

# EXTERNAL DEPOSITS IN BOILERS

BY

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External deposits in boilers have been with us as long as the boilers themselves ; this makes it rather surprising to find that very little is known about the whole subject. The solution to this apparent anomaly may be that with the comparatively low-power boilers which were in use up to the last war, the deposits were relatively easy to remove and, though they were a nuisance they did not present a serious problem. An article by Gray and Killner in this *Journal* in 1948 (Vol. 2, Nos. 3 and 4) ties up the subject with other results of sea water contamination and infers that if this can be eliminated no 'bonding' of deposits will occur. This is considered in more detail later.

Since that time, however there has been a continuous drive for more boiler power from less space and this has resulted in steadily increasing forcing rates with steadily decreasing sizes. This has made the removal of deposits more and more difficult until it is now one of the major problems with which we have to deal in connection with boilers.

The purpose of this article is to pass on to engineer officers some of the facts which have emerged from recent investigations in this field and to outline some of the difficulties with which we are all faced. It is hoped that this information will help E.O.s to appreciate some of the problems involved and to understand the background to some of the edicts which, from time to time, are issued by the Admiralty.

## The Nature and Origin of Deposits

As is generally known Admiralty fuel oil is a residual fuel 'cut back' with lighter fractions to give the required viscosity. When the crude oil is distilled the distillate is, by and large, pure hydrocarbons and all the impurities present in the crude are left in the residue—and hence in the furnace fuel oil.

In addition to this, contamination of the fuel invariably occurs during the extraction of the fuel, its refining and its transport and storage from the time it leaves the ground until it is burned in the ship. The most notable contaminant in naval fuel is salt due to contamination with sea-water.

At present there is no way of removing any of the impurities, except the salt, on a commercial scale at practicable cost ; and even the removal of the salt is unlikely to be practicable for naval vessels, as is explained later.

As well as these impurities in the fuel, salt enters the boiler with the combustion air. This aspect is more important in naval than in merchant vessels due to the inevitable closeness of the air intakes to the water.

When the fuel is burnt the hydrocarbons of which it is largely composed are burnt into  $\text{CO}_2$  and steam ; the trace impurities also oxidize but here the end products are not so easy to define. In the first place some of the constituents have several different oxides depending upon the amount of oxygen available (compare the burning of carbon into  $\text{CO}$  or  $\text{CO}_2$ ) ; in the second the constituents 'fight' for the available oxygen and hence the oxidation of one element depends upon the amount present not only of this element and of oxygen, but also on the amount of other elements present ; and thirdly the oxides of various elements combine together to form compounds which are very difficult to isolate and identify.

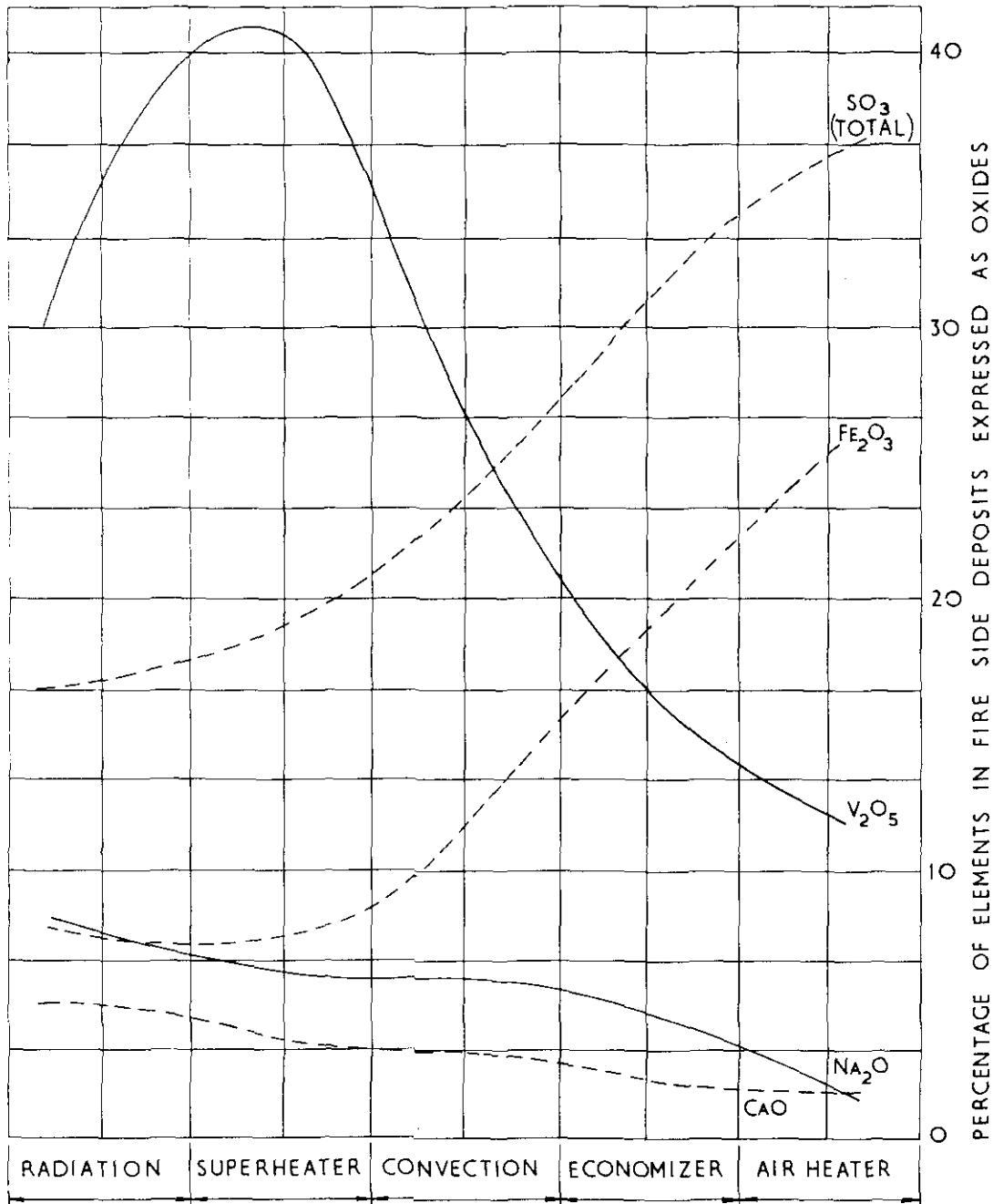


FIG. 1—TYPICAL DISTRIBUTION OF DEPOSITS IN OIL FIRED BOILERS

### The Constituents of Deposits

As indicated above, a large number of elements have been found in deposits and the number of compounds is even greater. But although much has still to be learnt about the various compounds and their method of formation, it is generally agreed that the elements which are the 'niggers in the woodpile' are sodium, sulphur and vanadium. These, combined with each other and with oxygen, form the major part of all tube deposits, although their proportions differ widely.

Sulphur is present in all Admiralty boiler fuel in amounts up to  $3\frac{1}{2}$  per cent. The amount of the other two elements in the original fuel is of a much lower order, usually measured in 'parts per million', though much more sodium may reach the boiler due to sea-water contamination of the fuel and air-borne salt in the combustion air, and much more is, in fact, always found in naval boiler deposits.



FIG. 2—TYPICAL FAIRLY HEAVY SUPERHEATER DEPOSITS

A typical distribution of the more important compounds in a boiler is shown in FIG. 1. It will be seen that, in very general terms, vanadium-rich deposits are found in the higher temperature areas (e.g. the superheater) ; in the lower temperature areas (e.g. the economizer) sulphates (measured as  $\text{SO}_3$  in FIG. 1) predominate. The sodium is distributed more evenly throughout the boiler and is largely found combined with the vanadium probably as sodium vanadate in the superheater area, and with the sulphur as sodium sulphate in the economizer area. Its chief effect, in the superheater at least, is to make the deposits very much more adherent.

Still speaking in general terms, the compounds of vanadium in the deposits are not soluble in water even if it is hot, while the greater part of the remainder are soluble in cold water and easily soluble in hot water.

### **The Mechanism of Deposition**

It is fairly well established that some of the constituents of the ash have boiling points below the temperature of a normal boiler furnace and hence they are vaporized in the furnace. Others leave the furnace as liquid droplets and some, often associated with carbon, remain in solid form. As the gases pass through the heat transfer surfaces of the boiler, however, they are rapidly cooled and, as the gases cool, ash constituents condense, some into liquids and some into solids. The temperature, and hence the position in the boiler, at which they do so depends upon the element concerned, its state of oxidation and its state of combination with other elements. To make the problem even more difficult, it does not follow that, because they have condensed, the ash droplets (or particles) will immediately hit and stick to a tube. The laws which govern the possibility of a given droplet sticking to a tube, being deposited as solid ash in 'dead areas' of a boiler gas path, or passing right through the boiler, depend upon a very large number of factors and the mechanism is at present by no means fully understood. In this connection it is worthy of note that by far

the greatest proportion of the impurities pass straight through ; if this were not so every boiler would be choked solid in a very short time.

There is no doubt, however, that a substantial quantity of ash is deposited in a molten, semi-molten or solid state on the heat transfer surfaces. This is by no means the end of the problem. Firstly, due to the temperature gradient through the gas film round each tube, the tube surface is at a substantially lower temperature than the gas. This normally results in the ash solidifying as it hits the tube. Secondly, reaction between the different constituents of the ash may continue after they have been deposited on the tube and there are also indications that the ash constituents may react with the metal of the tube itself. Thirdly, the presence of the deposits on the tube normally alters the conditions governing deposition and, according to the conditions, may encourage deposition, or may inhibit it ; in some cases ash already deposited may subsequently be removed by the scouring action of the combustion gases.

If the layer of deposit continues to build up, as is normally the case, the resistance to heat transfer is increased and hence, for a given heat transfer rate, the temperature difference between the inside of the tube and the outside of the deposit increases. The inside temperature being more or less constant, the outside of the deposit layer becomes progressively hotter until, in some cases, it may well start to melt again, thus presenting a sticky surface to the combustion gases and encouraging further deposition—now including solid particles which might not otherwise stick to the tubes.

### **The Effects of Deposits**

The above description of the mechanism of deposition is, of necessity, abbreviated and incomplete. As already mentioned, a great deal remains to be discovered in this field. The effects of the deposits are, however, clearer and more generally known. Deposits increase the resistance to heat transfer and hence more fuel must be burned to achieve the same output ; also the greatly reduced heat transfer to the superheater tends to reduce the steam temperature. In ships with damper control of superheat, the dampers are adjusted to correct this, resulting in more gas passing through the superheater, higher gas velocities and hence better heat transfer which brings the steam temperature back to the desired value.

A second effect is that the build up of deposits reduces the width of the gas passage between the tubes. This both increases the resistance to flow and also increases the gas velocity—partly, but not completely, counteracting the loss of heat transfer mentioned above. The increase of flow resistance increases the pressure drop through the boiler for a given gas flow—and thus for a given fuel input—and this process will eventually 'buy up' the available pressure head which the blower will provide and it will make it impossible to burn the designed maximum amount of fuel without making black smoke.

Both these effects—reduced heat transfer and increased gas flow resistance—reduce boiler output and efficiency but do not of themselves damage the boiler. If, however, a piece of the deposit breaks off a heavily fouled superheater, due, for example, to thermal shock or vibration, a dangerous situation arises : due to the increased damper opening (in a controlled superheat boiler) and to the reduced flow area, the gas velocity is appropriate to the heavily fouled tube. If this high velocity gas has access to a bare portion of tube, the heat transfer rate may become excessive and the temperature drop through the tube wall and steam film may become so large that the tube overheats and fails. At any rate high stresses will be set up by the temperature difference between the bare and the coated part of the tube surface. This danger is likely to be more acute in controlled superheat boilers.

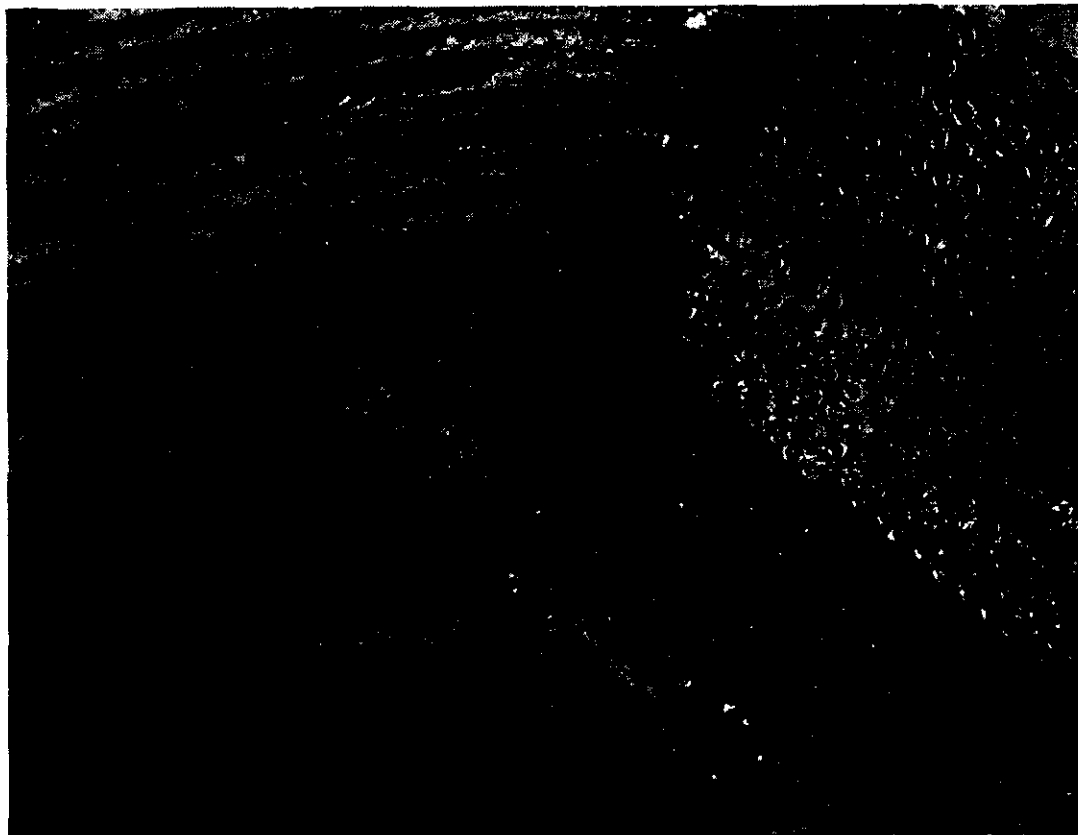


FIG. 3—AN EXTREME CASE OF SUPERHEATER DEPOSITS (H.M.S. 'VICTORIOUS', 1951)

### Deposits in Low Temperature Areas

The last two sections have been mostly concerned with deposits in the high temperature area of the boiler, that is the region round the superheater. In the relatively low temperature areas, such as the economizer and air heater (if fitted), the mechanism of deposition is believed to be somewhat different. Here the temperature of the surfaces is very important. If these are below the acid dew-point of the combustion gases—i.e. about 350 degrees F—sulphuric acid will condense and form a sticky liquid layer which induces the build up of deposits by the mechanical adhesion of solid ash particles. Naval boilers are designed so that, at full output, the temperature should be well above the dew point in the economizer, but at reduced powers the temperatures are inevitably lower and sulphuric acid condensation will occur.

The deposits which result are, as is well known, of a very different nature from those in superheaters, being much softer and generally more bulky. They are not usually very adherent and present a problem more by their quantity than by difficulty in their removal.

Their effects are similar to other deposits in that they reduce heat transfer and increase the resistance to gas flow, but they do not have the dangerous quality of superheater deposits, in that they cannot cause burning out of tubes. However, to make up for their innocence in this respect, they have a very undesirable feature of their own in that they are highly corrosive and if not removed regularly can cause great damage by corrosion.

### Removal of Deposits

Water washing of boilers was adopted for all ships in the Royal Navy in 1951, after trials which had been going on since 1946. It is also used in several foreign and Commonwealth navies and in most merchant ships. It depends

for its action upon the fact, which has already been mentioned, that most of the deposits except the vanadium compounds are soluble in hot water. In the low temperature parts of the boiler, the action is fairly straightforward as the deposits are bound to contain a high proportion of soluble salts and are usually in a friable form so that they can be washed off fairly easily. The chief problems are those of access and of the large quantity of deposit which may have to be removed.

In the superheater and high temperature areas the action is not quite so straightforward as there will be a substantial proportion of insoluble vanadium compounds. Here the action must be to dissolve the soluble portion of the deposit leaving a brittle skeleton of the insoluble part. This skeleton is relatively easily broken up and removed. In practice a large part of this skeleton is broken up and removed by the force of the water jet, but, if necessary, the remainder must be removed by physical effort with a suitable poker.

This procedure works well if the conditions are satisfactory. However, it is necessary, in the first place, to be able to get at the deposits with a poker or at least a jet of water; and in the second place the deposits must contain at least about one third soluble constituents or else the water will never penetrate them and in any case the remaining skeleton would be too strong to be easily broken up.

With regard to the first point—access—the compact design of modern boilers makes this more and more difficult and, in fact, in Type 12 and 14 frigates the leg of the superheater tubes remote from the furnace cannot be directly reached either by water jet or by poker; what is almost as important, they cannot be seen. Luckily the evidence at the moment is that the deposits in these areas are appreciably less and softer than on the furnace side and are largely removed by the action of the water running over the tubes, without the necessity for jet or physical force. The tubes nearer the furnace can be reached, though with difficulty, through the fire row tubes. This inaccessibility of the superheater is undoubtedly an undesirable feature and it has been avoided in later designs.

With regard to deposits with a low proportion of soluble constituents, this can be caused either by high-vanadium oils or by incomplete water washing of 'normal' deposits. Of these, the former has not, as yet, troubled R.N. ships. The R.C.N., however, has had considerable trouble with oils of Venezuelan origin which have a very high vanadium content and which cause deposits which are virtually completely insoluble in hot water\*. Although the R.N. does not normally use these oils, there can be no guarantee that we will not have to do so in the future, or in an emergency at the present time.

Trouble due to incomplete washing arises from the fact that, if the soluble part of a deposit is washed out, but the insoluble skeleton is not removed, the residue partly melts on subsequent steaming and consolidates on the tube. When the boiler cools this forms a skin of extremely hard deposit very firmly attached to the tube, and, being almost entirely insoluble, this cannot be removed by subsequent water washing. This insoluble layer may be quite thin and one such layer may not have a great effect; but if several successive layers of this nature are built up a heavy deposit can accumulate. What makes this form of deposit more invidious is the fact that, by the time the condition becomes serious, it may be a matter of years since the poor water wash. Put the other way, the result of incomplete removal of deposits now may not be felt until a couple of years later.

When the R.C.N. ran into their high vanadium troubles, they called in their scientists who discovered several substances which would dissolve the high

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\* The method used by the R.C.N. to combat this problem is explained in the article commencing on p. 446.

vanadium deposits. The most noteworthy of these was hydrogen peroxide. The R.C.N. has developed a procedure for using this chemical for cleaning. It should be noted, however, that this method is not suitable for use by ships' staffs and that the R.C.N. uses water washing for normal cleans and  $H_2O_2$  when it is considered necessary at refits.

Hydrogen peroxide may be effective against deposits from 'normal' fuels from which the soluble portion has been washed, but this has not yet been demonstrated and until it is, it cannot be adopted for this purpose. It may be possible to carry out trials in the near future.

#### **What Can Be Done About It.**

It is hoped that enough has been said to show that the whole problem of deposits in boilers is of enormous magnitude—and it should be remembered that the associated problems of high-temperature corrosion have not been mentioned. To help to review the whole field the Admiralty has invoked the help of a special panel of the Admiralty Fuels and Lubricants Advisory Committee (AFLAC) composed of representatives of Admiralty, Oil Companies, Universities, Research Establishments, etc. This panel, through working parties which it has set up, has reached certain conclusions which may very briefly be summarized as follows :—

- (i) Fundamental research is required into the mechanics and chemistry of deposits and the means of deposition
- (ii) There is at present no method on a commercial scale of getting all the harmful impurities out of the oil
- (iii) Little improvement can be expected from changes to combustion equipment unless they are very radical—e.g. combustion in two or more stages
- (iv) Additives are not very promising and would require a considerable amount of research work even to discover which of the many basic materials or proprietary additives are worth pursuing. (The U.S.N. and R.C.N. are, however, investigating the effects of additives and are passing the results of their investigations to us)
- (v) Trials, sampling of deposits and analysis of these deposits, all under carefully controlled conditions, are required.

These conclusions are being forwarded to the Admiralty officially and it seems likely that (i) and (v) will be put in hand, with (iv) at a lower priority.

Independently, trials are already in hand with boilers burning Diesel fuel. These trials have been started too recently to yield any results yet and it must be borne in mind that, even if they are completely successful, the general application of dieso firing would be dependent upon the solution of major economic and logistic problems which are outside the scope of this article.

Other trials are in hand to evaluate at sea the results of flashing boilers on dieso and keeping them on dieso until connected. This practice was tried at the A.F.E.S., Haslar, with promising results and there are other indications that a substantial part of the deposition takes place while the boiler is relatively cool during flashing-up. Preliminary results of the sea trial indicate that it may be beneficial provided that the practice is carried out from the time when the boiler is new.

From the remarks made previously about the role of sodium in 'bonding' superheater deposits, and from the inferences of Gray and Killner quoted in the first paragraph, it might appear that the removal of the salt—in which almost all the sodium is contained—might have very good results. Trials are in fact being carried out in some American tankers and preliminary reports are encouraging. The method is to wash the fuel by mixing it with fresh water and then to pass

it through a separator to remove the water and dissolved salt. However, in warships with their low air intakes the amount of salt entering with the combustion air is of the same order as that in the fuel and, as there is no simple way of removing this air-borne salt, treatment of the fuel is likely to be ineffective. Also it is necessary to carry out the treatment aboard the ship just before burning in order to avoid recontamination of the fuel, and the space required for the equipment and the quantity of fresh water required virtually precludes this treatment in H.M. ships. Furthermore, the trials on 'fuel washing' have been carried out on boilers with relatively low forcing rates and it is quite likely that with the higher forcing rates—and hence higher temperatures—in naval boilers, the vanadium deposits would melt, or at least become sticky, and form a tightly bonded mass even without the sodium.

All this is fairly long-term policy. What can be done here and now? Quite a lot can be done—though it is not always at all easy—to mitigate the trouble, if not to solve it completely. In the first place proper handling of combustion equipment *at all times* will help to ensure that the quantity of deposits are kept to the minimum—a short burst of incomplete combustion can put a sticky layer on the tubes which will collect further deposits even when the combustion condition has been rectified. On the other hand excessive air provides free oxygen which enables the sulphur in the fuel to form sulphur trioxide which is much more harmful than the sulphur dioxide formed if the excess air is low. As has been pointed out sulphur trioxide, combined with water to form sulphuric acid is the major cause of low temperature deposits and corrosion, and it is believed to play an important part in high temperature deposits also, although its action here is far from clear.

Secondly the regular and frequent use of soot-blowers really does remove a great deal of the loose deposit and prevent it baking and consolidating on the tubes.

Thirdly, and most important of all, water washing must be thorough and complete. In this connection it is worth noting that in the original trials of water washing a party of 1 P.O.M.(E) and 7 M.(E)s worked for 50 hours on each boiler. This time has, of course, been greatly reduced since but it does appear that the pendulum has swung too far the other way and that there is now a tendency to 'clean by the clock'—allowing one day only for cleaning and accepting that anything remaining at the end of that day will have to be left. As explained earlier, anything that is 'left' is most probably there for good—or until the tubes are renewed. The target must always be to leave no visible deposits at all at the end of a clean. Unless the supervision is very good, there is a natural tendency for the man using the lance to run it up and down between two tubes and then move to the next gap. In many cases this is not enough and it is necessary to have a good go with the lance, then to lever off the remaining deposits with a poker, and then to use the lance again. It may be necessary to repeat this lance-poker-lance routine several times before each section is really clean.

Several suggestions have been made to assist water washing. The two most hopeful are: (i) to use a wetting agent such as Teepol with the washing water; and (ii) to soak the deposits with steam or water possibly including a wetting agent for 24 hours or longer before starting cleaning. Neither method appears to be universally effective and the information is too meagre to issue formal instructions, but either or both may be of help.

There may well be other things which can be done to help and any bright ideas from ships—or elsewhere—would gladly be considered; even if an idea has already been thought of, additional evidence from sea will help to evaluate its usefulness.



**New Boilers**

A word of warning is necessary here. New (or completely retubed) boilers appear to have a period of grace of about two years before deposits begin to build up seriously. The reason for this is far from clear but it seems possible that there is an exceedingly thin layer which is built up on the surface of the tube over the first two years and which acts as a key to the subsequent deposits ; hence the deposits are relatively easily removed until this key is built up. The point is that this ' period of grace '—very acceptable though it is in itself—may lull the operators into a false sense of security ; it is just as important—it may even be more important—to clean the boilers very thoroughly during this period as it is later.

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