the prizes and conveyed the appreciation of all the members present to the Committee of the Burhill Golf Club for their hospitality.

It was announced that the next meeting would be held at Sandy Lodge Golf Club, on 23rd September 1965.

Section Meetings

Karachi

Annual General Meeting

The Annual General Meeting of the Section was held on Friday, 23rd April 1965, at the Merchant Navy Club, Karachi, at 4.30 p.m.

Commodore S. Z. Hasnain (Vice-President for Pakistan), in his address, thanked the outgoing members of Committee for their co-operation. He described briefly the events of the past year and referred to the report by the Honorary Secretary on the visit to Pakistan of the Chairman of Council, Mr. W. Young, C.B.E., and the Secretary of the Institute, Mr. J. Stuart Robinson, M.A.

Commander J. Ahmad, P.N. (Honorary Secretary and Honorary Treasurer) presented the annual report and financial statement both of which were unanimously approved.

Describing the activities of the Section during 1964, Commander Ahmad said that Karachi had a great potential as a section. The increase in membership over the last few years had been very good and should continue with the enthusiastic support of the Vice-President, Commodore Hasnain. It was important that the Committee should do its best to keep the membership growing.

The following were elected to serve on the Committee during 1965:

Committee: Capt. A. Ahmad, P.N.
A. S. Benjamin
J. G. D'Sylva
J. Mansoor, B.Sc.
Cdr. M. A. K. Niazi, B.Sc., P.N.
Capt. M. A. Toosy, P.N.

Honorary Secretary and Treasurer:
Commander J. Ahmad, P.N.

The programme for 1965 was discussed and it was decided to arrange a cocktail party to meet the marine superintendents, chief engineers and some young engineers of the Merchant Navy.

It was proposed that the possibility of showing technical films in different technical institutions might be explored in the interest of general advancement of the educational standard.

South East England

General Meeting

A general meeting was held on Tuesday, 4th May 1965, at the Clarendon Royal Hotel, Gravesend, at 7.30 p.m., when a paper entitled "Some Further Operating Experiences on the J Type Doxford Engine" by P. Jackson, M.Sc. (Member of Council), was presented by the author.

Mr. J. S. Allan (Vice-Chairman of the Section) was in the Chair and sixty-nine members and visitors were present.

Mr. Jackson commenced with a description of the new J type engine and followed this with a most interesting lecture on the experiences gained with the new Diesel engine.

The lecture was extremely well received by those present, this was indicated by the discussion which followed.

The Chairman concluded the meeting by thanking Mr. Jackson for his most interesting lecture and wished him every success with this new all-British Diesel engine.

Technical Meeting

A technical visit of the Section was made on Sunday, 16th May 1965, to the P. & O. vessel t.s. *Oriana,* by sixty-nine members and friends. Members were given the opportunity to visit the machinery spaces of the vessel while their wives and friends inspected the passenger lounges and accommodation.

Later the party were served with afternoon tea in the First Class Passenger Restaurant. Chairman of the Section, Mr. A. H. Stobbs, thanked the management of the P. & O. Co. for their kindness in allowing members to visit the vessel and for the hospitality accorded to the Section.

The party left the *Oriana* at 5 p.m.

Election of Members

Elected on 17th May 1965

MEMBERS

Satya Pal Adlakha
Edward Morrison Angus
Timothy Charles John Bailey
George Dickie Fleming
John Raine Gray
Hans Hajenius
Joseph Hall
Dereke Ernest Harper
John Pearse Harrison
Augustine Joseph Kane
John Lindsay
James Patrick Loughran
Philip Leslie Luby
William Albert Mason
Hugh Francis Mathers
Francis Henry Purcell
Anton Charles Pycke, Lt. Cdr., R.Neth.N.
Thomas William Reay
Harvey Newman Roberts
William Scrymgeour Ross, B.Sc. (St. Andrews)
Joseph Leonard Russell
John Thomas
Kenneth West

ASSOCIATE MEMBERS

Satish Chand Aggarwal
James William Allen
Alfred John Anderson
Thomas Knyveton Darnley Anderson, Lieut., R.N.
George Henry Bland
John Thomas Bowes
Henry Fraser Calvert
John Cecil Coupe, Lieut., S.A.N.
Peter Robert Croft
Keith William Thomas Elder
Robert Parry Emmas
Ralph Joseph Fernandes
Sydney Freeman
Paul Brandon Gale
Richard Percy Gambling
John Lorimer Gartlan
Anthony Hall-Patch, B.Sc.(Eng.) (Birmingham)
David Neil Henry
Norman Joseph Houghton
Brian Patrick Howard
Clive Jones, B.Sc (Swansea)
Alan Victor McCarroll
Donald McVicars
Noel Herbert Litster Manser
Brij Lal Mehta
Kondath Radha Krishna Menon
Philip Stanley Peter Muir, Lieut., B.E.M., C.D., R.C.N.
Adrian William Myers
John Robertson Ness
Bernard Leon Norman
Hubert Arthur Pinto
William Frederick Pittaway
Paul Hubert J. Proost
Robert Neville Richmond
Khurram Farooq Sair, Lieut. (E) P.N.
Jitendra Nath Sharma
John Shepherd
David Skinner
Clifford William Smith, Lieut., R.N.
Patrick Graham Stockbridge
Derek Taylor
Robert Osmond Thompson
Basil Edwin Troup
Nevin James Tunnicliffe
Ciriaco Uriarte-Perez
Frederick Hugh Venables, Eng. Lieut., R.N.
Edward George Whitehouse, Lieut. (L.D.), R.C.N.
Frederick James Woodgate

ASSOCIATES

Herbert George Abigail
James Barclay
Trevor Eric Anthony Ebert
George Raymond Gillespie
Bankim Bihari Ghosh, B.Sc. (Calcutta), B.Sc. (Hons) (Glasgow)
William James Hamilton
Norman Allan Herschell
Abul Quasem Lutful Khabir
Graham Stewart King
David Price Lock
Edward Joseph Powell
Albert Samuel
Joseph Seput
Brian Wilfrid Taylor
Floris Daniel Ventner
Richard Michael Warner
William James Watson

GRADUATES

Archibald Carmichael
Ian James Murray Carruthers
Andrew Thomas Crawford
Norman William Duke
Peter Head
John Hodson
David Longbottom
James Anthony Lyons
Eric Robert Stevenson
Tong King Nin

STUDENTS

Clive Arthur Bell
Christopher Dunscombe Binnington
Peter Blair
Bernard John Blankhart
Roger Downes Carthew
Kersi Jehangirji Choksey
Peter Robert Claiden
Brian Cooil
John F. Cormack
Marcus Davidson
Beverley Errol Rex de Niese
Robert Ashley Edson
Gordon Christopher Adewole Ehinlaiye
Steven John Goodchild
Richard James Christopher Grieves
Kenneth William Grime
Jimmy Rumsey Hamber
David John Harrold
Norman Hatton
Bill Higham
James Lintott
Barry McKay
David Pacey Manders
Nmaju Kalu Nmaju
Tony Penketh
Keith William Phillips

Ian Frederick Pidcock
Michael Gordon Ray
Robert Ian Rowley
Brian Russell
Ashok Kumar Sethi
Thomas Swale
Tham Yew Mun

PROBATIONER STUDENTS
Thomas Joseph Burridge
Christopher Paul Bond
John Lesley Bonnett
Denis Peter Howard Brookes
Michael James Court
Michael Alan Cowley
James Given Gillespie
Malcolm Greer
Paul Hemnell
John Richard Heseltine
Peter Norman La Costa
Brian Lamming
Christopher Charles Lockwood
Charles William Miller
Stephen Molyneaux
John Bryan Mulley
David William Venner Pack
Alan Miller Parkinson
James William Reed
Raymond John Roberts
David Richard Robinson
Graham Scott
David Kenneth Spence
Colin Alexander Smathers
John Henry Smithson
John Jeremy Thompson
John Hunter
Richard Upton
Peter Wells

TRANSFERRED FROM ASSOCIATE MEMBER TO MEMBER
Rajnish Bahl, Lt. Cdr., B.Sc., I.N.
Peter Jackson Bentley
Archibald Danvers Brown
Geoffrey James Morris Evans
Raymond Foster
George Herring
Derek Lipscombe
John Neil McCreadie
Stanley Mussett
Charles John Probett
Edward Pursell
Herbert John Rapson
Ram Saran Sachdev
Johan Karstein Thilesen
Edward Arthur Thomas
Edward Llewelyn Thomas
Jose Francis Viegas
Norman Walker, B.Sc.(Eng.) (London)
William Watson

TRANSFERRED FROM ASSOCIATE TO MEMBER
James Arthur Cockill
Leslie Clifford Jago
George Jailler
Percy John George Mack

TRANSFERRED FROM GRADUATE TO MEMBER
George Francis Ball

TRANSFERRED FROM GRADUATE TO ASSOCIATE MEMBER
Norman Lowrey Bell
Jacobus Boone
Gordon Reginald Burgomaster
Thomas Anthony Edwards
William Heading
Alan Anderson Howell
William Frederick Kidd
Brian Richard Melling
Peter Alexander Milne B.Sc. (Hons) Ph.D.
Alistair Ronald Montgomery
William Alistair Morrison
Alan Foster Mundell
John Francis Parkinson
Makarand Hari Riswadkar, Lieut I.N.
Gerald Henry Rundle
Edward James Sedgewick
Ivor Joseph Stuart-Sheppard
Pratap Narain Tickoo, Lieut. I.N.
John Ward
Alan Roger White

TRANSFERRED FROM STUDENT TO ASSOCIATE MEMBER
William David Cherry
Peter MacAulay
Hefin Bowen Salisbury
Norman Richard Vyvyan Warner
Donald Compton Wood

TRANSFERRED FROM PROBATIONER STUDENT TO ASSOCIATE MEMBER
Barrie Edmund Dakers
Walden Matthew David Whitfield

TRANSFERRED FROM GRADUATE TO ASSOCIATE
Demitrios Petros Gerakaris

TRANSFERRED FROM STUDENT TO GRADUATE
John Charles Wellbeloved

TRANSFERRED FROM STUDENT TO ASSOCIATE
Murray George Barrett
Reid Fleming, Jnr.
Richard Graham
Ian Stuart Hill
Badrul Islam, B.Sc. (Karachi)
Christopher Harrison Petrie
Robin William Rowstron
Ian Keith Simpson
Leonard Michael Stampton

TRANSFERRED FROM PROBATIONER STUDENT TO GRADUATE
Colin Francis Crandon
Roderick Meshach John Pedge
Robert Anthony Smith

TRANSFERRED FROM PROBATIONER STUDENT TO STUDENT
David Anthony Dawe
David Robert Dowling
Graham Howard Gollar
David William Manning
John Smith
John David Thomas

OBITUARY

Commander Nathaniel Afolabi Pearse, M.B.E., Nigerian Navy (LOCAL VICE-PRESIDENT)

Commander Nathaniel Afolabi Pearse, M.B.E., Nigerian Navy (Member 12,997), Local Vice-President, Lagos, died suddenly at Addis Ababa on 16th December 1964, while attending a conference as a representative of Nigeria.

He was born in 1914, and served his apprenticeship with the Nigerian Marine Dockyard Workshops from 1933 to 1939, at the same time attending the Nigerian Marine Government Technical Institute. He then served as junior engineer on various Nigerian ships, later resuming his studies for second and first class steam certificates at Poplar Technical College and Liverpool College of Engineering.

Then he was appointed a marine engineer in the Marine Department Dockyard and in 1955 was seconded to the Nigerian Navy, where he rose to the rank of Commander.

Commander Pearse was seconded to the Indian Navy for a year to study naval practice, and after serving in several capacities in the Nigerian Navy, was awarded the M.B.E. in 1960 for his good work.

He is survived by his wife and six children.

Herbert V. Jones (Member 22876) was born on 23rd August 1902 in Birkenhead. He served an apprenticeship with Messrs. Gallie Bros. of Birkenhead, following which he served as a fitter, and later as a draughtsman, with Grayson, Rollo and Clover Docks Ltd. in Liverpool. In April 1925, he decided to go to sea and joined Alfred Holt and Co., his first ship being the *Elpenor,* of 7,575 g.t. This vessel had a triple-expansion steam reciprocating engine which gave a service speed of 13½ knots. She later sailed under the name *Glenfinlas*—September 1935 to April 1947 and August 1950 to May 1952—before being scrapped at Blyth. An interesting fact is that when Mr. Jones retired from Alfred Holt and Co. (Blue Funnel Line) in August 1962, he was chief engineer of another *Glenfinlas,* a vessel which was originally named *Calchas*. This ship became the *Calchas* again in October 1962. A new vessel, to be named *Glenfinlas,* is being built at present.

Mr. Jones served as second engineer with the Royal Navy, in H.M.S. *Maron,* from 1940 to 1942. This ship was returned to commercial service in August 1942 and he was in her when she was torpedoed between Algiers and Gibraltar, on 13th November 1942.

He was promoted to chief engineer of m.v. *Orestes* in July 1947, and served in that grade in Blue Funnel and Glen Line vessels for the next fifteen years.

After his retirement, in 1962, he failed to settle to shore life and continued to serve periods at sea with various companies—Dundee, Perth and London Shipping Co. Ltd., MacAndrews and Co. Ltd., China Navigation Co. Ltd. and Chr. Salvesen and Co. Ltd.—until his sudden death in Antwerp on 18th December 1964. His body was cremated and the ashes scattered on the sea, off North Wales, from a Blue Funnel liner.

Mr. Jones was elected a Member of the Institute on 14th November 1960. He is survived by his wife, a married daughter and two sons. One son, a Student member of this Institute, will complete his cadetship with Alfred Holt and Co. in April this year.

James Joseph Kearney (Member 10708) died on 9th November 1964, in the General Hospital, Kuala Lumpur, after undergoing an emergency operation for the removal of a brain tumour.

Born on 18th December 1904, Mr. Kearney served his apprenticeship with R. and H. Green and Silley Weir Ltd. after which he went to sea for twelve years, serving from fifth to second engineer with Port Line Ltd. and the Asiatic Steam Navigation Co. Ltd. He gained his First Class Certificate of Competency in 1934.

In July 1938, he was appointed engineer in charge of ship repairs by the Hooghly Docking and Engineering Co. Ltd. and served with that company for more than eleven years, ultimately as senior float engineer in charge of all machinery and other repair work carried out by the company to ocean-going ships. He left Hooghly Docking and Engineering in December 1949 to join Fort Gloster Industries Ltd., at whose jute mill he was engineer in charge of the power plant, generating plant, workshop and all building maintenance and domestic services.

Mr. Kearney terminated his career in India in 1957 and subsequently joined the Atlantic Steam Navigation Co. Ltd. as a seagoing engineer, employed in their Ministry of Transport/War Department/L.S.T. fleet abroad. When the responsibility for that fleet was transferred to the British India Steam Navigation Co. Ltd. in 1961, he continued to serve under the new management and, at the time of his death, was chief engineer of L.S.T. *Maxwell Branda.*

Mr. Kearney was elected a Member of this Institute on 19th March 1946.

ROBERT LEE (Member 8068), whose death occurred on 12th June 1964, had been a Member of this Institute since 6th January 1936.

Born on 2nd September 1902, he served his apprenticeship with the Royal Naval Torpedo Factory, from 1917 to 1919, and with John G. Kincaid and Co. Ltd., from 1919 to 1923, after which he was employed at the Royal Naval Torpedo Factory for two years. He went to sea, in 1925, and, during his years at sea, gained a First Class Board of Trade Steam Certificate and achieved the grade of second engineer. Mr. Lee retired from the sea to become an engineer surveyor and, in this capacity, held appointments with the Scottish Boiler and General Insurance Co. Ltd. and with Lloyd's Register of Shipping.

LIONEL LE SUEUR (Member 15316) was born on 12th October 1884. He served an apprenticeship, from 1901 to 1906, with the Thames Ironworks, Shipbuilding and Engineering Co. Ltd., after which he went to sea for four years, being at one time fourth engineer in s.s. *Ghazee*.

From 1910 to 1915 he was a representative with Ross Schofield and Co. Ltd., and, from 1916 to 1919, held a similar position with J. R. Reedman and Company. From 1920, Mr. Le Sueur held directorships in several companies, however, his main connexion was with Lionel Le Sueur and Co. Ltd., boiler specialists, with whom he was associated until his death on 19th November 1964.

Mr. Le Sueur was associated with the Institute for a considerable number of years, having been first elected to membership in 1908.

THOMAS SCOTT MORRISON (Member 4111) died on 15th March 1965, leaving a widow.

Mr. Morrison was apprenticed with the Gourock Ropework Co., Port Glasgow, and then worked as a journeyman engineer with various firms. He had about seven years' sea service, and was for five years boiler inspector to the Travellers Insurance Co. (for part of this time was also Government boiler inspector for the Province of Quebec). He gained a First Class Board of Trade Certificate.

In 1917 he was appointed ship and engineer surveyor to Lloyd's Register of Shipping, stationed at Birmingham, Alabama. He was transferred to New York and then to Hong Kong, where he served until May 1941. He was appointed a senior surveyor in 1934. He served again in the United States and in Montreal, returning to the United Kingdom in 1946, when he retired from service.

He was elected a Member of the Institute on 14th September 1920.

SELVARAS MUDALIAR (Associate Member 23772) died on 6th January 1965, while serving as chief engineer in s.s. *Marahta Explorer*.

Mr. Mudaliar served his apprenticeship with Mazagon Dock Co. Ltd., and his career at sea was spent in ships owned by the Malabar Steamship Co., and the Mogul Line. He gained his First Class Steam Certificate in 1963.

Mr. Mudaliar was elected a Graduate member of the Institute on 30th May, 1961 and transferred to Associate Member on 13th January 1964.

EVAN CHARLES MURPHY (Member 10711) died suddenly on 2nd January, 1965, aged fifty-three. Mr. Murphy served his apprenticeship at the Vulcan Motor and Engineering Co. Ltd., and C. and H. Crichton Ltd. in Liverpool.

His career at sea started with Canadian Pacific Steamships Ltd. as eighth engineer in 1932; he rose to fifth engineer, and then went to Ellerman Lines Ltd. as third engineer in 1936. In 1938 he gained his First Class Ministry of War Transport Steam Certificate, and Motor Endorsement, in 1943. He joined Cunard in 1937 as a seagoing engineer in the *Queen Mary,* and during five years' service with that company, sailed also in the *Queen Elizabeth* and the *Georgic*. In 1943, he was transferred to shore duties in Liverpool and during the latter years of the war, was attached to the Ministry of Transport as a technical representative based on New York, where he remained for two years. He returned to Liverpool in 1945, when he was appointed assistant superintendent engineer.

Mr. Murphy was elected a Member of the Institute in 1946, and has been a staunch supporter of the activities of the Merseyside and North Western Section for many years.

He is survived by his wife, a married daughter, and a son who is still at school.

JOHN NEILL, B.Sc. (Member 7244) died on 30th November 1964. Mr. Neill served his apprenticeship with the North Eastern Marine Engineering Co. and attended Armstrong College, Newcastle upon Tyne, where he obtained a B.Sc. in Mechanical and Electrical Engineering. He then worked as a draughtsman with various engineering companies, until the First World War when he served in the R.N.V.R.

On demobilization he returned to the North Eastern Marine Engineering Co. as manager of the Superheating Department, then became manager at Sunderland and Wallsend. He was elected a Member of the Institute in 1933, and was also a Member of the Royal Institution of Naval Architects and of the North East Coast Institution of Engineers and Shipbuilders.

In 1936 Mr. Neill was appointed general manager and a director of North East Marine, and on formation of the Richardsons Westgarth Group, a director of that group also. He continued to hold these positions until he retired from the board of Richardsons Westgarth in 1949.

DAVID EUSTACE NEWTON (Associate Member 21707) died of coronary thrombosis on 11th February 1965, aged thirty-nine.

Mr. Newton sailed as chief engineer for Ellerman Wilson Line Ltd., and on leaving the merchant service, was employed as a steam services engineer at Lysaughts Steel Works, Scunthorpe. He also attended the North Lindsey Technical College in the evenings, where he gained a first class pass for iron and steel making; he was also awarded a prize for merit in chemistry and metallurgy in the first year. However, he was unfortunately unable to continue his studies owing to ill health.

Mr. Newton leaves a widow, and two small sons, aged 3½ years and 19 months.

ALBERT RIDINGS (Member 7823) died suddenly in February 1965, aged sixty.

Mr. Ridings was apprenticed with Edward Bennis and Co. Ltd. from 1919-1925, and in 1926 became a leading draughtsman with that firm, later being promoted to chief engineer.

After the war he went into business on his account, and was very successful in building up his firm, Steam and Combustion Ltd., of Farnworth, until they were handling contracts all over the country.

Mr. Ridings was elected an Associate Member of this Institute on 19th March 1935 and transferred to full membership on 27th July 1942; he was also a Member of the Institute of Mechanical Engineers, a Fellow of the Institute of Fuel, and was acknowledged as one of the foremost authorities in the country on combustion engineering. He was at one time a lecturer in engineering at Bolton Technical College. He took an active interest in local education and was a governor of several schools.

He is survived by a widow, a daughter and two sons.

CHARLES FRANCIS WHITE (Associate 12070) died on 27th January 1965. He was born in India in 1900, and served his apprenticeship at H.M. Dockyard, Devonport; he also studied engineering at Plymouth Technical College. After service as a fitter, he passed the inspector's examination and became an assistant Admiralty overseer at Scott's Shipbuilding and Engineering Co., Greenock.

In 1948 he was appointed as a senior production inspector at Thornycroft's Shipbuilding Yard, Southampton, where he remained until his retirement in 1964. He was elected an Associate of the Institute in 1948.