

No. 4

SOME PROBLEMS IN CHEMICAL ENGINEERING WHICH
ARISE IN H.M. NAVY

[Paper read at a Chemical Engineering Group Session.]

Introduction.—The conscious employment of chemical processes in the Royal Navy dates, presumably, from the first use of gunpowder but, with the introduction of copper sheathing and later of steam, such processes became a matter of daily use.

For a time after the first steamships were brought into service, effective combustion was mainly dependent on the skill of the stokers, while chemical tests were probably limited to a strip of litmus paper. That is not the position to-day. Over 99 per cent. of the effective ships in the Navy, submarines excepted, are now propelled by highly-forced steam plants which rely entirely upon a number of chemical processes, instruments, and tests for their efficient performance and without which, in certain circumstances, they would not continue to operate at all.

The explosives now carried—cordite, shells, bombs, torpedoes, detonators, depth charges, mines—have been made so adaptable to instant automatic use by the skill of the manufacturers, and so stable by the researches of the chemists that they require practically no attention on board, and even the necessity of maintaining the magazines at an equable temperature by means of cooling machinery is fast disappearing. In short, the interest of explosives lies in their manufacture and in their tactical use. Both subjects are outside the scope of this paper, which it is proposed to limit mainly to those points in connection with the running and maintenance of the hull and machinery of the ship where our profession is dependent to a greater or lesser degree upon the knowledge and advice of chemical engineers; passing reference will, however, be made to certain other matters of common interest.

Water—Importance of Pure Feed for Boilers.—Fresh water has always been of the first importance to seamen. Too often, in the old days, in the words of the Ancient Mariner, it was a case of "Water, water, everywhere, nor any drop to drink." Not that they were particular: they were glad to drink water which we should instantly cast away as foul, and yet our taste is gross compared with the fastidiousness of a modern boiler. A present-day naval water-tube boiler indeed is a very epicure and demands to be fed with the purest, de-aerated, distilled water obtainable. Failing this, corrosion, scaling, priming, or all three may be expected. Too much air and rust will appear; a trace of oil or a layer of scale-forming deposits and the tubes will overheat and distort; a

pinch of salt and the water in the steam-drum will fly into a foam so that the lighter particles are carried away by the out-rushing steam, to cause possible water hammer in the steam pipes and certain erosion of the turbine blades. And so, where our grandfather used his tongue, maybe his nose, or at best a battered, brass-bound, shot-loaded hydrometer, we to-day employ quite delicate chemical tests (or so they seem to us) to determine the oxygen content, the salinity, and the alkalinity of the boiler feed water.

Priming, Scaling, and Corrosion.—The importance of these tests will be better appreciated if the causes of priming, scaling, and corrosion are briefly recalled.

Priming may be due either to foaming, that is to say, the formation of bubbles over the whole surface of the liquid, or to entrainment, which is a mechanical process whereby drops of water are carried away by the velocity effect of the vapour.

Entrainment can occur in any liquid, but foaming is dependent on the nature of the liquid.

Conditions favourable to the formation of foam are the presence of soluble salts, together with finely-divided insoluble material, such as disintegrated scale. Entrainment and its avoidance are mainly a matter of boiler manipulation and design, and fortunately the liquid carried over in this way can usually be removed by mechanical means such as separators and internal steam pipes. It is difficult, however, to intercept the liquid carried over by foaming, and it is therefore of great importance to avoid conditions which give rise to the production of foam.

Scale on the heating surfaces is formed by those substances, such as calcium sulphate, whose solubilities decrease with increase of temperature. Substances whose solubilities increase with temperature will, if concentrated beyond their saturation value, eventually deposit as sludges, but this effect is less objectionable.

Corrosion and its causes are an extremely controversial matter, but broadly speaking it can be said that for corrosion to be continuous there must be a continuous supply of oxygen, since if the supply is cut off the action must cease when all the oxygen present has combined with the necessary quantity of iron. Oxygen, therefore, may be regarded as the prime factor in corrosion, but its action may be accelerated by the presence of other impurities. As a rule, acid solutions increase corrosion, and alkali solutions retard it; but there may be exceptions. Carbon dioxide is almost invariably present in water and forms a weak acid solution which consequently gives rise to corrosion. The action of certain salts may also favour corrosion, but this depends on their concentration; a low concentration causes accelerated corrosion, but a heavy concentration may arrest corrosion; a heavy concentration, however, is objectionable because it causes deposits. Sea water contains some salts, such as those containing magnesium, which are

cyclic in their action, that is to say, they cause continuous corrosion without renewal. Oxygen is not always necessary for such action, although it may accelerate it. Sodium salts are comparatively harmless from the corrosion point of view, but cause deposits.

Enough has been said to show the necessity for pure, de-aerated, distilled water. This is the ideal; practical factors always give rise to some impurities, even though the concentration be small. Thus, some oxygen and CO_2 due to incomplete de-aeration are invariably found, and sea water, wherever it has access, will not be entirely denied. The reserve feed tanks, formerly situated for convenience in the double bottoms, have for this reason recently been withdrawn within the inner skin, but the condensers remain a source of weakness.

Contamination of Feed Water by Oil.—Lubricating oil in the days of reciprocating machinery was a constant source of contamination, and from very early days the use of vegetable and animal oils was banned, since it was realized that their introduction into the feed water favoured the formation of oxygen concentration cells and fatty acids, both of which, particularly the former, would attack the plates and tubes of the boilers. Only high-grade mineral oils were permitted, and filters of towelling or sponges were employed which required constant attention. In modern ships, almost all the auxiliaries, as well as the main engines, are turbo-driven, with the result that the need for internal lubrication of the working parts and subsequent filtering of the feed water has disappeared. Occasionally, for some special reason, a few reciprocating auxiliaries are still retained, and in these cases the exhaust steam from the reciprocating engines is kept separate from the turbo-exhaust and the condensate of the former is passed through a small filter, generally of the coconut fibre type. There is evidence to show that extremely small quantities of oil may contribute to overheating of the boiler tubes, and if a simple and highly-sensitive oil detector could be devised it would be of service, but none has so far come to notice.

Salt detectors and oxygen detectors, however, are available, and for the latter the process used is the well-known chemical titration method of Winkler.

Measurement of Oxygen in Water.—This method can be used to determine the oxygen content down to 0.05 ml. per litre, and consists of adding to the sample of water to be tested, first a manganous chloride solution, then an alkaline iodide solution, consisting of sodium hydroxide and potassium iodide, whereupon a white precipitate of manganous hydroxide is formed which has a great affinity for oxygen. If any oxygen is present in the water it immediately reacts with the white precipitate of manganous hydroxide and forms manganous acid, which is a brown precipitate.

Hydrochloric acid is now added, reacts with the manganous acid and produces free chlorine (or more generally sulphuric acid which combines with the sodium chloride produced by the first reaction giving hydrochloric acid). The potassium iodide contained in the second solution now takes up the story. The potassium and free chlorine combine, free iodine is left, and the quantity of free iodine is a measure of the oxygen in the water. This can readily be verified if the reactions are set down in full, when it will be found that for every molecule of oxygen in the water, two molecules of free iodine are produced. The sample, no longer susceptible to the presence of air, is now poured into a dish, starch solution added as an indicator, and the titration carried out against standard sodium thiosulphate. The oxygen factor of the sodium thiosulphate having been determined when the solution was made up, the quantity of oxygen in the water can readily be arrived at, and in the case of the standard set supplied for use in the Navy, each ml. of solution used represents 0.1 ml. of oxygen per litre. This is quite sensitive enough for the purpose, and the process has the advantage that all calculation is avoided, but some care and practice are required to obtain dependable results and a great drawback is that the whole operation takes about 15 minutes to carry out. Clearly there is scope for improvement here. Ideally, what is wanted is a sensitive and yet robust automatic continuously recording instrument.

Salinometers.—In the case of salt detection we fortunately have such an appliance. These instruments make use of the well-known fact that the electrical resistance of pure water is very high, but falls off rapidly if certain compounds—of which salt is one—are added.

Essentially the apparatus consists of a vessel which is fed with water from the particular part of the feed system to be tested, into which two suitable electrodes are arranged to dip. Current from the mains is passed in series through the electrodes and an electric lamp. The lamp not only serves to indicate the purity of the feed by the brightness of its filament, but also enables the sensitiveness of the apparatus to be varied by the use of lamps having different resistances; the distance between the electrodes is also made variable for the same reason. In more elaborate forms of the apparatus a voltmeter is provided across the electrodes to give a quantitative indication of the amount of salt present. The voltmeter scale can be calibrated, but the readings will only be accurate at the temperature of the feed water at which the instrument was calibrated, unless some compensating device is fitted.

In one form of instrument the salinity is indicated by the readings of a milliammeter, instead of by the use of a voltmeter, and compensation for temperature is effected by a variable shunt resistance across the terminals of the ammeter. Some sections of the shunt are arranged to be short-circuited by the mercury column

of a special thermometer, the bulb of which is immersed in the feed supply under observation, and this device appears to give adequate temperature compensation. In the usual commercial forms, these instruments are adjusted to read from 0 to 0.5 grains of chlorine per gallon by steps of 0.1.

A further elaboration consists of a warning buzzer arranged to operate when the salt concentration reaches a certain figure and a cut-out device, arranged to break the circuit should the salinity exceed that corresponding to the maximum scale reading: this arrangement avoids damage to the instrument in the event of a sudden influx of contaminated water. The instrument, however, will not reach its full usefulness until capable of making an automatic record, and the attempts in this direction have so far not been entirely satisfactory.

These instruments are of course subject to derangement now and then, and on such occasions and at all times as a periodical check, the time-honoured nitrate test is employed.

Nitrate Test.—The ordinary nitrate test is very sensitive and, although its delicacy depends largely upon the illumination, and also to some extent upon the observer, it enables under average conditions, one part of sodium chloride in two million parts of water to be detected with certainty. By making use of potassium chromate as an indicator (Mohr's method), the test can also be used quantitatively.

A measured sample of the water under test is made slightly alkaline (if not already so) and a few drops of potassium chromate are added as an indicator, turning the water yellow in colour. A standard solution of silver nitrate is then added slowly, the mixture being well stirred throughout the operation, till it changes colour to a reddish-yellow throughout. Observation of the amount of silver nitrate of known concentration necessary to effect this change enables the chlorine content of the water to be calculated. The chemical reaction involved is the same as for the ordinary silver nitrate test, namely—

Sodium chloride + silver nitrate = silver chloride + sodium nitrate, and after the reaction is complete, the excess drop of silver nitrate, which cannot be converted into silver chloride and sodium nitrate, forms the reddish precipitate with the potassium indicator.

This test is a very satisfactory and accurate one, and is especially valuable, in the event of a feed reservoir becoming contaminated, in deciding whether the water is suitable for use subject to dilution, or whether it should be pumped overboard or otherwise disposed of.

The instruments described enable dangerously high concentrations of impurities to be detected, and a few words may be added as to the methods adopted to guard against the development of such concentrations and to mitigate the effect of such lesser degrees of impurity as cannot be entirely avoided.

Evaporators.—Evaporators are used for the first product. Here a digression may perhaps be made to notice that although evaporators are a comparatively recent introduction (until about fifty years ago a simple distiller to which boiler steam was admitted was the only provision) yet, like all else under the sun, the idea is far from new. By Pepys's day at all events the stage of practical sea-going experiment had been reached. Under the date of August 3, 1684 (the original may be seen in the library of Worcester College, Oxford, endorsed by Charles II and signed by the redoubtable Sam himself) the following directions were given to Captain William Gifford, of H.M.S. "Mermaid," "abt an Engine for making Salt Water, fresh.

Whereas a Proposal has been made to Us of an Engine to be fixed in one of Our Ships for the making of an Experiment of producing Fresh Water (at Sea) out of Salt, Our will and pleasure is, That, upon application to you by ye Persons concerned in ye said Engine, you doe receive ye same on Board, and cause it (at their Charge) to be fixed in some convenient place in Our Ship, in Order to your making ye said experiment in yor present voyage, and Reporting to Us yor Observations upon it, for Our Satisfaction, upon your Returns: Provided that you be first satisfied that ye same may be put up and made use of, without any sort of danger to Our Ship by Fire, or otherwise. For wch. this shal bee your warrant. Given at Our Court at Windser this third day of August 1684.

By his Mats. Command.

S. Pepys."

The immediate outcome of the experiment is not known, but the difficulties of our blockading fleet off Cadiz more than a century later show that it had no permanent result, and it is certain that when at last a practical form was devised, few inventions have proved a greater blessing to seafarers than the evaporator. Nowadays, the production of water in this way for washing, cooling, and drinking, when necessary, is taken for granted. The process, however, is somewhat expensive, so that water for general ship purposes is always taken in from shore when practicable, but as few naval ships carry more than four days' supply, it frequently has to be supplemented by the evaporators. Distilled water is extremely pleasant for washing with, but very flat for drinking. To counteract this to some extent, the made water is sprayed into the tank through a rose, but this does not effect much improvement. No doubt other substances besides air are required to make it palatable, and any ready means of doing so would be a welcome refinement.

For boiler purposes shore water, as already stated, and as some have found to their cost, is useless unless first passed through an

evaporator or through an auxiliary boiler at low output, the boiler being frequently blown down during the process and subsequently emptied to the bilge and thoroughly cleaned. The water made by the evaporators is checked for salinity by means of instruments of the type already described, and if not within the prescribed limit is passed to the drinking water tanks or to the bilge, depending on the degree of contamination. As soon as the water leaves the distiller, however, and reaches the feed tanks, it necessarily becomes aerated and the air must again be eliminated before it is used in the boilers. This is effected by means of a system of closed feed which has been claimed to be the most important development for the reduction of boiler corrosion that has taken place in recent years.

Closed Feed System.—Any feed system possesses in the condenser a very effective de-aerator, since the water therein is at, or near, its boiling point, and providing effective arrangements are made for continuous extraction of the air, the condensate removed from the bottom of the condenser will contain the minimum of dissolved gases, and if not allowed to come into contact with the air before re-entering the boiler, the objective is achieved. Unfortunately, the amount of water contained in the boilers is subject to large changes under varying rates of evaporation (amounting to as much as 4 tons per boiler) and a reserve capacity of feed water must therefore be incorporated in some part of the feed system. When, as is usual, this cannot be accommodated in the well of the condenser, automatic arrangements are provided for passing the required extra water from the feed tank into the condenser, where it is de-aerated before it is allowed to enter the feed system. Similarly, the extra water supplied by the evaporators to make good wastage, is dealt with in the same way.

In passing it may be stated that this wastage, although less than formerly, is still very considerable, amounting in the case of large plants to as much as 100 tons a day at full power, while 25 tons a day under cruising conditions is quite normal. Only a proportion of this water is found in the bilge; the majority is carried in suspension up the ventilating trunks, and any light and practical means of recovering such losses would clearly be worth consideration.

To return, the main boilers are sometimes in use for supplying steam to large auxiliaries, such as electric generators and hydraulic pumps, when the main condensing plant is not. In these conditions, provision for removing the air from the feed water is made by means of special de-aerators. The most satisfactory method of de-aeration consists in passing the feed through a chamber where it is subjected to a vacuum, and where the water, near its boiling point, is broken up into small particles by means of a spray. The air liberated under these conditions is removed by an ejector, leaving the de-oxygenated water to be withdrawn by an extraction pump and discharged to the feed-pump suction.

Treatment of Boilers for the Prevention of Corrosion.—By the use of these appliances the water should reach the boilers at a high degree of purity, but certain precautions are still necessary in the boilers themselves. Thus, the water in the boilers is always kept in a slightly alkaline condition by the use of lime. The test is generally made by means of two drops of phenol-phthalein to a test tube of water, when a light shade of pink indicates sufficient alkalinity. Usually it is only found necessary to add a very small quantity of lime which is conveniently done when filling the boiler after cleaning, and this generally suffices until the next occasion of opening. It is realized that this slight alkalinity actually favours corrosion, as compared with perfectly neutral water, since alkalis do not exercise an inhibitive action on corrosion until an appreciable concentration is reached. It is considered preferable, however, to accept this effect than to risk the possibility of acid conditions which would give rise to much more serious corrosion, while the higher alkaline concentrations are unacceptable from the point of view of deposits. Boiler compounds purporting to cure all ills are legion, and in some other Navies elaborate boiler water-conditioning is resorted to by such means, but this has been found neither necessary nor desirable in our Fleet, and the same remarks apply in general to evaporator scales and the many compounds offered for their mitigation. Zinc slabs are still fitted, but it must be admitted that there is little positive proof of their value for minimizing corrosion. The traditional galvanic action, to which their possible protective action was formerly attributed is questionable, since metallic contact between the zincs and the boiler is very soon severed by a layer of zinc oxide. It appears that their function, if any, must be to direct to themselves the action of any gases present. It may be added that prolonged trials, still in progress, show up to the present that no harmful effects result from the omission of zinc slabs entirely, and this is the present tendency.

The subject of pure feed water has been dwelt upon at some length because it is of particular importance in modern steam plants and pre-eminently so in naval ships, since not even the high-powered ocean liners adopt rates of forcing which are quite common in the Navy.

Combustion and CO₂ Recorders.—It is not proposed to say anything about combustion, except that CO₂ recorders, whether of the electrical or chemical type, have been tried but discarded. Service conditions are not particularly suited to the use of such instruments. Boilers are seldom steamed at steady rates for long periods, except on passage, and even then only the flagship will be steaming absolutely steadily. Further, during exercises, smoke must be completely avoided, and this precludes steaming the boilers at their highest efficiency. Finally, gunfire and the vibration which may be experienced at high powers are prejudicial to their

accuracy, and they would certainly resent the occasions when smoke is deliberately made for tactical purposes.

Smoke Screens.—Smoke screens made with the boiler fuel have the advantage that they can be produced instantly without previous preparation or warning, nor do they necessitate the provision of special stores. The appliance is extremely simple, and consists only of a jet led into the furnace high up in the combustion space, so as to be away from the swirl from the air cones. The objections to this method are that it tends to clog the boiler tubes with soot, and that in some conditions it forms a less satisfactory screen than that produced by chlorsulphonic acid.

The latter apparatus consists of 50 per cent. chlorsulphonic acid and 50 per cent. sulphur tri-oxide stored in steel drums which are kept at the base and decanted, as required, into containers carried by the ships. When required, the fluid in the container is discharged to the pipe line by means of a pump or by air pressure. The pipe line is led towards the stern of the ship where it divides into three leads, each terminating in a jet sprayer and each fitted with a volume-control valve. The settings of these valves are varied to suit the speed of the ship relative to the wind, and also for the prevailing atmospheric conditions which affect the persistency, and to some extent the volume of the smoke produced.

Chlorsulphonic acid causes serious deterioration of structural steels, particularly those of higher quality, such as those used in destroyers, for which reason it is necessary to wash down and thoroughly scrub the structure near the apparatus after each occasion of use with a basic solution, such as soda ash in salt water. This is all very well in peace time, but in war may have to be deferred until after the damage has begun; consequently a smoke-producing chemical which did not suffer from this drawback and required less care in handling would be welcome.

Poisonous and Inflammable Gases.—The larger question of chemical warfare gives rise to no problems peculiar to the Navy; indeed, many hold the opinion that the use of such gases against ships is likely to be rare, since if it be possible to approach sufficiently near to employ them, explosives are likely to be more effective.

Poisonous or inflammable gases or vapours, however, are apt to be found on board at all times in enclosed spaces such as bunkers, fuel tanks, double bottoms, and machinery cases, and special precautions are necessary to guard against their effects. The majority of these gases (such as methane), when mixed with air in certain proportions are explosive at ordinary temperatures, while higher temperatures and finely-divided matter such as coal dust, if present, usually increase the danger.

The instrument employed for their detection is the miner's safety lamp, and the method employed is to draw down the flame until only a faint line of blue is seen above the yellow centre. The

presence of any gas in the air will then be shown by the appearance of a pale triangular "cap" over the top of the blue line. The "cap" is produced by the combustion of any combustible gases which there may be in the air, and the greater the concentration of these gases the larger the cap. The degree of visibility of the cap varies according to the natural luminosity of the flame of the burning gas, for which reason it is difficult to observe hydrogen whose flame is almost invisible. When it has been said that it is possible in certain conditions for the cap to appear when no injurious gas is present, and that it is practically impossible to observe the "cap" in certain other conditions, although such gases are present, it will be agreed that the test is not entirely satisfactory, and that a better one would be a boon.

In coal bunkers, the lamp is used as a safe form of illumination, but when the wick is turned up sufficiently to make it effective in that way, it is very little use as a detector, since the flame required for the latter purpose must be small and non-luminous. In oil-burning ships, few of the compartments to be tested have means of *suddenly* producing a dangerous supply of fire-damp, hydrogen, or other inflammable gas as may happen in coal mines or bunkers, so that there is no need to work with a safety lamp, provided the compartment is tested before entering and after each prolonged absence. The difficulty of forming a satisfactory testing flame, and the fact that the testing flame and cap are transparent and difficult to observe under practical conditions, results in more reliance being placed on thorough ventilation and careful approach, than in the safety-lamp test itself. Prolonged delay for complete ventilation, however, is sometimes impracticable, and on such occasions an improved detector is badly wanted.

Occasionally, gases are deliberately introduced into ships, particularly submarines, for purposes of disinfection. The most effective of these is prussic acid (HCN). Tins containing absorbent material of a cellulose nature saturated with the liquid are used, or alternatively the fluid may be released from cylinders under pressure. Owing to the danger to the operators, contractors who specialize in the process are engaged when it is necessary to use this method. A simple and less dangerous method, which can be used by service ratings, is sulphur. Sticks of sulphur are burnt in the space to be disinfected, the concentration required being 40-60 oz./1,000 c. ft., and the time required about eight hours. A disadvantage is the corrosive effect of the gas, so that here again it would seem that there is scope for improvement.

Gases are also carried on board in connection with the cooling machinery. The refrigerant most commonly employed for the main cooling machinery is carbon dioxide, although ammonia (NH_3) is still met with in a few cases. For the smaller automatic refrigerators used for food lockers, soda fountains, chemical cupboards, photographic rooms, serum cabinets, and similar small detached

services, stock commercial machines using various refrigerants, such as methyl chloride, sulphur dioxide, and ammonia are accepted. In all large plants, however, CO_2 is retained on account of its low toxicity. This feature is of particular importance in submarines, where CO_2 alone is permitted, and even then provision is made for pumping out the whole of the charge to a special reservoir outside the pressure-hull in the event of a gas leak developing when submerged. In this connection it may be of interest to mention a refrigerant recently produced in America and generally known as "Freon" or F. 12. Its full name is dichloro-difluoromethane.

This fluid is a clear water-white liquid boiling at -21.6°F. , and is claimed to have advantages over other refrigerants in that it is the least toxic so far discovered, is non-inflammable, has no odour, has no chemical action on the metals commonly employed in refrigeration, and has working pressures above atmospheric, thus avoiding troubles due to inward air leaks. It is, however, miscible with lubricating oil, a disadvantage which it shares with methyl chloride.

Air-conditioning in Submarines.—From the qualities enumerated, it will be seen that Freon should be particularly suitable for air-conditioning, and on this account would be useful in submarines and has, it is believed, been so employed in the American Navy. De-humidifying the air in our submarines is receiving some attention at the present time, owing to the fact that they are now employed in tropical waters to a greater extent than formerly. Up to the present it has been usual to rely upon condensation in the air coolers operated by a CO_2 cooling plant, but the smaller submarines are not so fitted. For the latter a process using silica-gel (SiO_2) has been suggested. This agent can absorb 40 per cent. of its own weight of water and up to 20 per cent. does so with great efficiency. As proposed for submarines, two tanks would be used, each with four hours' capacity before the gel became saturated. Thus the time the submarine could remain below in comfort would be limited to eight hours. On coming to the surface, the silica-gel would be re-activated by passing over it a stream of heated air. The suggestion is interesting but has obvious drawbacks, and a more promising proposition is to compress the air in an axial flow compressor to a fairly high pressure and temperature, pass it over a tube-nest cooled by sea-water only, and then re-expand it through a turbine attached to the blower, where part of the work of compression would be recovered.

Detection of Water in Fuel Tanks.—Another instance where unwanted water can cause great inconvenience is in the fuel tanks. A hit by a practice torpedo in peace time is quite enough to ensure this, and other causes are not unknown, while in war we have to consider the effect of live torpedoes, shells, bombs, and mines. The removal of the water in this case, since it is heavier

than the oil, is very simply effected by means of the suction, but it is not desirable that this should occur when the pump is supplying the furnace sprayers. It is usual, therefore, to test the tanks in use frequently and all others periodically, for the presence of water. For this purpose, we have fortunately been provided with a very simple and reliable test. A strip of sensitized paper is attached to the sounding rod and lowered to the bottom of the tank. The agent with which the paper is impregnated is a treacle or sugar base with red colouring matter, and the extent of any sea water in the tank will be shown by the length of the paper which has been turned white by the dissolution of the sugar.

A recent and slightly more convenient variant consists of a sensitized paste which is smeared on the rod and is bleached to the extent to which it is submerged in water.

Sea Soundings.—A somewhat similar principle is sometimes made use of for taking soundings of the depth of water under the ship when steaming fast. A glass tube, open at the bottom, sealed at the top, and coated on the inside with a red-coloured compound of silver chloride is placed in a brass guard and attached to the lead. The height to which the sea water will rise in the tube against the compression of the entrapped air, is proportional to the depth of water and the extent to which it does so is registered by the amount of the red-coloured silver chloride, which is turned white. When the lead is hauled in the sensitized tube is laid alongside a scale and the depth of water read off directly. Ample sea water under the bottom of the ship is the mariner's friend, but its attentions in other directions are less welcome, since it causes fouling and it causes corrosion.

Anti-corrosive and Anti-fouling Paints.—It has been estimated that 29,000,000 tons of iron and steel are dissipated in the form of rust every year, and with it four or five times as much coal or coke involved in its production. These figures illustrate the economic importance of a problem which is particularly acute at sea owing to the salt-laden atmosphere.

The effects of this attack on the hull and fittings of ships are, generally speaking, combated less by resistant materials than by the use of suitable paints and galvanizing, or in the case of certain unoccupied internal spaces, such as torpedo protection compartments, by a coating of heavy mineral oil.

It is not sufficient, however, to protect the underwater surface of the hull with anti-corrosive compounds only; it is also necessary to provide against fouling by the adhesion of marine animals and growths. The figures just quoted for the annual cost of steel corrosion are astonishing, and if a similar estimate were made of the losses due to the fouling of ship bottoms, the result would also be remarkable. All the dry docks of the world are filled for the

greater part of the year, not with ships requiring repairs to their plates, rudders, propellers, or underwater fittings, but simply for the removal of barnacles, while every ship upon the seas pays a daily toll in extra fuel burnt.

A concrete figure may help. The annual cost of docking the ships of our own Navy alone, for this purpose, even at its present reduced strength is of the order of £150,000 a year and yet it is economical to do so. The problem has of course engaged attention for centuries. In the past our wooden ships were sheathed with copper, and if the copper was good the result was good, because the pure copper wasted quickly. The reason for this may be seen by considering the reactions which take place.

When a clean sheet of copper is exposed to sea water, the first result is the formation of a film of cuprous oxide, due to the action of dissolved oxygen in the water. The cuprous oxide is then converted by the carbon dioxide and salts present in the sea water into carbonate and oxychloride, both of which are practically insoluble, and form a greenish-blue deposit. This deposit peels off from the surface of the metal and carries with it any vegetable or animal organisms or other matter which may have attached themselves thereto. For economy, inferior kinds and alloys were sometimes substituted, which certainly reduced the rate of loss, but also increased the fouling. When iron ships replaced the wooden ones, attempts were naturally made to use the metal which had given relief up till then; but it was quickly found that the effect of the galvanic action set up by the copper was fatal to the iron plates of the ship.

Wood was then re-introduced as an insulator between the copper plates and the iron or steel hull, and this method was employed from time to time down to about thirty years ago. In 1840 the first patent for an anti-fouling paint appeared, and there have been many since. But the end is not yet. Whether by paint, or in some other way, we ought not to rest content with the position as it is now. In the case of the Navy, moreover, it should be emphasized that this difficult problem is complicated by the fact that the ships spend a large proportion of their time at anchor or otherwise at rest, and what is suitable then may be less so when they are sweeping through the water. The germs of marine animal and vegetable life are more abundant in the surface water near the shore than in deep water, and therefore the period when the ship is in port is the time when the germs are most likely to make good their attachment. At this embryo stage it is possible to poison them, but not later. Once they have made good their hold, they draw their nourishment from the water, and no amount of poison applied to their roots will have any effect upon them while an agent sufficiently active to burn off the roots would no doubt involve also an attack on the plates of the ship.

For ships which spend much time in harbour, therefore, a composition containing poison may be effective, but in general a more

promising line of approach is a compound which will gradually peel off, in the same way as copper, and thus remove the growths attached to it. But there are difficulties. In order to secure success, the composition must waste at a fairly uniform rate when the ship is at rest, and also when she is rushing through the water; and this is the more important in the case of Service vessels for the reason already given. If a composition is made to waste rapidly enough to keep a vessel clean for months in a basin, then the composition is good for that purpose: but when the vessel goes to sea, where the water may be at a higher temperature, and where the friction caused by her passage through the water exerts its influence upon the composition, the coating which did its work well for six months in the basin, may in the course of one month at sea be all washed away and fouling set up.

Another factor which is often overlooked, and which tends to give misleading results, is the action of brackish water, which in many cases seems to exert a special action in keeping the bottom of a vessel clean; the fresh water having a tendency to disagree with certain forms of marine growth, whilst the salt water is apparently equally unpalatable to the fresh water forms of fouling. A notable example of this occurs in China, a visit to the Yangtze by the ships stationed there being almost as good as a docking for removing underwater growths.

To sum up, if a vessel is to remain at rest for a considerable period, an anti-fouling composition which exfoliates rapidly, and which also contains poisons known to act on germ life should be used, the amount of such poison depending on the seasons and the waters in which the ship is to reside, but for a vessel which is continually running a slowly exfoliating composition may be employed, since a very small percentage of poison is sufficient, because skin friction and the comparative absence of germs and spores in deep water will do the rest.

To facilitate criticism, the present procedure with Naval ships may be summarized. The submerged part of the hull is given two or more coats of anti-corrosive composition, followed by one coat of anti-fouling composition, the latter being applied immediately before the dock is flooded, owing to its deterioration when exposed to air. A belt averaging about 3 ft. wide, which is exposed to alternate wetting and drying is covered with a composition known as boot-topping. The boot-topping is applied in the same way as the under-water composition, that is to say, anti-corrosive undercoatings followed by an anti-fouling finishing coat. The anti-corrosive undercoatings are usually spirit varnish compositions consisting of naphtha or white spirit solvents, with a soluble medium of gums and resins and an insoluble paint medium of iron or zinc oxide. The anti-fouling composition contains solvents similar to those in protective paints with the addition of poisonous compounds of copper, lead, arsenic, or mercury.

An average analysis of a protective composition would yield approximately :—

- 25 per cent. solvent (naphtha, paraffin, or white spirit),
- 35 per cent. soluble medium (resins and drying oils),
- 40 per cent. insoluble solid (zinc or iron oxide, etc.).

An average anti-fouling analysis would be similar, but the solid medium would be made up of varying percentages of poisonous compounds (copper, lead, arsenic, mercury), according to the maker.

It is not only on the outer skin of the ship, however, that marine growths, cause trouble. Unless steps are taken for their removal, they gradually choke the fire-main and other pipes to which they have access, while periodically they appear in bulk in the condensers or their inlets and choke the supply of circulating water; jelly-fish and sea-weed are particular offenders in this respect, and it is no unknown thing for a ship to have to stop while they are cleared away.

A more obstinate and constant loss of condensing efficiency, however, is provided by the inanimate constituents of sea water. Scale-formation on the salt water side of condenser tubes proceeds continuously, the principal deposits being calcium sulphate, calcium carbonate and magnesium sulphate, of which the hard scale of calcium sulphate contributes by far the greatest part.

No method of preventing or restricting this deposition has so far come to notice, and the only present solution is its periodical removal. Two methods are employed. They may be called the "chemical" or pickling treatment, and the "mechanical" or shot-blast process. The choice of method, that is to say, "pickling" or shot-blast, is determined by the extent of the scale, since it has been found that with a badly-scaled tube, shot-blasting does not clean the middle portion completely, and excessive blasting tends to destroy the ends of tube.

In the "pickling" process the tubes are first immersed for about 30 minutes in a bath of boiling caustic solution to remove the external grease, and are then transferred to a tank containing hydrochloric acid of strength three parts acid to one of water. The period during which the tubes are pickled is determined by the extent of the incrustation, and varies from 20 minutes to half an hour. The acid tank is inclined at a few degrees to the horizontal to permit the escape of gas generated inside the tubes, which, if not liberated, would form pockets and restrict the action of the acid. After completion of the acid treatment, the tubes are washed in fresh water, either in a tank or by hose pipes, the latter method being more usual.

For the shot-blast process the apparatus used consists of a sand or shot-blast unit of commercial type fitted with two nozzles, each arranged to deal with two tubes. The tubes are supported at the blasting end on a stand of convenient height, and at the other end

enter a steel box through holes cut in a rubber curtain. The used shot and dust from the tubes are collected in this box. The dust is removed by means of an exhaust fan and the shots fall to the bottom, from whence they pass through a valve to a lower container, and are returned to the blast apparatus by closing the valve and admitting compressed air into the lower box. Samples of the tubes to be cleaned are first blasted to determine the length of time necessary, which is then set on an indicator of the sand-glass type for the guidance of the operator. The time taken varies, as in the pickling process, with the condition of tube, the average time being approximately one minute. After blasting, the tubes are immersed in a boiling caustic soda solution in large batches for the removal of external grease, and afterwards washed with fresh water by hose. The immersion period is about 30 minutes.

Whichever process is used, the tubes, after washing, are polished externally with moist fine sand applied by means of a canvas pad, the tubes being revolved by an air motor.

As to the time taken, shot blasting is the quicker for lightly-scaled tubes and "pickling" when they are heavily scaled. The greater part of the time in both processes, however, is taken up in handling, and both necessitate the expense and delay of removing the tubes from the condensers. It is most desirable that this should be avoided and some method developed whereby the tubes can be descaled in their working position. This would, of course, still leave the problem of external cleaning to be solved, but this is becoming yearly less important, with the discarding of reciprocating engines and their associated oil. The method now periodically employed of "boiling out" the steam side of the condenser with a strong soda solution, heated and allowed to stand for some hours, which is even now reasonably effective, might then meet all requirements.

Fire Extinguishers.—The restricted spaces on board in which chemical extinguishers are most likely to be employed demand that they shall be non-toxic, but this is a requirement which few commercial types fulfil. Fortunately, water is always available on board ship and can be used in the majority of cases of fire, while steam has been found effective in the boiler rooms. Nevertheless, a fully non-toxic extinguisher for use in connection with petrol-driven boats, aircraft, and electrical apparatus would be welcome.

Miscellaneous.—Among other matters of common interest, mention may be made of the manufacture of oxygen in the dockyards in connection with oxy-acetylene welding and the saving of life; the production of enriched air on board ship for torpedoes; the maintenance of the large electric batteries fitted in submarines and the gases liberated therefrom; the nature of the brine employed in magazine cooling plants and the staining agents used in the study of metals.

Conclusion.—To conclude, it has been seen that we still lack facilities in several important matters and that among other things we have no oil detector ; a very imperfect means of ascertaining the presence of poisonous and inflammable gases ; no way of observing continuously the oxygen content of the feed water ; no method of descaling condenser tubes in place ; and that we lack a fully satisfactory solution of the ancient problem of underwater fouling. On any of these points, suggestions will be welcome, while it is only to be expected that continued development will raise further problems for solution in the near future.