# Boiler Cleaning

## With Particular Reference to Experience by, and Practice in the Royal Navy

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The opening section of the paper is concerned with the fact that, uniquely among the components of a ship's main propulsion plant, boilers need cleaning at set intervals which are quite short compared with the life of a ship, so that attention must be given to this problem in the design stage. The rest of the paper is divided into two parts dealing respectively with the "fire side" and the "water side" of boilers. In each case the author reviews briefly the respective development of boilers, the fouling problem, and cleaning processes over about the last fifty years. The main part of each section consists of a discussion of the current practice and equipment of the Royal Navy; in the section on internal cleaning reference is also made to some of the basic advantages, and disadvantages, of chemical cleaning as compared with mechanical.

### INTRODUCTION: DESIGN CONSIDERATION

Boilers are the only components of main propulsion machinery systems which require extensive cleaning, at comparatively short intervals, as part of their normal life cycle. Furthermore, they require this both on the water side and on the fire side although not generally with the same frequency.

This means that the cleaning requirement has to be taken into account from the start of the design. Generally speaking, there are three principal ways of meeting it:

i) By the provision of a boiler, or boilers, in excess of the number required to supply the ship's maximum steam demand. One or more boilers can then always be off the line and available for cleaning and any other maintenance work which may be needed.

This solution avoids the need for any co-ordination of boiler cleaning cycle and ship's operating cycle. Speed of cleaning, and the high degree of accessibility which makes for speed, do not matter greatly. The designer can consider them of secondary importance. In conjunction with some monitoring of performance, so that unnecessarily frequent cleaning is avoided, it will allow the most efficient utilization of the equipment and give greatest freedom. However, it inevitably involves some degree of waste of capital and, even more serious in a ship, waste of weight and space. This, together with the implied tendency to fit a large number of small boilers rather than a small number of large boilers, which is in opposition to the general trend, means that it is rarely possible to accept this solution for a warship.

ii) By having it agreed that the ship's operating cycle shall be adjusted to meet the necessity of cleaning, so that cleaning simply forms one item of work during a normal maintenance period. Speed and ease of carrying out the task are more important; just how important they are depends on the overall maintenance requirements, staff available, etc.

This solution necessitates either a (reasonably) standard working cycle which is known to be, or can be made, consistent with the cleaning requirement, or alternatively, a reserve of ships such that, when a boiler or boilers become due for cleaning, the ship concerned can be withdrawn from operation and replaced by another.

Generally speaking, this is the solution aimed at in the Royal Navy for normal conditions, although even then, unscheduled changes in the cleaning cycle have to be accepted.

iii) By maintaining a continuous check on the performance of boilers, and cleaning them when there is a noticeable falling off in performance. In some ways, this makes for most efficient utilization of the boilers but obviously, it reduces cleaning to a sort of emergency operation. This places a great responsibility on the designer since a decision must be reached on how far other qualities of the design shall be prejudiced in the interest of easy access for cleaning. Unfortunately, under war-time circumstances the Royal Navy sometimes has to work in this fashion and this problem must therefore be kept in view in warship boiler design.

Summarizing then, the attitude towards boiler cleaning which it is intended to take in a given case must be defined in a very early stage of the design and, generally speaking, some concessions will have to be made. These must inevitably be guesswork to some extent. It is therefore unfortunate that if the guess is wrong this is unlikely to show up before the ship has been in service for some time, and when it does show up it is rarely possible to do much about it. This, incidentally, emphasizes the importance of contact between the designers, and the operators and maintainers, on this subject.

### EXTERNAL CLEANING

The pattern of this problem, viz: the inevitable accumulation of deposits on the fire side of the boiler, and its solution by the mechanical removal periodically of these deposits, has remained basically the same since the time when the water tube boiler generally replaced the fire tube boiler for large scale steam generation at sea. (In the last fifteen years the practice has gained ground whereby water is used to supplement mechanical force for the removal of deposits. This is

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TABLE I.—MARINE BOILERS—CHANGES IN OUTPUTS AND SPECIFIC WEIGHTS, 1913—1950

| Date | Boiler Type | Output (in s.h.p.) | Specific weight lb./s.h.p. |
|---|---|---|---|
| 1913 | Babcock and Wilcox (Header) | 3,100 | 32 |
| 1925 | Admiralty 3-drum | 10,000 | 13 |
| 1935 | Admiralty 3-drum | 15,000 | 8·7 |
| 1945 | Admiralty 3-drum | 20,000 | 8·5 |
| 1950 | Babcock and Wilcox (Controllable superheat) | 15,000 | 6 |

now standard practice in the Royal Navy and will be referred to later. However, it is considered a development rather than a new departure.)

However, the seriousness of the problem has undoubtedly increased with the development of marine boilers. These have, on the one hand, become larger in output and, on the other hand, more compact in themselves. This has meant that passage room for mechanical cleaning devices became more restricted, while at the same time they had to penetrate further in many cases. Table I gives some idea of the scale of this development. The situation was further aggravated by the introduction of superheaters whose tubes generally do not conform with the layout of those of the generator bank so that usually they form a barrier to cleaning.

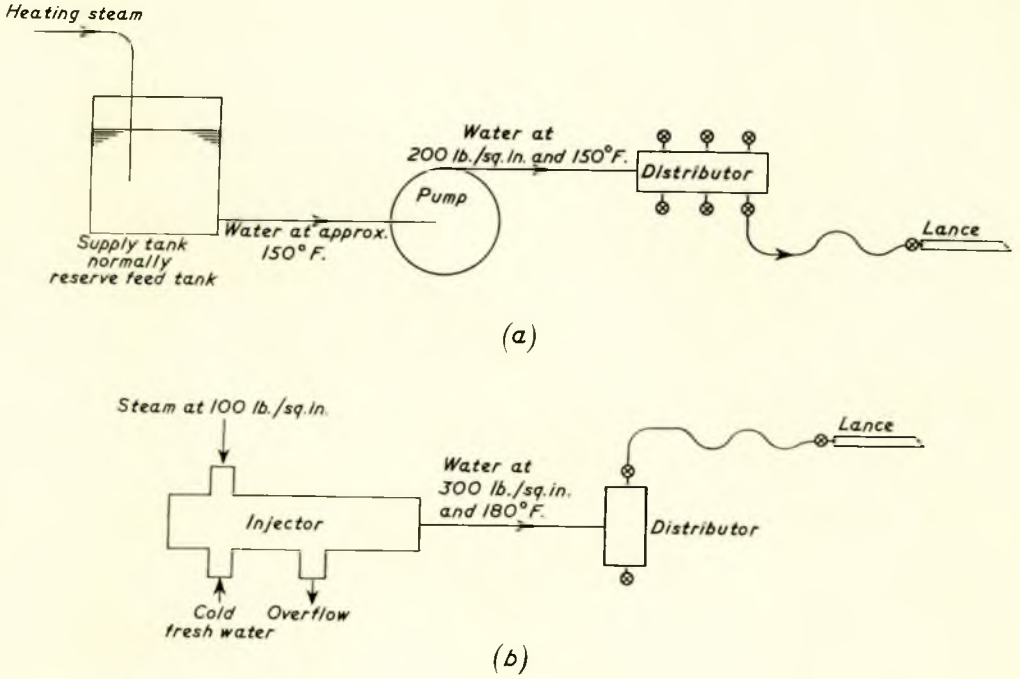
The author also considers that another factor must be mentioned here, namely, that of changes in boiler fuels during the period under review. He is aware that there are wide divergences of opinion in this matter and that even where the factor is accepted its significance is hard to define. However, it is quite clear that before the Second World War the Royal Navy was generally supplied with a type of boiler fuel which other boiler operators referred to as "liquid gold". Today, although the fuel supply to Admiralty under the N.A.T.O. specification is still different from that generally used in marine boilers, the difference is much less.

It seems fair from this to judge that the deposition problem in naval boilers before the Second World War was substantially less than that in other marine boilers, and that this difference also has been greatly reduced since then.

Furthermore, looking at boiler fuels generally and considering petroleum refining operations on a world-wide basis, it seems undeniable not only that the extraction rates have substantially increased in the last twenty years but also that the complexity of the refining processes and of the different products nowadays can be much greater than it was. Particularly relevant seems to be the practice of "cracking back" whereby two fractions from the extremes of the refining range are mixed to achieve some of the qualities of a middle fraction. In the author's opinion, this change in fuel quality has affected the merchant navies more than the military navies. On the other hand, the drive for compactness has been more intensive in the latter. Altogether the net result is that thoughts everywhere have progressively turned towards more powerful cleaning methods. Such evidence as the author has, suggests that this started in the United States Navy at the beginning of the '40's.

At this time Britain was at war and the whole boiler fuel usage pattern was changing radically and all the time. However, for fairly obvious reasons, records about this stage are very scant. It is a consolation here that, even if the records were available, their message would have to be treated with great caution because of the basic difference between war and peace as regards operation of ships as a whole, and because any future war would not be like the last one.

As far as the Royal Navy is concerned, when circumstances once again became such that what might be called the finer points of ship operation, like routine boiler cleaning, assumed importance it was found that in at least some ships the situation was critical! Aircraft carriers seem to have been the worst affected. This is not surprising, since they were at that time the Navy's hardest worked ships, as they have remained ever since. It was in one of these ships that what has since become known as "water washing" of a boiler to remove external deposits was first carried out on an Admiralty 3-drum design, early in 1946. The process is now well established and on the whole, standardized, The principle is that hot water under pressure is used to dissolve those deposits which




(a) Original method
(b) Improved method

FIG. 1—*Principle of water supply for water washing boilers*

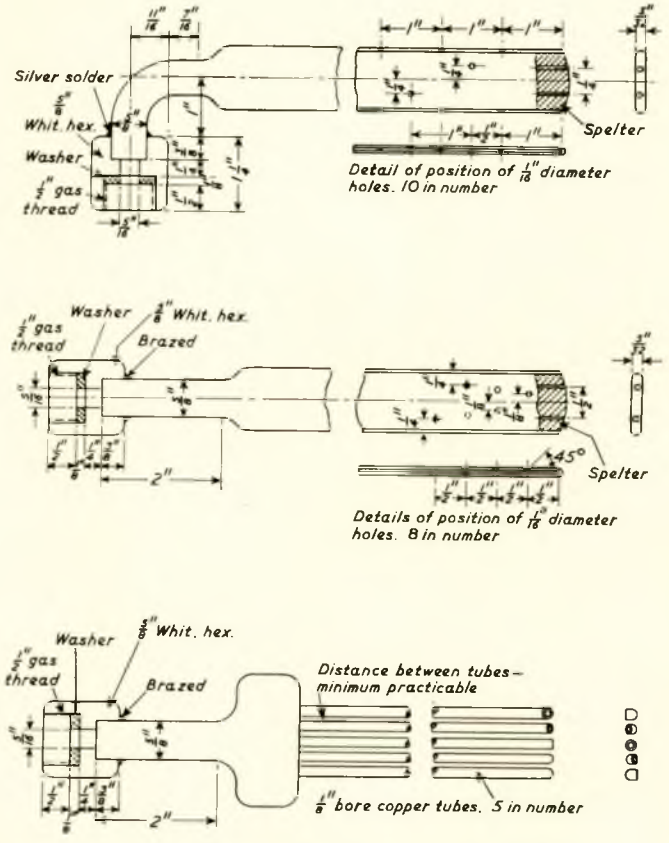



FIG. 2—*Boiler external washing lances*

are water soluble and to dislodge the proportion (normally less than half) which is not water soluble. Two methods of providing the hot water are shown in Fig. 1. The original method did not involve any commercial equipment—mainly because at the time it was not known that such equipment existed. The improved method has been arrived at after considerable and completely successful trials which leave no doubt that it is more powerful, as well as being easier to arrange, than the old method.

The part labelled "injector" in the figure is a perfectly standard commercial product and forms part of a hydraulic jet cleaning set. It is therefore not proposed to go into details about this. The matter of the (so-called) lances however, is worth some amplification. The purpose of these is to ensure that water, as hot as possible and at the highest pressure possible, gets to the places in the tube nest where the deposits are. It is also desirable to get a good quantity of water there but this aspect needs treating with some care both from the point of view of the amount of water used—which may have to come from ship's tanks—and from that of the amount of washing to be disposed of, which matter will be explored later in the paper.

The exact size and design of lance must be related to the tube pitching and tube nest configuration of the boiler to be cleaned; some types of lance which have proved satisfactory for naval boilers are shown in Fig. 2. These were initially developed by ships' staffs and made from freely available materials—this approach is recommended as it keeps development expenses down and ensures that all relevant factors are taken into account.

The number of lances which can be employed simultaneously without interfering with one another again depends on the design of boiler, and on boiler room layout, but generally speaking cleaning from the furnace side and uptake side at the same time is possible. However, it should be borne in mind that, roughly speaking, the injector produces a constant quantity of water so that doubling the number of lances fed from one injector halves the amount of water each of them gets.

The hose connecting the lance to the injector must be able to stand the pressure and temperature involved, and a good deal of wear and tear; at the same time it must be reasonably light and flexible. Recent progress with plastics has made this combination of requirements less difficult to meet than when the Royal Navy first investigated water washing. A satisfactory size is ½in. bore.

Exactly what inspired the early trials is not recorded but there is no doubt in the author's mind that the contacts in the Pacific with the United States Navy, which had already accepted water washing as an alternative to mechanical cleaning for very dirty boilers, played a part. Incidentally, it is interesting to note that an article in the Marine Engineering and Shipping Review in March 1947 by an employee of the Babcock and Wilcox Company of America refers to experience with water washing boilers over the previous six years, i.e. since the United States entered the war. In this country, the Royal Navy seems to have been the first organization to try this process on marine boilers although it had been used for cleaning economizers in some power station boilers.

Be that background as it may, both the initial trials sponsored by the operators themselves and subsequent trials sponsored by the Admiralty, established clearly that water washing produced much better results than dry cleaning where deposits were bonded to any degree or where access was at all difficult. However, the trials also established that disposal of the washings created a problem and that unless they were disposed of adequately, and were prevented from soaking into the furnace lining while awaiting disposal, considerable damage could arise when the boiler was used again after cleaning. In extreme cases, moisture trapped in the furnace lining was released almost explosively, breaking up the refractory.

This problem slowed down the acceptance of water washing and it must be admitted that, even now, there is no 100 per cent satisfactory solution.

There are two ways of looking at the problem. One is to accept the impossibility of completely preventing any penetration of the washings into the linings, and to establish a drying out routine which ensures against physical damage to brickwork from explosive steam release. This approach is generally associated with arrangements to keep the residence time of washings in the furnace to an absolute minimum, either by fitting large drains or by continuous pumping out. Even so, however, in order to allow for various factors during cleaning which can detract from the effectiveness of these arrangements, such as temporary chokage of drains or pump suctions, the drying out after cleaning, during which the boiler must be steamed in a laid down fashion to dry out progressively, and is therefore not available for service, generally takes about 48 hours. Furthermore, this still means that some of these washings which, in practice, are always acidic, although the concentration does vary, and contain a variety of chemical compounds, either in solution or suspension, penetrate into the furnace lining. This must be considered to involve some deterioration of that lining's protective qualities and thus some falling off in its performance subsequently. This falling off may not be a serious factor where, for other reasons, frequent (say biennial) complete renewal of linings is already carried out, but it is a point which should be borne in mind.

The other way of tackling the problem is to apply a protective coating to the furnace lining, making a sort of trough in which the washings collect. Removal can be by drainage or by pumping out as before; in the former case, care must be taken that there is no break in the protective coating at the drain. Care must also be taken to see that there are no gaps around the edge of the coating, where washings could get underneath it. This last requirement varies in its implications with boiler design, and in some naval boilers is actually very difficult to achieve. It is from the cases where it was not achieved that we have obtained the experience about the amount of damage which can be done by even a small quantity of washings penetrating the lining!

In spite of these problems, the overall picture is that this cleaning process is generally an improvement on the dry mechanical one, and that where it still poses problems it is worth continuing to look for a solution.

The first coatings actually used by the Navy were bituminous. They were chosen mainly because they would burn off after use and because the raw material was already available in Naval stores. It was also convenient that their consistency could be varied fairly simply by heating, to suit the size and type of crack, etc., which needed to be filled. On the other hand, this need for heating immediately before application introduced some handling problems and bitumen was basically unattractive to those who were aware of the damage that can result from carbon penetration of refractories, from experience with burner throats, etc. An investigation was therefore started to find an alternative coating. None of the substances on the market for similar purposes had quite the right qualities, which incidentally, included ability to be stored for several months and under a wide range of climatic conditions without deterioration. However, one product came close enough to requirements to be worth developing and the development has now reached a satisfactory conclusion. The problem of making it less difficult to achieve the perfect seal, referred to above, is continuing to receive attention but has to be tackled on the basis of a specific boiler design rather than in a general fashion. In the meantime, it appears that where reasonable care is taken in the application of the coating material the damage done by washings which manage to get past it can at least be tolerated in conjunction with the present life of the refractory lining as a whole.

Ideas for the future are of increasing the efficiency of washing—either by some additive to the water such as a surface active agent or by carrying some chemical in it to increase its chemical activity. Surface active agents were used during the early trials and did show some promise but introduced complications which were considered to outweigh the gains. With the latest water washing units shown in Fig. 1(b), metered introduction of additives should be less difficult and when it comes to cleaning modern naval boilers the possible gains are also more substantial.

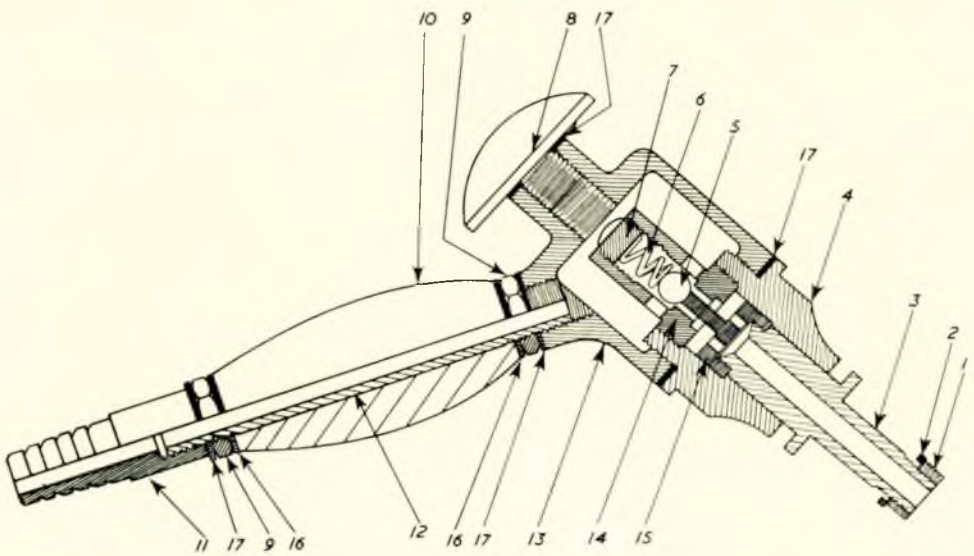
Among chemicals, hydrogen peroxide has been tried and substantially increased the effectiveness of the washing process where vanadium rich deposits are concerned. Most of these are non-water soluble and remain behind when the other deposits are dissolved. Where they are less than about half the total, they may be removed by jet force or by direct mechanical attack. Where they are more than about half the total this removal is much more difficult or impossible and, unless a more powerful method is used, they accumulate and presently compel withdrawal of the boiler from service[1].

However, hydrogen peroxide requires careful handling, must be kept away from refractories even more assiduously than water, and is much more expensive than water. It can, therefore, really only be considered for extreme cases. In view of the considerable research which was necessary before even this substance was found, hopes are not high that an alternative will be quickly or easily found but this work is nevertheless considered worthwhile.

There are, of course, situations where using water to clean a boiler is unattractive or even impossible. Under these circumstances, industrial vacuum cleaners can be used to remove at least the soot and loose deposits. Where access is good and deposits which are bonded or adhering to the metal can be attacked mechanically, this vacuum cleaning process becomes more effective and, since the one process not only removes the deposits from the boiler but also halves the disposal problem very effectively, at least as far as the boiler is concerned, this form of cleaning also is worth further development.

Before leaving the subject of external cleaning the author wishes to sound a note of caution. "Water washing" is a very elegant expression but is liable to give a wrong impression of what is involved in the complete cleaning process. The water does dissolve some deposits and carries away others but even if there is only a little vanadium in the fuel—and it is very seldom that there is none—there will be a proportion of deposits whose removal by water alone cannot be assumed. At the very least therefore, it must be checked that they have been moved, and in most cases some mechanical means can be used to get rid of the last of them. If this is not done however, they are bound to accumulate, they will then tend to compact and bond together when the boiler is in service, and, sooner or later will necessitate tube renewal because of the extent to which they have choked the gas passages.

The author feels he must also here briefly mention fuel




1) Brass knurled nut
2) Steel spring washer
3) Brass stem
4) Gunmetal cover
5) Steel ball valve
6) Phosphor bronze spring
7) Brass spring adjuster
8) Brass and wood blank cap and pad
9) Brass lock nuts
10) Wood handle
11) Brass tail piece
12) Brass handle spindle
13) Gunmetal body
14) Brass valve seat
15) Brass clack
16) Brass washers
17) Leather washers

FIG. 3—*Push gun*

FIG. 4—*Crimped brass wire bullet brush*

additives. There is no doubt in his mind that, with certain fuel characteristics and burning conditions, additives can be a help in delaying the formation of deposits or in altering their character. However, even the most rabid promoters of additives have not so far claimed that these keep boilers clean forever. When the time comes that boilers in which additives have been used need cleaning, the author considers that what has been stated above still applies.

### INTERNAL CLEANING

The most important innovation in the field of internal boiler cleaning for a long time, and one which is really still developing, is the use of a chemical instead of a mechanical cleaning process. However, since the author's direct and detailed experience is limited to the mechanical process, he will deal with this first.

Even as regards the mechanical process there has recently been a significant change in Royal Navy practice where the direct driven brush has been replaced by an air pressure propelled brush, with air at 100lb./sq. in. pressure providing the driving force. This method of cleaning is much simpler than the other, in that the long, flexible drive to the brush, where, in the author's experience, most of the breakdowns used to occur, disappears. The gun used to "fire" the brushes is shown in Fig. 3 and one of the brushes in Fig. 4. There are two basic types of brush—one with crimped brass wire twisted into a galvanized mild steel core for generator tubes; the other similarly made up but using stainless steel to avoid any risk of copper contamination in alloy steel superheater tubes. All brushes have fibre washers at each end—coloured to indicate size—and a rubber washer at one end to form an air seal in the tubes. Brush size differs with tube bore. The most effective size for each of the types of tube used by the Royal Navy was arrived at by experiment at the Admiralty Fuel Experimental Station, with the co-operation of the brush manufacturer.

The "gun" contains an air valve; when the nozzle is pressed into the end of a tube, a rubber nozzle (not shown in the figure) makes a seal with the tube end and the valve is opened, so that air pressure builds up in the tube.

The most important additional equipment is that for arresting the brushes after they have passed out of the tube, having cleaned it. Unless proper attention is given to this, damage to fired brushes and to others already lying in the header is possible because the brushes leave the tube with high velocity. Although the details of the arresting equipment may vary somewhat, two main types are distinguished. Where the header concerned can be entered, a heavy mat, big enough to cover the "target area" for all the tubes to be cleaned, is placed in the header at an appropriate angle. Onto it then is piled loose canvas or sacking. The mat stops the brushes; the sacking stops them bouncing. If the angle of tube entry is nearly horizontal so that the mat will not be against the header wall opposite, a sheet of canvas is hung up in the header from cords coming down through tubes. This should be long enough to have several folds resting on the mat, which is arranged, as far as possible, as before.

When the header cannot be entered, it is packed with loose sacking, again arranged so that the whole "target area" is protected.

It has also been found that a counting tray is useful, with partitions for individual brushes so that numbers can easily be checked. It may also be necessary to provide extension tubes for the gun, whereby the air pressure can be applied to boiler tubes not accessible to the gun itself; this obviously depends on the design of boiler.

As can be imagined, the cleaning process produces a lot of dust. A suction fan is used to remove as much of this as possible, but in addition it is advisable for the operators to wear some sort of breathing mask.

The cleaning team consists of one senior rating in charge, and three others: gun operator, brush loader and brush collector.

Before cleaning can start, internal gear must be removed as usual, holes into which brushes are liable to drop must be plugged and the brush arresting gear rigged.

So far the process has been, if anything, slower than that of preparing for the old style clean, but the next stage is very much quicker. Exactly how much quicker is not easy to establish; it is obvious that speed will increase with practice but the new technique has not been in use long enough to produce really practised teams. However, in H.M.S. *Ark Royal* recently it took 5¼ hours to shoot brushes through all the tubes of one boiler, whereas pushing rotating brushes through them takes about 20 hours.

In detail, the drill for this stage is as follows:

The team is issued with a set of brushes. The actual number will vary with the design of boiler: a reasonably standard figure, for example, would be enough brushes to clean all the tubes in two rows of tubes. To this is added a percentage for wastage, say 25 per cent. Only brushes of one size are issued at one time. The rating in charge receives the whole set. He keeps the spares, issues the others to the brush loader. The latter loads them into the tubes with the rubber washer at the back and the gun operator fires them through. The brushes are then collected, counted, checked for damage (damaged brushes are replaced by the rating in charge) and then used to clean the next two rows.

When all tubes of one size have been cleaned, the set of brushes is returned to store and a set of another size obtained, until all tubes have been cleaned.

Collecting the fired brushes and returning them to the rating in charge for counting is carried out by the brush collector. In order to safeguard him, he is not allowed to enter the receiving header until the rating in charge has checked that the gun has been removed from the firing header.

Should there be any brushes short, a quick check of the last two rows of tubes cleaned is carried out by blowing them through again with the gun. The sound of air blowing out of a clear tube is quite characteristic, and anyway if a brush has managed to bounce up into a tube, the most common cause of temporarily lost brushes, it will probably be blown back out.

In the very unlikely event of a brush really becoming jammed, short lengths of old condenser tube for example, fed into the tube and driven through, are used to dislodge it. Less radical means should be tried first!

If the drill is carried out properly by far the most likely reason for a brush jamming is that it is damaged. That is why the rating in charge has the responsibility for checking

between runs that no brushes have been damaged. An additional check is carried out when a set of brushes is returned to store.

The most common form of damage is a bent core wire, the next most common, crippled filament wires. In both these cases the brush must be discarded. If the rubber sealing washer only is damaged, or becomes worn, as it will after the brush has been used some 10-20 times, this washer can be renewed. Wear on the brushes themselves is very hard to measure but experience indicates that the life of a brush is about three times that of a washer with normal wear. In practice, therefore, a brush is discarded after is has been re-washered twice. A form of marking should be agreed to indicate re-washering has taken place.

Some types of tubes unfortunately cannot be cleaned by this method, e.g. tubes which do not have an approximately uniform bore throughout and tubes bent to too small a radius (1½in. is considered the minimum). Fortunately except in superheaters, which have been found to need cleaning only very rarely, tubes of these kinds are not used much in naval boilers.

The largest tubes for which brushes have been developed are 2in. outside diameter. There is no reason to suspect that this is a limiting value for this cleaning method, but it is possible that there is a limiting size.

As stated already special brushes for cleaning some types of superheater are available. Because, generally, superheater tubes are bent to smaller radii than generator tubes, these brushes are smaller than generator tube brushes for tubes of a given bore. For this reason, and because they are more expensive, superheater brushes should not be used for cleaning generator tubes. On the other hand, brass brushes must not be used for cleaning alloy steel superheater tubes.

Where superheater headers are close together, additional precautions may be necessary to eliminate any risk of injury to the gun operator from brushes which manage to "avoid arrest".

It is naval practice to "sight" tubes with steel balls after bullet brush cleaning, as is always done when cleaning with rotating brushes. Whether this is strictly necessary is arguable. Since in the case of, e.g. floor tubes "sighting" with steel balls is not possible and the only feasible check is by blowing through with the air-gun, it might be considered acceptable to use this form of check for all tubes.

Where it is intended that boiler cleaning shall be carried out away from base, using bullet brushes, the question arises of an outfit of brushes being provided for a ship. The "set" referred to earlier can be used as a basis, viz. an outfit consists of enough brushes of each size to clean two rows of tubes in one boiler without stopping, plus 25 per cent of each size of brush. In some designs of boiler it is possible, and worth while, to have two cleaning teams operating simultaneously. If this is so, the brush outfit must be increased of course.

An analysis of comparative costs suggests that, in the long run, this cleaning method may be cheaper than that with rotating brushes, as well as being quicker. Whether this is so or not obviously depends in part on brush life. This makes it even more important that the arrangements for stopping the brushes are good enough to avoid damage and that an organization is set up for re-washering undamaged brushes.

Where there is an indisputable saving, compared with rotating brush gear, is in skilled man-hours spent on maintaining the gear.

In the hope that he will be forgiven for a touch of levity the author would here like to mention that, some twenty years ago, a senior officer in the Navy suggested that a wire-haired mouse should be developed for internal boiler cleaning. This development can now be claimed to have been achieved; even the problem of eliminating the tail has been solved.

Until the change to air driven brushes, the only thing that had really varied about internal cleaning was the frequency, which had been reduced in consequence of progressively more effective water treatment and slower build-up of deposits. Before the Second World War, feed water treatment was by the addition of lime, via the feed tank and boilers used to require internal cleaning every 750 hours steaming, or every 6 months, whichever was the less. However, steam drums were comparatively spacious and internal gear simple so that the actual cleaning was not very difficult. Even so, when the war started and every ship was needed with the highest possible availability, everything which affected the frequency of maintenance periods was very critically examined. Research into feed water treatments used elsewhere was started by the Royal Navy, because it was appreciated that herein lay the best hope of longer steaming between boiler cleans. It was found that the "boiler compound" used by the United States Navy—a mixture of disodium phosphate, caustic soda and corn-starch—was enabling that navy to steam in safety with much longer periods between cleans than Royal Navy ships and it was, therefore, adopted for all major Fleet units progressively from 1942-1946.

The benefits of this change understandably took some time to show up but cleaning intervals for all ships were increased to every 12 months with an examination every 6 months, in 1948. It should be appreciated that this interval had to be based on the worst combination of circumstances to avoid any risk of boiler damage. An investigation carried out after the war showed that where water condition was closely controlled, very much longer intervals between cleans were possible —some boilers were steamed for as much as 8,000 hours at varying powers without requiring to be cleaned. In the light of this evidence, and the continuing pressure for increased availability of ships, the basic interval between cleans was increased to 18 months in 1958; at the same time abnormal conditions which would necessitate cleaning "out of routine" were more closely defined. This information is contained in Table II.

TABLE II

Degrees of Contamination of Boilers, and their Consequences

a) Salinity between 5 and 7·5 grains/gal.
Reduce below 5 grains by blowing down; change water as soon as possible.

b) Salinity between 7·5 and 10 grains/gal.
i) for under 24 hours: open up boiler as soon as possible, wash through and refill with good water.
ii) for over 24 hours: clean the boiler completely, as soon as possible.

c) Salinity over 10 grains/gal.
Clean the boiler completely as soon as possible.

*Note:* Normal conditions are alkalinity between 0·25 per cent and 0·5 per cent normal; salinity less than 5 grains Cl/gal.

This 18 month interval was intended to line up with the 18 months commission; unfortunately the length of the general service commission was changed to two years very shortly afterwards.

It is perhaps appropriate at this stage to point out that although efforts are made to phase boiler cleaning, particularly internal cleaning, so that it falls into a general maintenance period this is not an overriding consideration nor does it mean that the responsibility for the task ever rests with anyone other than the ship's staff. It is not suggested that this concentration of responsibility is universally practicable but the Navy's philosophy in this respect must be taken into account when considering the procedures which are adopted.

A further review of the problem of internal boiler cleaning has been carried out recently and it was agreed that a basic interval of two years, to come back into line with the general service commission, could be adopted without risk of failure. At the same time is was decided to make this interval more freely variable and in particular dependent on the actual condition of individual boilers. This is a new approach and obviously

places greater responsibility on those who must decide when a boiler needs cleaning. It has accordingly been arranged that this decision shall be reached at a level where the necessary experience will always be available. Arrangements have also been made for additional checks on boiler condition and water treatment to be available when the decision has to be made. It is too early to say whether this new approach will in fact produce the hoped for benefits for the operators but it does at least appear that its implementation is considered practicable by all those concerned.

It is interesting to note that the United States Navy is at present carrying out an investigation in the hope of extending internal boiler cleaning intervals. In view of the many differences in important factors, it is not intended to draw any conclusions from what transpires on the other side of the Atlantic, but is is obvious that on both sides it has been decided that this important aspect of ship availability requires renewed study.

Regarding chemical cleaning, although, as already stated, the author has no direct experience, he and many others in the Navy have given considerable thought to it. These thoughts have been mainly on the basic issues involved on which some comments can, therefore, be made. There are, of course, exceptions where these issues do not apply, namely, boilers whose tube configuration does not allow mechanical cleaning.

The relative effectiveness of chemical and mechanical cleaning is one of the biggest points at issue. In the author's opinion chemical cleaning is unquestionably the more potent process and the only one which can ensure the removal of scale which is very hard and adheres closely to the tube surface. It is also the only process which can ensure cleaning out of pits. In fact a really effective chemical clean results in having nothing but bare metal inside the boiler. There are still two big questions that must be answered, however. One is whether that matter, which chemical cleaning removes and mechanical cleaning does not, really requires removal. The second is whether, if this matter must be removed, its presence in the boiler is so widespread as to justify the inevitable removal throughout the boiler of the protective layer which is built up by proper water treatment when steaming.

To the first question the author's suggested answer is that if these deposits are significant they will lead to a failure and the cause of failure should be reasonably easily established. In the ships with which the author is concerned there is no recent history of such failures. If this situation were to change an immediate review of cleaning policy would have to be carried out.

To the second question the author can only give an answer based on the experience of others, but as this is a practical solution it seems worth giving. Attempts have been made in the U.S.N. to restrict chemical cleaning to those zones of the boiler which are considered definitely to need it in the light of the general presence of scale. However, this greatly complicates the process and is not considered worthwhile. Proper water treatment, when steaming is resumed, should result in a rapid re-formation of the protective surface layer uniformly and with relatively little loss of metal.

Another basic issue is the choice of the type of acid to be used. The acids which have been tried—and here again the United States Navy experience is quoted—range from the very mild to the distinctly strong. The precautions associated with cleaning vary in the same way and the practicability of carrying out cleaning by ship's staff varies inversely! The important disadvantage of the mild acids is that their effectiveness in removing all types of deposit cannot be relied on. Even with the stronger acids, it is desirable to obtain a sample of deposit and carry out tests to decide on the composition of the mixture to ensure their removal, although increasing experience has indicated a standard composition which is generally satisfactory. Where it is not, this will become obvious when the boiler is examined after cleaning, and a different method of attack can then be used. Incidentally there is no information that any failures have been precipitated or even contributed to by incomplete passivation after acid cleaning, except where some fairly gross breach of the recognized precautions has been involved.

Time taken for cleaning is another of the basic issues. The actual process of removing the deposits is generally quicker using chemicals than using the rotating brush. However the preparations necessary, before this stage is reached, and the further treatment afterwards, before the boiler can be considered in all respects ready to resume steaming, vary widely, depending on the acid used, etc., and may well alter the picture when the total time from shutting down for cleaning to flashing up after cleaning is considered. It is relevant here that, after chemical cleaning, a fairly uniform, probably harmless, but nevertheless undesirable powdery deposit may be left in the boiler. It may, therefore, be necessary to follow the chemical cleaning by the mechanical removal of this new deposit. If this is so, the time taken is increased further.

A clear decision must be reached as to where the responsibility lies for the satisfactory execution of the cleaning. As pointed out above, in the Royal Navy there has never been any doubt about this and, since the mechanical cleaning process is completely within the capacity of the ship's staff, no doubt need arise. This is not so with chemical cleaning, particularly using the more virulent acids. The United States Navy generally uses approved contractors, although recently some of the dockyards have been prepared to take overall responsibility while contracting out the actual work. This immediately brings up the point of how contractors shall qualify for approval. Obviously, "experience" must be one of the factors and looking at Britain, as compared with the United States, it is considered that there are big differences in this respect. This situation is almost certainly changing and must be kept under review, but as it stands at present, the author considers it is one of the most important factors in deciding one's attitude in this matter.

Finally the author would like to suggest that the use of both chemical and mechanical cleaning might produce the best result—chemical early in the steaming life of the boiler, to ensure removal of any undesirable surface condition and the formation of a uniform protective film; mechanical periodically thereafter to remove accumulated deposits before they can upset the heat transfer; chemical again if some abnormal situation arises which the mechanical cleaning process is considered insufficiently powerful to rectify.

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The paper is published with the approval of the Lords Commissioners of the Admiralty, but the responsibility for any statement of fact or opinion expressed in it rests entirely with the author.

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# Discussion

COMMANDER V. M. LAKE, R.N. (Member), in opening the discussion, said his friend Commander Inches had given an excellent statement of the Navy's approach and the results of much dirty work on his part and others! He wished to add as his contribution, some thoughts which it was hoped would stimulate others present.

While he had occupied the chair now held by the author at the Admiralty, they had been forced to reconsider the whole business of boiler cleaning. The main reason for this was a change in fuel source, forced upon them in the years after the war—a circumstance not foreseen when the ship designers had been forced by the financiers to create machinery designs whose performance in terms of weight, space and economy had to be such that more and more power was forced into smaller spaces. He thought it would be unfair to say that maintenance was not given any thought, but in the light of subsequent events clearly the answer produced was not the correct one.

The basic difficulty was the sudden appearance, in boilers of compact design, of deposits which could not be removed by the established brushing methods or washing. If these deposits were not removed then there was a strong possibility that boilers or boiler rooms would have to be cut open to clear the gas paths. As a result of this the boiler designers had been asked to design casings, tube nests, etc. in such a way that there was a reasonable chance of removing all deposits by water washing, and further, that visible proof could be given that the nests were clear. He felt it would be of advantage to all if the representatives of the boiler designers could say what steps had now been taken to provide the necessary access in such boilers.

It was of particular interest to hear the author mention that in-line tubes were now considered to be as satisfactory with regard to heat transfer as staggered tubes. The latter had formerly been accepted as being the optimum method of arranging tubes for heat transfer. Commander Lake asked if it was possible by any chance that this arrangement of tubes pitched closely was such that the tubes were self-cleaning due to inherent vibration.

Commander Inches had also mentioned the question of soot blowers, and it would be of interest to everybody if he could give his opinion of the automatic sequencing of soot blowing and whether or not this was effective. It was considered to be a fair criticism of old designs in the Navy that soot blowers were rarely used because they were difficult of access—if indeed they were operating.

Commander Lake's belief was that it was high time that the fundamentals controlling deposits in the gas paths of boilers were reviewed. It was very easy to be self-congratulatory about a high performance combustion system and an economic boiler built around it; but it seemed unwise not to expect some modification in the deposits formed as a result of the advancing combustion process. It was clear that the fuel additives had a part to play, but he suggested that the secrecy around the proprietary compounds must be removed and a scientifically acceptable theory produced to enable the boiler designer and operator to assess what would be left in the boiler, whatever the combustion system or whatever the fuel used.

The slides which the author had shown, giving the distribution of deposits through the banks, substantiated the present line of argument. The type of deposit was dependent upon the conditions at any given point in a boiler. As combustion systems advanced, so these conditions altered. Having established the type of deposit likely to occur, the general aim would then be to solve the practical problems involved in water washing. It seemed unlikely that this method would be improved upon under present-day circumstances.

In the Navy, as a result of the emphasis on external cleaning, so was a pressure built up to reduce the chore of internal cleaning. In addition, this was becoming more difficult as internal gear became more complex. The fact that the Navy accepted boiler designs, so arranged in a ship that only special men could enter the steam drum, was contributory to stimulating the research into the methods so well described in the paper.

Internal cleaning was essential, but it could be reduced to a reasonable frequency. The means were simple and cheap. All that was required was a certain fastidiousness in what was put into boilers in the way of feed and boiler treatment. A high standard of water purity had to be maintained for make-up to a closed feed system. This did not demand a super purity of water; that the make-up was clear by the old-fashioned silver nitrate test was adequate for pressures in general use now.

As a complement to this there was a requirement for normal care with feed treatment. This was accepted by all operators at the present time. It was particularly necessary that care should also be taken when boilers were idle, but corrosion could be minimized at that time by keeping idle boilers pressed full with feed water.

These principles which he had outlined had been maintained in the Navy and had been proved over a number of years since the war, under circumstances which were much more conducive to boiler troubles than those possibly met with in the Merchant Service. In the Merchant Service boilers tended to steam for longer periods than those in the Navy, and yet the troubles actually involved in the Navy since the war had been reduced since former times. He excepted from this argument Merchant Service ships which had been laid up.

Chemical cleaning had always been a tantalizing "carrot". It appeared to offer a minimum of work with the maximum efficiency. However, from his experience, there were disadvantages which still made it a doubtful process. For instance, it was possible to end up with a boiler dirtier at the end of the operation than at the beginning if the conditions were not controlled within close limits. He hoped that some of the experts would refute this statement, but this was his experience. While those directly interested in the chemicals and metals involved could control this situation, it was the human element less directly involved—those people in the shipyards and the stand-by chiefs, etc.—which provided the difficulty. It was extremely difficult to carry out boiler cleaning by chemical means if no steam was available for heating, in a dead ship.

The other limitation imposed was a material one. It

was essential that there be a detailed knowledge of all the materials actually fitted. Perhaps Commander Inches or some others with experience would be able to show some of the things that could happen. For instance, it was pointless, in cleaning boilers chemically, if a lot of time was then spent in replacing valves and spindles which had been attacked, repacking glands that had gone, and taking extreme measures to blank off superheaters to prevent copper deposits being passed over from the boiler to the superheater.

Finally, he suggested that as a general rule old boilers should never be acid cleaned unless there was plenty of time and money available or a meticulous history. There was in the Admiralty records a most delightful signal from a British Admiral in the United States who had had the unfortunate experience during the war of having an escort come into a United States yard for a routine maintenance. It was routine at that time to acid clean boilers in the States. As a result of this the boilers were left like colanders and they had had to re-tube the whole lot. Scale was wonderful stuff, if it was in the right place at the right time!

DR. D. WYLLIE said that he was extremely pleased to receive the invitation to say a few words on this interesting subject, and the author had given a most useful survey of boiler cleaning practices. At the Admiralty Oil Laboratory they were concerned with the fuel for those boilers and hence his main interest was the external or fire side deposit side of the boiler, rather than the internal side. He was particularly interested in the slide which Commander Inches had shown, as it drew attention to the types of deposits that occurred in modern boilers, and he wished to underline the author's plea for regular and thorough cleaning, which was well put in the paper. Although the mechanism by which these deposits formed was still a subject which required investigation, it was only too likely that any residual deposit, in addition to itself obstructing heat transfer, would form a base on which fresh deposits could build.

Mrs. Beeton's famous recipe for hare soup was said to have started "First catch one hare". Hence, when talking of cleaning boiler tubes, it was as well to consider what was likely to be found. The slide had shown fairly recent types of deposits in boilers, but there had been a change over the years. When the first water washing experiments were carried out in 1946 they had been carried out on a three-drum type boiler, in which, of course, the superheat temperatures developed were low—probably about 650 deg. F. With such boilers and such temperatures the great bulk of the deposit would be water soluble. Figures in the Admiralty records suggested that about 60 to 70 per cent of the deposit was water soluble. This would consist very largely of acid sodium sulphate. Vanadium compounds had been found in the deposits, but not enough and not of such a form as to be a serious problem.

The higher steam temperatures for vanadium rich deposits could be a nuisance. Deposits had been seen which contained as much as 50 per cent of vanadium compounds, and some people had quoted figures of up to 80 per cent, which was mighty high, hence the interest in some quarters in drastic methods such as hydrogen peroxide. He suggested that before resorting to this method, the use of water washing with detergents should seriously be considered. He was glad that the author had mentioned tank cleaning vessels, because they were a help to the hard-worked man who had got to get his ship in good order as soon as possible. These tank cleaning vessels did carry detergents—mainly issued for another purpose. He suggested that the detergents might be well worth trying on some of the deposits before the extreme measure of peroxide was considered. If the deposit could be thoroughly wetted with detergent solution some hours before getting to work, attacking with jets and lances, a marked improvement in the results might well be obtained. One ship was known in which this had been tried with a fair degree of success. It was rather analogous to the homely matter of trying to clean the pots after being somewhat burnt.

Turning to the question of fuels, he recalled that the author referred to a form of fuel known as "liquid gold". That fuel was substantially less viscous than the Class E fuel, which according to the British Standard for fuels was described as a marine and industrial fuel which could sometimes be handled in unheated storage; but Class F, G and H fuels were much heavier and required heating, and many of those present would be well acquainted with them. The current specifications called for fuel which could be a bit heavier than the maximum for Class E fuels, but a determined effort had been made to write specifications so as to retain a high standard of pumpability. Sulphur contents had undoubtedly risen from 1·5 per cent maximum to 3·5 per cent maximum at the present time. Vanadium compounds varied widely from fuel to fuel. Vanadium was associated with the heavy residues in the fuel rather than with the distillate used to bring it to the correct viscosity level. Hence the vanadium content would vary widely from fuel to fuel, not only because different crudes contained different amounts of vanadium, but different fuels might contain different amounts of residual. However, it was likely that the naval fuel which the boilers referred to had been burning, contained less residual, was considerably less viscous and probably contained less vanadium than many marine fuels.

Finally, he noted that Commander Lake had asked if the author could give information on how these deposits got there in the first place. That was a matter that his organization had very much in mind. There was a wealth of literature on the subject, but it was a bit too early to be in a position to say much about naval boilers on that subject just yet.

MR. E. G. HUTCHINGS, B.Sc. (Member) said that he was afraid he found himself disagreeing with the author on several points in the introduction of the paper. The ideal way to keep ships in service was to eliminate the necessity for external and internal cleaning. With modern water treatments and close control thereof internal cleaning should not present a serious problem. External cleaning unfortunately was not quite so simple, but the need for this could be significantly reduced by attention to the arrangement of heating surfaces, the use of more efficient soot blowers and more efficient combustion equipment. Experience had shown that in the simple two-drum boiler (Babcock Integral Furnace or Foster Wheeler D Type) the combination of long retractable single-nozzle soot blowers in the superheater zone, together with wide pitching of the superheater tubes and steam atomizing burners, was having a remarkable effect on the general cleanliness of the plant and the periods between cleaning; so much so that some owners were even considering the possibility of thinking in terms of 18 months or even two years between external cleaning periods, although they were not burning a particularly good fuel.

Contrary to Commander Inches, he felt it was absolutely essential in this day and age to do everything which was reasonably possible to improve access and reduce time spent on the unpleasant task of external cleaning when this became necessary.

However, he whole-heartedly agreed with the author that co-operation between designers, operators and maintainers of boilers was essential, and it was unfortunate that the time between the conception of an idea which could result in an improvement and the time when the proof or otherwise was available was an unavoidable obstacle in this direction.

While agreeing generally with the rest of the paper, he felt that in certain parts the emphasis was misleading and there were some rather important omissions.

With regard to chemical cleaning, he suggested that this should never be adopted as a matter of convenience but only as a last resort, when other methods had proved unsatisfactory, the one exception to this rule being that it could be a sound investment to chemically clean the boiler and the feed system immediately prior to the ship's trials. Commander Inches had stated that damage had never been shown to result

from acid cleaning unless some fairly gross breach of recognized precautions had been involved. He might have agreed with this if the author had defined the meaning of "a gross breach" and "recognized precautions". In his opinion it was essential that the whole chemical cleaning process be under the continual control of a qualified person who was fully aware of the chemistry involved and the dangers associated with the plant and the materials of the plant, and also—and this was very important—that the man in charge of the process had the authority to insist that the correct procedure was in fact observed under all conditions. Trouble had been experienced due to the correct procedure being followed minutely except that the process had been stopped for an hour or two. He said he imagined this was not considered a gross breach of recognized precautions, but nevertheless it could result in considerable trouble. One single departure from the correct routine could sometimes result in extensive damage.

The author had certainly made an impressive case for the bullet brush in the paper, but unfortunately had omitted to comment on its effectiveness compared with the more common types of mechanical cleaners. Undoubtedly if this bullet brush was as effective it was a very great improvement.

He felt that undue emphasis had been placed on the danger to refractory during and after external water washing. Admittedly protective coatings applied to brickwork could be an advantage, but in merchant ships serious damage to refractory had seldom resulted from water washing, providing the boilers were lit up as quickly as possible after the water washing had finished. It was an advantage to water wash the boilers at sea since it was then very easy to light up afterwards to dry the boilers out. The explosions referred to had only occurred to his knowledge, when boilers had been left standing for several days after water washing and before being lit up.

Returning to the sealing of brickwork, it would be interesting to know the type of products which the Navy had developed for sealing brickwork when water washing.

The previous speaker had already made this point, but it was considered to be worth saying again. In certain cases incomplete water washing could in the long run be worse than no water washing at all, since, particularly on superheaters, the deposits left behind after incomplete water washing not only provided a base for further deposits, but themselves became much more difficult to remove at a later date.

CAPTAIN H. FARQUHAR ATKINS, D.S.O., D.S.C., R.N. (Member) wondered if the author found, as he did, that the trouble with being in charge of the boiler section was that every marine steam engineer reckoned he knew all about boilers. The story of the introduction of the United States Navy boiler compound into the Royal Navy bore this out. The paper dated this from 1942, but to his knowledge no naval ship was authorized to use it before 1944. When Commander (now Captain) D'Arcy handed over the boiler section at Bath to him late in 1943, he had found himself chairman of the Admiralty Boiler Corrosion Committee composed of eminent experts from Lloyd's, the Merchant Navy, railways, boilermakers, water treatment firms and the Admiralty. The United States Navy had most generously given the Navy their records of the splendid results of their boiler compound over some years. The committee had advised its immediate introduction. He had been convinced they were right, but the Deputy Engineer in Chief had raised objection after objection, caustic embrittlement and every other bugbear. The Committee were, on investigation, able to prove each in turn unfounded. Then it had been said that if the hours between boiler cleans were extended, small ships would never be given time for refitting their machinery, and that their ships' companies depended on boiler cleaning periods for their leave. The latter practice was grossly unfair, unless shore-side or depot ships boiler parties were provided, as the engine room department had to clean boilers and refit instead of enjoying their well earned rest and leave.

Later in the war it had been admitted that ships' companies needed rest, sometimes before the machinery did. He said that he thought some ships were lost in the evacuation of Crete, because officers and men were so dog tired that they could not think clearly to take the right action when their ships were damaged. He, too, had found himself in that state, but luckily not until after his ship had got back to Alexandria and subsided on the mud alongside Pier 14. An understanding Squadron Officer had sent the chief of the sunken H.M.S. *Kelly* to relieve him whilst he slept for a week ashore. It was inevitable at times to lead or drive men beyond their limits, but captains should say when their men must have a spell, and not shelter behind boiler cleaning or machinery refits.

There was one sound cause for delaying the use of the compound, and that was the completion of issuing the new water testing set, which with its pills must have simplified the use of the compound. But while arguments still went on, a report had been received from H.M.S. *Victorious* to say that she had used boiler compound for some months with excellent results. Her Senior Engineer, Leonard Baker, had gone straight to her from being Captain Atkins' assistant, and their connivance had been suspected! Actually the treatment had started before Lieut.-Commander Baker joined her.

On the report he said that he had minuted that the Engineer in Chief should authorize the use of the compound forthwith, or the Commander in Chief would do so because British ships could not operate with the Americans off Iwojima, Okinawa and Japan, using lime and cleaning boilers every 500 or 750 hours; boiler cleaning at sea was out of the question and they would be at sea continuously for months. The Engineer in Chief had given way, but, before the Admiralty message went out, a signal had come from Admiral Sir Bruce Fraser that he had authorized the use of boiler compound in all the major units of the British Pacific Fleet. Oddly enough, Captain Atkins had been given public notice to quit at about this time and asked to join H.M.S. *Formidable* in the Pacific. She had already started to use the boiler compound, and during 18 months and over 100,000 miles steaming in her they had never put a brush in a boiler. Then the Boiler Corrosion Committee had been invited to inspect the boilers and all agreed that they had never seen boilers in better condition. He wondered if this committee still existed.

The moral of this yarn seemed to be that even in a technical department endeavours must be made to see what strategy would require of ships and plan ahead, because what availed it to keep the boilers perfect if the ship could not do her task? Help would be obtained in this from general list experience, staff and war courses. It was useless to provide a man with the best technical advice in this country and the United States if his superiors were going to ignore his reports. It was interesting to hear that Commander Inches now awaited the policy decision on the use of hydrogen peroxide. Rigid naval discipline was not thought to be entirely a good thing in technical decisions, as the man with the extra stripe might not have had time to study the subject. Lastly, of course, nothing was so fatal as to be proved right.

The boiler section would no doubt take over nuclear reactors when these were a little more developed, commonplace and common sense, and he trusted that it was now consulted over the water treatment in H.M.S. *Dreadnought* and at Dounreay. At Dounreay care had been taken to establish a magnetite film before closing the primary loop, which everyone would know was made of a low alloy chrome molybdenum steel instead of the stainless steel or stainless steel lining of all the previous pressurized water reactor primary circuits. It would, he thought, be quite impracticable to clean, either inside or out, by mechanical means, the U-tubes of the boilers, which the nuclear boys preferred to call steam generators, and it was doubtful if chemical means could be used without decontamination, opening out the whole system and much palaver. The great hope was, of course, that the very high purity of the primary water obtained by ion exchange filters, would mean that cleaning would never be needed. One happy day he hoped that internal cleaning would never be needed in fossil fuel fired boilers either. "What never? Well, hardly ever!"

MR. P. F. DILNOT (Member) thought that the paper was of great interest to many. Its bias was, as the sub-title suggested, mainly concerned with Royal Navy practice. Merchant Navy practice did differ and it was regretted that their experience appeared not to be available to the Royal Navy.

He said that, in the Merchant Navy, boilers had been externally cleaned by water washing for a number of years and some companies did use an additive or a detergent. He had gained the impression that the author believed the internal cleaning of boilers, by chemical means, to be an American idea and that, furthermore, experience in this country was of limited duration, the example quoted in the paper being all of U.S.N. practice.

The Royal Fleet Auxiliaries played an irreplacable part in the logistic support of the Royal Navy; they were a very important department of the Admiralty. For many years their boilers had been chemically cleaned internally.

The advantages of chemical cleaning over mechanical cleaning by brushes were:

a) Saving of time, as extensive dismantling was not required.
b) Saving in labour costs.
c) Areas inaccessible to manual cleaning could be dealt with chemically.
d) Chemically clean surfaces ensured maximum heat transfer with consequent fuel economy.
e) Surfaces cleaned chemically were returned to their initial state, while mechanical cleaning did at times roughen and distort the surfaces, which encouraged future scales to cling.

It was realized that this last advantage possibly did not apply to Royal Navy boilers, but it did apply to Scotch boilers which were still in service in the Merchant Navy.

These advantages were appreciated by Messrs. Timpson, Thatcher and McLennan in 1914 and, after considerable experimental work, they discovered that hydrochloric acid was the most efficient and economical acid for the purpose; provided that it could be inhibited against attacking the metals utilized in the construction of marine machinery, it could be safely used for descaling all types of boiler. They had therefore set about devising an inhibitor; chemical cleaning of boilers had been carried out, in this country, since that date.

The need for internally cleaning boilers could be sub-divided into three aspects. First of all was the acidizing and pre-treatment of boilers, prior to their going into service. New boilers could contain rust, millscale, weld spatter, grease and dirt. Only the dirt could be removed mechanically and that not entirely thoroughly. If the millscale was not removed it would be reduced (in a chemical sense) to magnetic iron oxide, when the boiler went into service. The presence of magnetic iron oxide caused poor heat transfer, which could result in tube failure. Furthermore magnetic iron oxide could carry over and deposit on the turbine blading, it could not be cleared by blowing down and it was difficult to remove when the boiler was finally shut down. He agreed with Mr. Hutchings that the pre-service cleaning should also include, if possible, the entire steam and feed systems.

The next sub-division was the cleaning of boilers in service to remove salt scales (salinity scale). This was the type of cleaning touched on in the paper. He said that he had already mentioned the advantages of carrying out this type of cleaning chemically.

Fig. 5 showed a John Thompson-Lamont boiler. The Admiralty maintenance instructions stated that these were to be chemically cleaned internally at periods not exceeding two years. It was a very simple cleaning arrangement, but the procedure was basically the same, no matter what the size of the boiler. As could be seen, the pre-treatment preparation was very small. First of all a connexion was required at the bottom of the boiler, in Fig. 5 the manifold blow-down line was being used, a return connexion at the top, here the drum blow-down line had been used, and some form of vent hose to make certain that the whole boiler was full. With larger boilers, obviously, more connexions and hoses would be needed. There was also a header tank, placed on the upper deck for convenience, because, in this type of ship, space was rather short in the boiler room. A steam coil was used for heating the descaling solution. Commander Inches had mentioned that it was essential to heat the descaling solution. This was in fact not the case, though it did speed up the descaling process. The solution was circulated round the boiler by a pump. The progress of descaling could be checked, throughout the process, by titrating the descaling solution; operators should be provided with a portable test set for carrying out this titration. After the descaling was complete, the boiler was well flushed out and then a neutralizer circulated, to deal with any stray pockets of acid which might have remained, though this was unlikely. Then the boiler was finally flushed out.

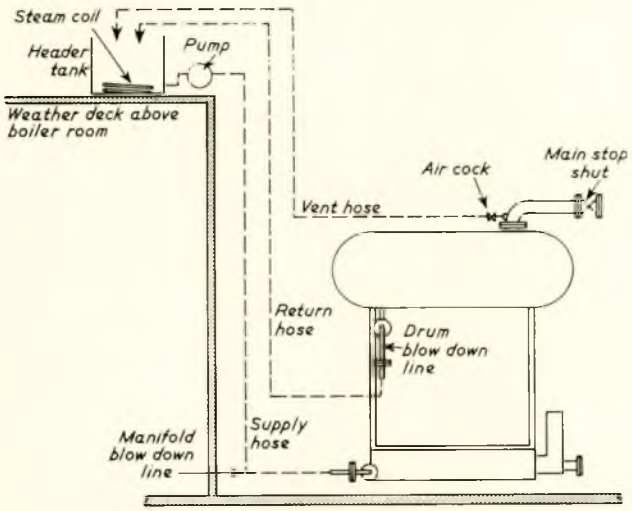


FIG. 5—*John Thompson Lamont auxiliary boiler descaling rig*

In Commander Inches' paper (and this had been mentioned by Commander Lake) it was suggested that, after chemically cleaning the boilers, the residue left behind by the chemical cleaning should be removed. It was possible, though most unlikely, that some dust could be left behind, but in very minute quantities and this dust could be and probably was, in the case quoted, very finely divided ferric hydroxide (though it was not known to which ship the author was referring), which might have been due to a mistake in descaling procedure. As the paper correctly stated, it was completely harmless. Having looked back through his past records, Mr. Dilnot said that he could find no trace of ever having to mechanically clean a boiler after chemically cleaning to remove such deposits.

The last type of cleaning, which was very important and again not mentioned in the paper, was the cleaning of boilers in service to remove contamination by lubricating oil, fuel oil and even palm oil. Oddly enough, this type of contamination (lubricating oil and fuel oil) seemed to occur in Royal Navy boilers more than in Merchant Service boilers. This type of cleaning could only be carried out chemically.

The most satisfactory method of doing this was the vapour process developed in 1928 by Mr. S. B. Freeman, who was then the Superintendent Engineer of the Blue Funnel Line, and Imperial Chemical Industries. The liquid degreasing solvent boiled at 186 deg. F., forming a vapour which was heavier than air. Viewed from the top, it looked rather like a Dartmoor mist, rolling up a valley, as seen from a tor. As the vapour, which could be seen in Fig. 6, reached the surfaces (this particular print was taken of tubes being cleaned on the outside), it condensed and the combination of the properties of the vapour plus the loss of latent heat dissolved the contamination. Fig. 6 showed the process in various stages of cleaning;

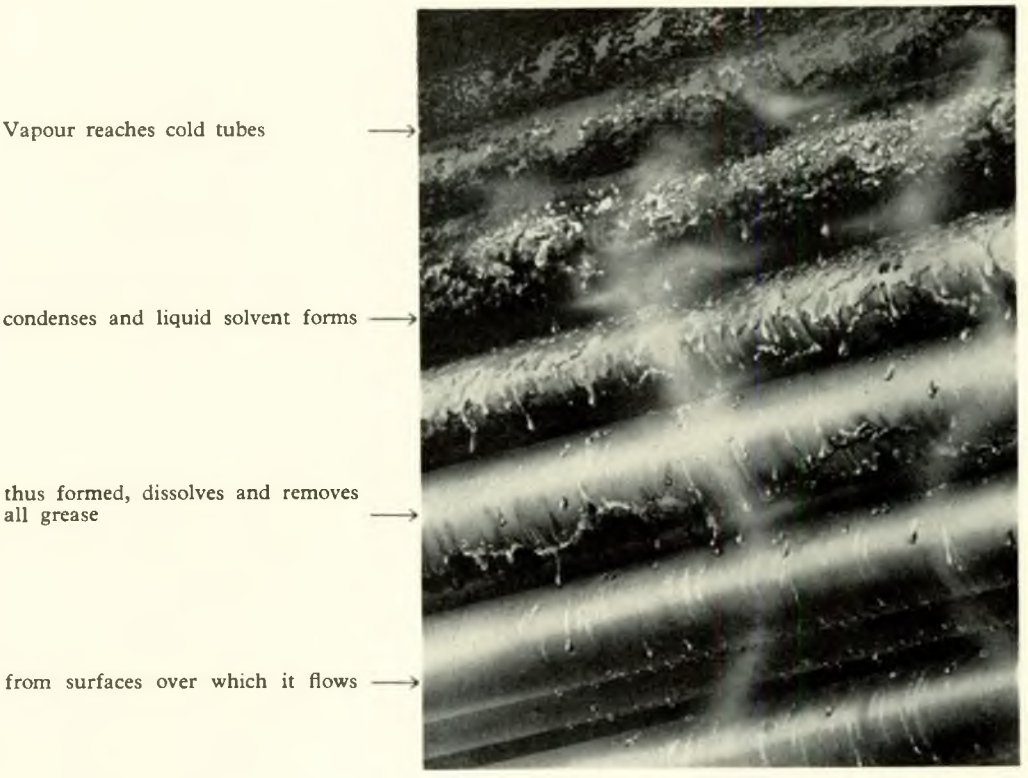


FIG. 6

the contamination was dissolved by the liquid and the dirty solvent ran down to the bottom.

The chemical cleaning of marine machinery had been the subject of a paper*, read at the Merseyside and North Western Section in 1961 and, because of the time limitation, he had tried to deal very briefly with the subject, but hoped that he had said enough to dispel the impression that experience, on this side of the Atlantic, was either limited or of a short duration. He concurred entirely with Commander Lake that chemical cleaning was a safe, sure, satisfactory method of cleaning, provided it was carried out by skilled personnel, supervised by qualified engineers, i.e. chartered engineers.

LIEUTENANT N. E. WARNECKE, R.N. said that as a result of the discussion, he had picked up three points which he would like to have answered for his own education. One was with regard to the injector equipment mentioned in the paper. The point made by the author, was that with a change of the number of nozzles in use there was a change in output. This was understandable in itself, but from what had been heard of experiences in the Fleet (and several of these had been on trial), it appeared that when the number of nozzles in use was in fact changed, it was difficult to get the machine to work again.

Another point which had come out was that the products of combustion occurring in the watertube type boilers in use in the Service, were, generally speaking, soluble products and were readily removed by the water washing process. Would the author like to go into more detail as to how the non-soluble products should be removed, especially in cases concerning boilers in such confined spaces, that it was in fact impracticable to remove these insoluble products mechanically?

The third point which he wished to see clarified was that it appeared from a recent article in one of the engineering journals, that in certain cases water washing of economizers had been tried while actually steaming. He would like to know if the author was in a position to qualify this and whether it was the intention of the Admiralty to try this procedure on marine boilers.

MR. P. DIXON thought perhaps the most controversial issue put forward in the paper was the question of mechanical versus chemical cleaning. The naval boiler clearly received the attention it deserved as the Royal Navy were in the unique position of being able to do a good mechanical job. Chemical cleaning was, however, more difficult for them. For the hard-pressed merchant ship this situation was almost reversed. Mechanical cleaning, usually at the mercy of extremely fickle shore labour, could be expensive and time consuming, and it was against this background that chemical cleaning became increasingly attractive.

If the experience of one boiler maker was any guide, there was no doubt about the effectiveness of the chemistry involved and sufficient experience had been gained elsewhere to ensure safe handling. It could be argued that a poor mechanical clean might not be in any way dangerous, whereas any mishandling of the acid process could only lead to disaster. Again, from individual experience, instances of this latter sort had been very rare. It did seem that if mechanical cleaning were to be enforced marine boiler design would inevitably become static, whereas chemical cleaning could help to open the door to more advanced designs in the future.

Once the idea was accepted, the boiler designer had a little more scope for arranging heating surfaces, but it was also up to the designer to make provision for introducing and removing acid solutions, avoiding stagnant pockets and providing ready access. There was a great deal to be done in this direction.

On the external or fire side of the boiler, details of water washing were most interesting. Copious quantities of water had been referred to, but could the author venture a guess at the minimum quantity of water which would be required? Would he agree that, say, five tons of water was sufficient to wash the superheater of a destroyer boiler? Clearly this

* Dilnot, P. F. and Hamburg, H. R. 1962. "The Chemical Cleaning of Ships' Machinery." Supp.Trans.I.Mar.E., Vol. 74, No. 6.

depended on how dirty it was, but there might be an average sort of figure.

He asked if the author had any thoughts on the so called steam soaking process, which had been used in land practice for particular forms of deposit. Reverting again to individual experience, the monolithic lining for refractory material seemed to stand up to repeated wetting very much better than the majority of jointed brick constructions, and could be recommended for future design.

LIEUTENANT-COMMANDER W. J. R. THOMAS, R.N., began by asking the author whether there was any evidence to confirm that mechanical cleaning, whether with rotary brushes or with bullet brushes, was capable of removing some of the very hard scale which could form inside boiler tubes. Was it not possible that the brushes only removed the loose flaky deposit which would in any case be kept within bounds by the scouring action of the water and boiler tube vibrations, and so on?

In discussing chemical internal cleaning, the author had mentioned the undesirability of removing the protective film from the boiler surfaces. Was it not equally possible that mechanical cleaning also did more harm than good? In this connexion it would be interesting to know whether the internal condition of the boilers, which the author stated had steamed without cleaning for 8,000 hours, was measurably worse than those of normal naval boilers, and also to know what was the average life of a boiler tube, in steaming hours. If the boilers had apparently come to no harm, did not the author consider that further trials were justified to determine whether internal cleaning could be dispensed with entirely, in view of the fact that the Royal Navy did keep a fairly close eye on feed water treatment?

He endorsed the author's view that inspection of the boiler after external cleaning by water washing was absolutely essential. When water washing was introduced into the Service it was hailed by those who had to do the mechanical cleaning as the finest thing since steam. In fact it was a snare and a delusion, a trap for the unwary, and it was his opinion that much of the Royal Navy's trouble with heavy boiler deposits since carrying out water washing had been due to lack of inspection after such washing, and mechanical sawing to remove insoluble deposits was in his opinion absolutely essential.

He was currently concerned with the shore testing of the latest prototype naval boiler at the Admiralty Fuel Experimental Station, and could testify to the efficiency of the nine soot blowers which were fitted to that boiler. They were automatically operated in sequence and never failed to dislodge very significant daily quantities of soot, to the delight of the boiler operators and the infuriation of the local inhabitants. The boiler was still in very clean condition despite having now steamed for about 600 hours on trials involving good, bad and indifferent combustion and with more or less daily lighting up, which were not the ideal conditions for a boiler.

MR. J. T. ULLMAN stated that it would seem that in general those present seemed uncertain of the chemical cleaning of boilers or ships' systems. He hoped that he could do something to allay this fear. There were companies in existence in Great Britain, as well as in the United States of America, who were well experienced in the handling of chemical cleaning both in ship and land power plant. Cleaning of power plant would roughly come under two headings: the cleaning of new plant and the cleaning of plant after operation. The cleaning of new plant was nowadays, as pressures and complexities in plant increased, most essential. It was important in a modern boiler to have a homogeneous film over the whole boiler surface, this film should be a magnetite film as it was naturally produced under boiler operating conditions. Any breakdown in this film would result in local corrosion of the boiler surface. Before the boiler could go into operation the metal surface had to be prepared and absolutely clean so that its magnetite film could be put down.

As to cleaning plant after service, the method of cleaning had to be adapted chemically to the type of scale present. Basically these types fell into two groups. One group would be due to improper water treatment whilst the other was sometimes known as hydrogen embrittlement. Traces of copper, perhaps, came into the modern high pressure boiler and broke down the magnetite film in the boiler, causing local overheating of the tubes by the formation of scale. Whether this was attributable to copper was not really known, but nevertheless in land plant, especially where pressures went above 900lb./sq. in., it had become an increasing problem to maintain boilers free from tube failure. The only way of removing this form of deposit was by acid cleaning and it was essential that the boiler should be acid cleaned at the start of the trouble. If it was left too late, tubes were half eaten through by magnetite scale.

Comments had been made about the problem of differential metals in feed systems and in power plant in general. The practice nowadays was to take power plant as a unit involving the whole of the feed system, bled steam system, superheater and reheater and cleaning it as a unit in one complete chemical circulation. For this citric acid was used. The different types of metals that might be found, would range from pure copper, through the brasses, cast iron, mild steel, austenitic steels—in fact almost anything that could be imagined. In one case there had even been white metal in the system. None of these metals was affected adversely, nor were the joints or jointing rings in any of the boilers or component parts.

Mention had been made of iron dust found in boilers and boiler systems after acid cleaning. This was due only to an improper method of acid cleaning.

If the iron taken into solution during acid cleaning was not properly flushed out of the system, then during the subsequent neutralization of the surfaces it would be reprecipitated and dust would be found on the clean surfaces.

Examples were quoted of four ships where the whole plant was cleaned as a unit both on the water and on the steam side, and very effectively.

He said he had not dealt with mechanical cleaning, but did not think it could be assumed that it was 100 per cent effective; whereas with properly controlled chemical cleaning, with large pumps on a quayside delivering acid solutions to the parts that had to be cleaned, taking a heat source from shore boilers, a 100 per cent clean metal surface in the system at the end of the operation could be fairly guaranteed.

The CHAIRMAN (Mr. R. Cook, M.Sc., Member) before calling on the author to reply, put forward one matter on which he asked for the author's comments. In a recent paper* before the Institute by two authors from the Central Electricity Generating Board members had been informed that, in land practice, boiler availability had now been brought up to that of the turbines. That situation did not apply generally to marine boilers, and he found himself wondering whether this matter was not worthy of more attention. It could be argued, of course, that the ratings of marine boilers were much higher and that the quality of the fuel with which they had to deal was frequently much more variable; but on the other hand the land boiler had to deal with some very difficult fuels. It seemed that an intensive attack on this problem might be well worth while. It might even be that relaxation of the ratings at present used in marine practice might produce a more overall economic result.

* Dransfield, F. and Gray, J. L. 1962. "Land Practice in Modern Steam Plant". Trans.I.Mar.E., Vol. 74, p. 141.

# Correspondence

MR. D. O. CARMICHAEL (Associate Member) wrote that the development of the marine watertube boiler had combined modern trends of compactness with increased inaccessibility.

Cleaning the external side of a modern boiler had become an expensive consideration in the annual maintenance bill. This was particularly so in merchant ships, where external cleaning was normally carried out using shore labour. The economics of savings in fuel consumption were soon offset by the high labour costs incurred in frequent cleaning.

Despite the progress made in water washing technique, as indicated in the comprehensive paper, it still appeared to be somewhat unsatisfactory. In view of this he envisaged that "prevention" rather than "cure" was the solution.

The author stated that additives could be a help in delaying the formation of deposits or in altering their character. This effect was, Mr. Carmichael thought, understated. It was agreed that additives would not keep a boiler externally clean but they should be capable of preventing formation of the hard vanadium pentoxide deposits that were so difficult to remove.

His personal experience with additives, gained several years ago, had been promising. This applied particularly to the powdered type chemical which was independently injected into the furnace by means of a small blower. Serious depositing on the tubes did not occur, and subsequent boiler cleaning consisted of air lancing and brushing.

Perhaps the author would enlarge upon his remarks concerning additives and give his opinion upon possible development in this field.

MR. J. H. CLARKE (Member), in his contribution, wrote that Commander Inches was to be complimented on his excellent paper which had been read with great interest. However, commercially, shipping companies could not always apply naval design and operational methods to vessels in the Merchant Navy, and more particularly to ships operating under tramping conditions, whether the tonnage concerned was tanker or dry cargo. The following comments applied to these types of tonnage rather than passenger liners.

a) *Design Consideration*

Shipping companies invariably place financial restrictions on their technical staffs with the result that only essential plant and equipment is installed, usually of compact design with a large power/weight ratio. For this reason the superintendent is often forced to accept standard designs for the service required and to operate the equipment for a twelve-month period until the ship is drydocked and annual surveys carried out. Thus it is essential that the designed plant should be as foolproof as possible, otherwise, due to poor personnel (which, nowadays must always be taken into consideration) disastrous delays and expensive repair accounts will result. The Royal Navy, fortunately, is not faced with this crew problem.

b) *Cleaning by Water Washing (external)*

Tramp ships normally carry out boiler cleaning concurrently with the drydocking period which means that all ship's services are closed down, and to obtain the supply and pressure of water necessary for this operation is a difficult and expensive procedure. Experience has shown that the refractory materials are not always in perfect condition so that if water is applied at high pressure for the cleaning process, it will gain access behind the brickwork causing complications when fires are lit. To apply recommended preventative treatment necessary to avoid trouble whilst cleaning by this method normally interferes with other work being carried out in the stokehold and engine room at the same time. Under normal circumstances the use of a first class boiler cleaning contractor with good turbine equipment and skilled labour gives excellent results but meticulous inspection and supervision by ship's personnel is necessary.

c) *Vacuum Cleaners*

An industrial vacuum cleaner is an essential part of the boiler equipment both during operation and cleaning. These vacuum cleaners should be used whenever possible to eliminate soot and dust collected, especially in the uptakes and air-heaters.

d) *Modern Fuel Additives*

These chemicals used in conjunction with certain grades of fuel have assisted in reducing the carbon deposits on the fire sides, although sometimes the reverse is the case due to the additives breaking up the sludge in the fuel tanks which is pumped through the burners into the furnaces under conditions of bad combustion.

e) *Internal Cleaning*

Commander Inches' experience of internal boiler cleaning should prove invaluable to the shipping industry as a whole.

f) *Manual Cleaning versus Chemical Cleaning*

By manual cleaning, removal of scale can be controlled, which will prove beneficial under conditions of operation and maintenance, whilst chemical cleaning uniformly removes scale from all surfaces in contact with the chemicals used, which is not always advisable. Upon the actual state of the boiler, the amount of scale present, and the condition of the tube metal, will depend whether mechanical or chemical cleaning should be carried out. Economically chemical cleaning costs approximately 2·5 times that of mechanical cleaning and takes 1·5 times longer. Adequate flushing is essential to remove all traces of the cleaning compound.

g) *Boiler Water Treatment*

Boiler water treatment using the products of a reputable supplier is essential in modern high pressure watertube boilers. Special attention should be given to reaction adjustment of the water after boiler cleaning and inspection has been carried out.

MR. D. COCHRANE (Member) had been actively engaged in chemical cleaning for the past 15 years.

During that period internal chemical cleaning of marine boilers had gradually increased in the Merchant Navy. In the Royal Navy, to the best of his knowledge, resort had only been made to it in special instances—one which the writer could recall was for the cleaning out of pitting and removal of surface oxides in superheaters.

The main reason for the increase in chemical cleaning of boilers in the Merchant Navy appeared to be the lack of success of mechanical cleaning for the removal of tightly adherent scales such as those to which Commander Inches referred. An analysis of such a scale chemically removed from a watertube boiler in 1955 was:

| | *Per cent* |
|---|---|
| Iron oxide ($Fe_2O_3$) ... ... ... | 26 |
| Copper oxide (CuO) ... ... ... | 9 |
| Zinc oxide (ZnO) ... ... ... | 16 |
| Silica ($SiO_2$) ... ... ... ... | 5 |
| Aluminium oxide ($Al_2O_3$) ... ... | 9 |
| Calcium (Ca) ... ... ... ... | 4 |
| Magnesium (Mg) ... ... ... | 0·5 |
| Sulphate ($SO_4$) ... ... ... | 2 |
| Phosphate ($PO_4$) ... ... ... | 28·5 |

This was successfuly removed chemically. In recent years, there appeared to have been a gradual increase in the number of boiler tube failures associated with this type of scale; therefore there had been an increase in chemical cleaning of watertube boilers.

With "on load" corrosion, it was best to carry out some experimental work on sample tubes before applying a particular technique. The acid most generally used was inhibited hydrochloric for "on load" corrosion, but in some cases the

acid alone would not completely remove the deposit and other treatments might be necessary either prior to the acid cleaning or following the acid cleaning. This was not always the case; but where difficult deposits were encountered the company he represented were guided by laboratory investigation. Many shipowners were prepared to consider regular chemical cleaning on boilers in order to minimize the risk of tube failures occurring at sea.

With new ships it was now found to be widely accepted as desirable to have both boilers and feed systems chemically cleaned prior to commissioning. Tests carried out on a number of ships during chemical cleaning indicated that the boilers, with their large heating surface area, had more iron oxides than the feed systems. For example, in the last four new ships chemically cleaned, the iron oxide in solution was 0·1 per cent-0·2 per cent in the feed systems, the iron oxide in solution in the boilers was of the order 0·9 per cent-1·2 per cent. This was one reason why it was preferred to clean the boiler as a separate unit. Citric acid was normally preferred in feed systems and in new boilers. It was a milder acid than hydrochloric, but to effectively remove millscale, it should be used at a temperature between 160 deg. F. and 200 deg. F.

The quality of inhibitors used in the various acids, such as hydrochloric and citric, had improved considerably over the last few years and even at a temperature of 200 deg. F. the corrosion rate of boiler mild steel was only in the order of 0·0022lb./sq. ft. per 24 hours, for hydrochloric acid and 0·0004lb./sq. ft. per 24 hours for citric acid.

So far as the process itself was concerned, it was recommended that a definite specification be laid down, giving times of immersion, temperatures and the tests to be taken. A system of check was normally laid down to cover the acid process, flushing and neutralization. Provided strict attention was paid to these tests, there should be no cause for alarm.

Mr. F. E. Langer, O.B.E. (Member) wrote that in his opinion the author, while compiling an interesting paper on naval practice where labour was unlimited, was completely out of touch with commercial requirements, commercial manning and normal merchant ship operation.

In his introduction this was made clear. Commercial concerns were interested in first costs and were not prepared to carry, in tankers and cargo liners, a boiler or boilers, in excess of requirement. First costs, for material which was not in continual use, apart from excess deadweight, ruled this out.

Apart from this, modern chemical cleaning made such action completely unnecessary. The fleet with which Mr. Langer was concerned averaged 330-340 days per year at sea. The boilers were chemically cleaned during a 20 day refit and in the following 330-340 days service, had one period of self-maintenance when the fire sides of the boilers were cleaned. This was carried out by the ships' staff, in the case of the cylindrical boilers, and, for the high pressure, high temperature watertube boilers, by water washing which, with occasional brickwork repairs, was all that had proved necessary. Chemical cleaning had proved entirely successful over a period of eight years.

The remarks about the quality of naval fuel in comparison with commercial fuel were a complete divergence from fact, which was:

Admiralty fuel 200-300 sec. Redwood.
Commercial fuel 3,000 sec. Redwood.

Mr. J. H. Milton (Member of Council) felt sure that, after listening to Commander Inches presenting his paper and the lengthy discussion which followed, he was only one of many who had found the whole proceedings extremely interesting and enlightening.

Several of the speakers had stressed the fact that from the boiler cleaning aspect labour conditions in the Navy could not be compared with those existing in the Merchant Service.

With regard to internal cleaning, the very thought of a gang of boiler scalers being let loose, with guns and bullet brushes for cleaning the tubes of a vessel undergoing boiler survey, filled him with trepidation—no matter how keen their chargehand might be, or how thoroughly the tubes were subsequently searched. Also, even if the flexible drive did fail occasionally, surely a rotating brush, scrubbing its way slowly through a tube, gave a cleaner finish than a bullet brush taking a straight, unrestrained path under air pressure, and was far less likely to become jammed than a brush without any tangible attachment. Driving a jammed bullet brush out with short lengths of condenser tube sounded a very precarious operation and could, it might be thought, result in having to cut out a tube as a consequence of its becoming blocked with crumpled brass!

With regard to chemical cleaning, despite having once seen tubes of new boilers attacked by chemical cleaning solution, to such an extent that they had to be replaced, he was very wary to condemn such processes, which after all must clean in crevices and corners where no other method could penetrate.

The nature of the acid, the inhibitors and the range of temperatures at which they operated, the method of obtaining, maintaining and recording the temperatures of the acid, etc. together with a past record of the operators, were worth considering before embarking on such cleaning, which in any case should surely only be necessary for new boilers.

In the case of external cleaning he gathered that vanadium deposits were most troublesome on the tubes operating at the highest temperatures, such as superheater tubes. If this was the case, did this mean that, even though the designer produced boilers accessible for cleaning, progress was always going to be "dogged" by vanadium deposits from fuel oil until the "oil man" produced a vanadium-free fuel?

Mr. D. M. V. Parkinson, M.V.O. (Member) wrote that the author was to be congratulated on presenting a very clear and informative paper, of real practical value to those concerned with the operation of steam ships.

Since the idea of providing and carrying a spare boiler was as unacceptable to the merchant shipowner as it was to the Admiralty, both services might be considered to be faced with a similar problem.

That consideration should have been given to the question of cleaning in the design stage, was of obvious importance and though this appeared to be receiving far greater attention, in the past there had been occasions when considerable ingenuity had been called for on the part of ships' staff to devise ways and means and design tools to effect a satisfactory cleaning, even to the extent of altering boiler casings to provide sufficient access.

He was pleased to hear that Commander Inches had found that judicious use of boiler water treatment, so reduced the need for internal cleaning—scaling no longer seemed the appropriate word—that a period of up to two years had been adopted between cleaning, indeed in many cases, when opening up for annual survey, it was apparent that the boiler could well have continued much longer without the need for cleaning.

On the other hand, present-day fuels along with other factors had done nothing to relieve the external cleaning problem and, before the general adoption of water washing, real difficulty was often experienced in fitting efficient cleaning into the ships' schedule. Water washing had, however, so reduced the time required for external cleaning as to normally allow quite sufficient time to gently dry out the refractories and prevent subsequent damage.

He would like to ask the author if he would recommend the use of an alkali solution for the final washing, to combat corrosion both within and without the boiler during the washing. Commander Inches had confined his remarks to the cleaning of the actual steam generating portions of the boiler, but Mr. Parkinson felt that the author's views on the cleaning of economizers and air preheaters would be of value and wondered if he would have recommended water washing these units.

Mr. Parkinson was most interested in the description of

air propelled brushes for internal cleaning, but felt that this would prove an expensive and elaborate system, unless time were a vital factor and, since internal and external cleaning could be carried out concurrently, there would seem little point in speeding up one in excess of the other.

He was also pleased to hear that Commander Inches was not a slave to the steel ball method of searching boiler tubes, indeed the delay occasioned by a lost ball could prove most embarrassing and air searching might well have proved a satisfactory solution. He wondered whether Commander Inches had considered searching with a water hose, which would serve to both lay the dust, wash out the boiler and indicate that there was a sporting chance of the tube being able to circulate.

Again he would like to thank Commander Inches for a very interesting paper.

MR. W. F. QUINNELL wrote that this interesting paper had dealt with the vexed problem of boiler cleaning very concisely.

Having regard to the deposits, mainly soft and friable, that might be found in the uptakes and funnels of boilers, it might be better if the arisings from water washing these parts were prevented from gaining access to the tube nests of the economizers, superheaters and boilers.

Perhaps the funnels and uptakes could be dealt with by vacuum cleaning with more advantage.

A drying out routine, after water washing, had been mentioned to avoid damage to brickwork. It was also considered essential that water washing should be followed immediately by drying out, to ensure that no acidic moisture remained in the residue around the necks of the boiler tubes where they entered the lower drums.

With a normal standard purity of feed water in use in boilers and the correct control of feed water treatment, no appreciable build-up of internal deposits nor the presence of active corrosion along the bores of tubes, might be expected, so that boiler tube life might be governed by the rate of external wastage of the tubes at their lower ends.

# Author's Reply

The author greatly appreciated the interest taken in his paper and wished to thank all those who had contributed to the discussion. When writing the paper he had been very conscious of the comparative narrowness of his experience; he was therefore doubly grateful for the contributions which had closed gaps which he had had to leave. He hoped he would be forgiven if, after this general acknowledgement, he restricted himself to answering the questions that had been asked and the specific new points that had been raised.

Commander Lake had raised the point of the space premium in naval boilers and indeed this was a very big talking-point. All the author could add was: it had now become clear that, in some ships at present in service in the R.N., the saving of space in machinery rooms had been given too much priority. This conclusion had been reached the hard way! A considerable proportion of the Fleet was involved in this problem, but specific steps to solve it had now been taken which looked as if they might be successful. This was an acknowledgement, in a way, of failure in that the importance of maintenance had, at one stage in naval design work, not been given sufficient priority; it was, however, gratifying that this error had been not only realized but also put right and the evidence was so clear that the error was most unlikely to be committed again. This point was worth making, because this departure from the "inside space race" (as distinct from the Outer Space race) brought the Admiralty now more into line with ordinary marine practice. Thus, while there was no doubt that the Merchant Navy had good reason for considering impracticable some of the boilers at present in service in the R.N., efforts were being directed towards getting away from this situation, and to arrive at something which was practicable for the ordinary seagoing man. That after all was the type of maintenance personnel and the type of operator who had to be catered for, whether one was designing ships for a merchant fleet or a fighting fleet.

Commander Lake had also referred to in-line tubes, in connexion with the possibility of vibration producing an automatic removal of deposits. This was perhaps a possibility but the author had to be honest and admit that it had not been taken into account in design so far. The chief obstacle was a complete lack of confidence in the ability to control these vibrations so that they just removed the deposits without weakening the tube metal! Where there had been positive evidence of vibration in R.N. boilers, unfortunately it had arisen from the weakening of the tube metal resulting in failure.

Regarding the automatic sequencing of soot blowers, opinion was that this was only worth while where maintenance on the blowers and on the sequencing gear was possible without shutting down the boiler. It had always been realized that automatic sequencing demanded a system complication, with an increased risk of breakdown but only experience had shown that this was a significant factor. In short, provided it could be certain that all the gear, whatever its complication, could be kept running at all times, then things like automatic sequencing were well worth while because they ensured proper operation. Unfortunately meeting this proviso was often difficult and sometimes impossible. The author thought it a worth while alternative to consider special training of personnel to understand the purpose of sequencing, so that they did operate soot blowers properly, as distinct from trying to ensure that they could not do it incorrectly by installing automatic sequencing.

Both Commander Lake and Dr. Wyllie had made reference to the need for research into the combustion process and how it affected deposition. This was being pursued very actively and there was considerable interest in the work on the part of industry and the universities, so that information was accumulating quite fast. Unfortunately one of the major conclusions which had been reached from this information was that the problem was, if anything, even more difficult than had been thought. Rapid progress towards a solution was therefore not being made, but the author felt that it was not for want of trying.

As regards a simple check on water quality sufficing to keep down the need for internal boiler cleaning, which Commander Lake had also mentioned, the author very much agreed with this. Silver nitrate was still used for feed water taste in R.N. ships and still found generally adequate. The only element of sophistication was that chlorine content was now expressed in parts per million as distinct from grains per gallon.

Commander Lake had also referred to the dangers of chemical cleaning, but the author felt that other speakers had ventilated that particular subject so much that he could not add anything useful in a general way. One specific question which Commander Lake had asked, however, was about the effect of chemical cleaning on system materials. The author was sorry that he had no pictures to show this effect, but in spite of all that other speakers had said, there was a certain amount of evidence of damage to system materials which had been attributed to chemical cleaning, or rather to something going wrong with chemical cleaning. It came back again to the author's own statement that, provided chemical cleaning was properly controlled, it was perfectly safe—but that, of course, was one of the snags: it could not be guaranteed that it would always be properly controlled.

The problem of high vanadium deposits also was a very difficult one. It was known that, as the steam temperature was raised, so the chances of compounds with a high percentage of vanadium in them either depositing or attacking metals in the gas path increased. In the laboratory and on paper, a great deal more than that was known, but there was still considerable difficulty in tying together practical, full scale, experience and laboratory results. A paper on this subject which the author had found most useful had been given to the A.S.M.E. in 1959;* unfortunately he could not give any details of it from memory. Briefly, this paper had given a very illuminating picture of the rapid increase of vanadium attack with increasing metal temperature and obviously in the temperature range below that attack pattern there was a deposit pattern, probably developing in the same way with temperature. It seemed to the author that with increasing temperature the vanadium

* Phillips, N. D. and Wagoner, C. L. "Oil-ash Corrosion of Superheater Alloys in a Pilot-Scale Furnace—Reduction by Use of Additives". A.S.M.E. 59-A-281.

rich compounds first of all reached a condition where they were sufficiently fluid to adhere to a metal surface and encourage other materials to deposit there as well and then, as the temperature went up further, they became aggresive and not only adhered to the metal surface but also attacked it.

Dr. Wyllie had referred to pre-wetting boilers before external cleaning. Five days had been quoted by one very big organization as being a reasonable time for pre-wetting. If people could spare five days it would be a jolly good insurance of success; unfortunately not many could. However, even shorter periods would undoubtedly help, provided the deposits were kept really soaked with water, not just kept moist.

Pumpability of fuels had also been referred to. The author thought that this might be one of the explanations for some of the rather peculiar fuels now being supplied. Perhaps, in the interests of maintaining pumpability, which was laid down in the specification, deterioration in some other respects had been accepted, because that did not infringe the specification.

Mr. Hutchings had referred to the need for more efficient combustion equipment. With this the author whole-heartedly agreed, adding that it seemed as if considerable progress in this direction was being made. The Admiralty had, for a very long time, developed its own combustion equipment because it was considered, that for one reason or another, normal commercial equipment would not meet the Navy's requirements. This work had, on the whole, produced very satisfactory results and was being continued. Obviously improvements in the efficiency of combustion equipment would bring a benefit for all users of liquid fuels and indeed there was a lot of room for improvement in that direction. However, in the author's opinion this did not affect the basic issues involved in his paper; sooner or later boilers would become dirty and would have to be cleaned. He hoped, therefore, that he would be excused for omitting any reference to the efficiency of combustion equipment from his paper.

Having been asked to define "gross breach of reasonable precautions" the author said he could only do so in a retrospective sense. In each case where damage had been found to result from the use of a chemical for cleaning a boiler internally, looking back on the process it had been found that some departure had been made from the standard drill. That departure then became recognized as a gross breach of the precautions! The author regretted that he could not put it any better than that.

Mr. Hutchings had also asked about the effectiveness of bullet brushes for internal cleaning. The author was sorry that he had not mentioned this in the paper; perhaps the reason was that, in his own mind, he was so completely certain that they were quite as effective as any other mechanical means of cleaning boilers known to him. He would go further than that and say that he considered them more effective than most other means. This might seem rather a vague definition, but it must be appreciated that there were some factors involved which made it very difficult to be categorical. For example, on the third occasion of using a bullet brush it would probably be not quite as effective as on the first occasion. If then this third time it was used on a boiler which had scale more adhesive than normally was the case, or abnormally sticky deposits, whichever way one liked to express it, the result would probably be not such a good clean. He was certain that if he gave a categorical answer, somebody would find a case that contradicted it. Under those circumstances he preferred not to give categorical answers!

Regarding brickwork sealing compound, first of all because he had not got the details to hand and secondly because he was not allowed to advertise, the author would have to invite Mr. Hutchings and anyone else who might be interested, to ask him for details in writing, or in some other place, when he would gladly supply them. In the meantime he could confirm that the Navy was still very happy with this compound.

Captain Atkins had said he had suffered from people who reckoned they knew all about boilers. There were still some of those about, but they had now been joined by the other team who were certain that they knew nothing about boilers. The author was not sure which were the most difficult to deal with.

With regard to Captain Atkins' point that boiler cleaning time used to be regarded as a bonus for general ship maintenance, this now applied much less than in the past. The author felt that this was perhaps a peculiarly naval matter but it was quite true that in certain circumstances people welcomed a clear ruling from a superintendent, or whatever style he carried, that they must clean their boilers. With this they could go up to the bridge and say, in effect: "Look, time is up, we have got to stop for boiling cleaning". Then and there this provided an unanswerable argument. Nevertheless, in the overall pattern of ship operation this was most unsatisfactory. The author was happy to be able to say that the problems of personnel fatigue and having to allow for it, were receiving consideration in their own right. It was not necessary any more to support such a general and reasonable requirement on a peculiar and arguable one. There was a growing realization that it was not just that people needed a rest, but that even if machinery did not actually break down, it was bound to suffer heavier wear and tear if personnel interest or energy level were allowed to get below a certain minimum.

The Boiler Corrosion Committee was still in existence, or to be more precise, had been reformed. It was still a body with a large amount of experience from all sides, to be fed into Admiralty and, the author was sure, knowledge was being gained through it. In fact, some of the steps that had been taken recently to extend boiler steaming hours between internal cleans and laying down guidance lines on how boilers should be handled, stemmed from the breadth of experience which had been provided through the Boiler Corrosion Committee.

Captain Atkins had also talked about nuclear steam generators. The author was glad to say that he had a nuclear "hat", although he was not wearing it that evening. It was his responsibility, within the Ship Department, to see that in any nuclear ship plant the secondary steam generator, as the boiler was called, did not fall short on performance because of any mistakes in conventional engineering. He would claim no more responsibility than that, because the detailed design of the whole unit, not only in the American-born *Dreadnought* but also in the later British designs, involved much that still had no parallel in the conventional field. He was, therefore, very happy that there were many other experts involved, apart from himself.

A question of cleaning these units had been brought up. It was a very valid one. All he could really say was that he was sure that the Americans had done this and he was confident that the British could do it the same way.

Mr. Dilnot had made the point that the paper showed little evidence of Merchant Navy experience being fed in. He had used the expression "appeared not to be available", but the author wished to make it clear that he was sure the experience would have been made available to him if he had got around to including it in his paper. He could only quote the excuse of pressure of work for not doing so.

It was very interesting to learn that no boiler chemically cleaned by Mr. Dilnot's firm had ever had to be cleaned mechanically afterwards. Nevertheless, this had been necessary in some other cases to the author's certain knowledge.

Mr. Dilnot had also mentioned that some of the ships operated by Admiralty had their boilers chemically cleaned internally. This was very good news to the author, but news all the same. He had to point out here, that, as his appointment, included in the heading of the paper, indicated, his department was that of the Director General Ships. This department need not necessarily be involved in the design or operation of the Fleet Auxiliaries, to which Mr. Dilnot referred. At the same time, co-operation between departments was getting much closer and the author would see to it that he found out more about the experience of the Fleet Auxiliaries in this respect. If it would help to ease the boiler main-

tenance problem, he would be very glad to apply it to H.M. Ships.

One of the arguments made for chemical cleaning was that it cut labour costs. He had to make the point that, rightly or wrongly, labour costs as far as naval staff in ships were concerned, just did not appear. On the other hand, they certainly would appear if an outside firm had to be given a contract for the work. This was a very important point.

It had been agreed by everybody present that evening that the handling of chemical cleaning by the inexpert was not safe and indeed this seemed to be generally accepted throughout the world. So, whereas at present more or less expert handling of bullet brushes by the normal naval personnel could be accepted without causing worry about damage to boilers, if the Navy went over to chemical cleaning it would have to employ an expert team from outside the Navy and this would have to be paid for. This was perhaps a rather sordid argument and certainly not a technical one, but to any tax payer a very valid one.

Mr. Dilnot had also made the point that new boilers might contain dirt, scale, etc., etc. This seemed to be indisputable; not just might but in fact did. This was not so much a criticism of the cleanliness of those who build boilers as recognition of the facts of life in a boiler shop. A great deal of attention was being paid to increasing cleanliness in all parts of marine and naval engineering practice, with a lead from the nuclear field, but it was necessary to be realistic. To hope to produce a complicated piece of equipment like a boiler and the elaborate feed and steam systems for which, in operation, it acted as a dirt collector, without somewhere or other introducing a certain amount of dirt, was over optimistic under the circumstances that had to be contended with for the time being. If the engineering industry as a whole were able to accept a reactor compartment standard of cleanliness, the situation would be different, but costs alone ruled this out as an acceptable solution.

For the removal of this dirt, then, the author quite agreed that chemical cleaning had very much to recommend it.

Mr. Dilnot had put up a picture of a Lamont boiler to which he had referred as being "simple". In some respects that was probably true, but if he had shown the array of tubes inside the boiler the author reckoned the term "simple" could not really have been applied. Actually this was one of the types of boiler for which the Navy had accepted chemical cleaning as being the only feasible method. Even supposing one could get at all the tube ends to put brushes in and fire them through, it would need a pretty intelligent brush to find its way to the other end of its circuit! However, from the other part of this picture, which showed the circuit necessary for acid cleaning and from the whole tenor of the evening's discussion the author stood confirmed in his opinion that chemical cleaning could not be recommended for Jack Tar in Manus Harbour, which was usually the sort of place where internal boiler cleaning had to be done in war time. Mr. Ullman later had referred to having a pump on a quayside and a shore boiler available. In places like Manus there was no pump, there was no quay and there was no shore boiler.

The explanation provided of dust present after chemical cleaning was accepted, but even if this was a minor hazard it presented an awkward problem. It must be remembered that navy ships had to face the possibility of no chemist being available. Then, if the boiler operator, when he had gone through the drill of cleaning, found that there was still something in his boiler which should not be there, he had just got to clean it again. It was not possible to have two alternatives here; no risks could be taken. However harmless a deposit might be the operator had to remove it before considering the boiler clean.

Regarding the removal of oil of one kind or another from boilers, the author considered this in the nature of decontamination rather than normal cleaning. Certainly, if it occurred resort had to be made to solvents for cleaning in naval ships as in others, and indeed their use had caused no trouble. But this was still not the same as acid cleaning.

Lieutenant Warnecke had talked about the injector equipment being "temperamental". This point had not been mentioned in the official trials reports submitted to the author's department, which were on the contrary generally enthusiastic. However, the author accepted that there could have been some unreported trouble and would appreciate it if Lieutenant Warnecke, or those who originally experienced the trouble, would let him know just what happened.

The author could not add anything more on the question of removal of non-soluble deposits from boiler fire sides. He had not said that their removal was always easy, but suggested that, provided they were not more than about half the total deposits it had been found that they could be coped with after the soluble products had been removed.

The author was in favour of water washing economizers on load, and hoped that it would be possible to arrange for this in some naval boilers. Unfortunately, it demanded rather more space than was readily granted, unless nobody wanted it, and then it was usually in a locality where his section could not use it. Nevertheless, this was a line worth following. Economizers were bound to be a part of the boiler where deposits accumulated—not that they were all originally deposited there, but it was a zone of high solid to gas path ratio, and so had a high collecting efficiency for any solids dislodged from elsewhere and passing through. It would certainly be a great help if these deposits could be removed without having to shut down the boiler.

Mr. Dixon's report on his experience with chemical cleaning was very encouraging. The author shared his opinion, that the acceptance of chemical cleaning was essential to any significant progress in boiler design. In fact, some of the future projects being considered in the author's section had already brought out this point.

Five tons of water for externally cleaning a superheater had been suggested as a reasonable quantity. The author unfortunately had no figures for superheaters alone; for a whole boiler he thought ten tons was a better broad figure. However, at the same time as suggesting this figure the author felt that he had to warn against attempts to economize on water in this undertaking. There was bitter experience of trying to wash boilers with too little water. What was achieved was, that the soluble deposits were leached out and the insoluble ones, which then compacted, were left. A very parlous situation then resulted, because the next time a water wash was attempted, however much water was used, there was something like a 70 per cent insoluble base deposit at the bottom of the boiler, which could not be shifted.

The author regarded steam soaking in the same way as pre-wetting: helpful where it was possible, but time consuming.

The answer to Lieutenant Commander Thomas' first query depended rather on what sort of hard scale he was talking about. No form of mechanical cleaning removed the hard magnetite film, whilst chemical cleaning did. However, the only reason for wanting to remove this film was, that it had got thicker than was necessary for the protection of the steel, and this condition was not even remotely approached in the intervals between boiler cleaning as they stood at present. Whether mechanical cleaning would remove other forms of hard scale depended on a lot of factors, but the author could only say then that, if it did not, and the scale built up to a dangerous extent, there would be tube failures of a certain unmistakable type. The absence of any history of tube failures of this type, the author interpreted as evidence that, with normal operation, there was no build-up of dangerous scale.

It was possible that the deposits which mechanical cleaning removed would reach the limiting thickness without any removing action, and the author hoped that the new policy on internal cleaning introduced recently might help to shed some light on this. Anyway, it was certain that these deposits did nothing to protect the tube metal, and their removal ensured that the heat transfer circumstances were restored to the

"as designed" condition every now and then. Although there was no specific evidence that this was necessary in order to maintain the design steam generating capacity, it seemed logical that it was desirable, and appeared to have been universally accepted as an argument for cleaning periodically.

In the boiler which had steamed 8,000 hours without cleaning there had been some thickening of the magnetite film. The author agreed, that there was a case for further trials, but as the only conclusive trial was one to destruction, he foresaw some reluctance on the part of the Admiralty to authorize it! A further point was that it would not be possible except in the broadest of senses, to apply the results of such a trial to designs of boiler other than that tested.

The question which Lieutenant Commander Thomas had asked, about the tube life in terms of steaming hours, was an extremely difficult one and not even the copious naval records provided an answer. Tube life was expressed in years, and in terms of years it was something like 25, for a tube which had been looked after reasonably well. However, evidence was accumulating that conditions when steaming were not the only criterion for tube life. Non-steaming hours, if the circumstances were right, could be more effective even than steaming hours in reducing tube life, and Lieutenant Commander Thomas would appreciate that the separation of the two factors was an impossible task over that sort of period of time.

The penalties of successful soot blowing experienced at A.F.E.S. were the same as those in the Fleet. Unfortunately the traditional remedy—to alter course to bring the wind on the beam—could not be applied there.

Mr. Cook finally had made the point that the Central Electricity Generating Board was aiming at a boiler availability as great as that of the turbines. The author was very conscious that boilers in the Navy demanded attention, on a regular basis, more frequently than any other piece of machinery, but on the whole, on a breakdown basis, they demanded it a lot less. At the same time he had not been idle in this respect, inasmuch as the recently introduced intervals between internal cleaning of boilers could be lined up with the intervals when the ship had to go into dockyard hands anyway, for a refit or general overhaul. As regards internal cleaning therefore, the average machinery availability had been equalled. However, externally, they were still a long way from that situation. But they were working really hard, with the assistance of the best brains that could be obtained in the country, to try and beat this bogey of external cleaning at comparatively very short intervals of operation.

The author was most interested to have Mr. Clark's comments on vacuum cleaning. It was not clear why these well established and generally reliable aids to domestic cleaning had not been more widely accepted for engineering housekeeping, and the author hoped that this situation would change soon.

Mr. Clark's figures for relative cost and time of chemical and mechanical cleaning were most interesting and it seemed to the author that they tended to support his own arguments on the subject.

Mr. Cochrane was quite right in stating that chemical cleaning had been used in R.N. warship superheaters. Unfortunately the author had to add that, in no case was the undertaking an unqualified success!

The analysis of scale which Mr. Cochrane provided, the author would not consider representative of naval boiler deposits. It was quite obvious, that there were differences here which, the author considered, accounted fully for the differences in cleaning policy which existed.

The author had already been advised by others that Mr. Langer was very satisfied with chemical cleaning of boilers; he was therefore very happy to have Mr. Langer endorse this.

Mr. Langer's comments on fuel quality the author considered as confirmation of his own remarks that this was a very complex subject. He wished to point out however that, whereas fuel oil viscosity figures probably presented quite a good picture of relative burning qualities 25 years ago, they were of little value in that respect today.

The points of concern about bullet brush cleaning felt by Mr. Milton were amongst the principal points considered by the Navy when the matter was first investigated. However, bullet brushes had proved better than rotated brushes, possibly because with the greater power to push them, it had been possible to make them somewhat larger, for a given size of tube, than the others. Undoubtedly, whereas ease of access to boiler fire sides helped the cleaning problem, the presence of a vanadium in any quantity in the deposits made it more difficult. The removal of the vanadium from the fuels was also obviously one of the possible solutions. However the problem was being attacked on many lines apart from this one and there was hope of success, although perhaps not in the near future.

The author was happy to hear again from his old colleague, Mr. Quinnell, as usual with a set of pertinent remarks. There were continual reminders that the uptake and funnel deposit problem was not quite the same as that in the rest of the boiler, and action along the lines suggested by Mr. Quinnell was being considered.

Mr. Quinnell's warning about acidic residues the author knew to be based on bitter practical experience. The cure Mr. Quinnell suggested was good, but the author preferred avoidance of the disease—by having no residues.

Although the author agreed with Mr. Parkinson's statement that a spare boiler was rarely feasible, the justification for making reference to it as one solution of the cleaning problem was that there were a number of large multi-boiler ships in service, in both the fighting and merchant navies, where there was a spare boiler. From those ships it was clear that, where this solution could be adopted it had great advantages—although the author could not claim to know that this was the primary consideration when deciding on the number of boilers.

Whether an alkali wash after a water wash was beneficial depended rather on whether the boiler was due to go back into service straight away or not. In the former case, the application of the wash might cause a delay which would do more harm than good. In the latter case it should certainly do good.

Water washing of economizers and air pre-heaters was certainly the most effective way of cleaning that had been found for naval boiler application. At the same time it seemed desirable to restrain the removed deposits from these units, which were generally above the generating part of the boiler, from falling down into the latter. The rigging of special screens over the generating banks could help in this respect, so could the use of vacuum cleaners to remove as much of the deposits as possible before water washing.

Internal cleaning of modern naval boilers took a great deal longer than external cleaning. Mr. Parkinson's argument against the need for speeding up one process therefore did not apply in these circumstances.

Searching boiler tubes with water had not so far been considered. It was certainly a possibility, but the author rather thought that some corrosion problems would arise.

Because the question of additives and their uses was such a very big one and because it appeared to him to lie on the very edge of the subject of his paper, the author had intentionally excluded them from any mention. However since Mr. Carmichael had asked a question, the author would try to answer it insofar as this was possible in general terms. One of the big problems regarding the effective use of additives was the need to know more about the fuels and their impurities, and the mechanism of deposition of the fire side deposits, than was normally the case except perhaps inside the oil companies. It was evidently of the greatest importance to get just the right type of additive for the foreign matter present in the fuel and to add it in just the right quantity—there was a good deal of evidence that the wrong additive or too much of even the right one could produce a final situation which was worse than if no additive had been used. It was the author's firm opinion that insufficient attention to these points accounted for the great majority of the contradictions which would be found if the total experience of the use of additives was investigated. To try and help with the solution of this problem, studies had

been sponsored by Admiralty to explain the deposition mechanism and the part played in it by the different elements which were known to be present and probably involved. Assuming that some of the impurities were more important than others, the next stage would be to check fuels for the presence of these impurities and then to deal with them as far as practicable, either by elimination in the refining stage or by neutralization later on. Evidence was accumulating that a form of neutralization was achieved by avoiding the presence of any excess oxygen during and immediately after the process of combustion, but obviously additives would provide another solution of this form. If the advances in the oil refining techniques continued as they had been going in the last 25 years, elimination should not be beyond the bounds of possibility either and some studies were going on in the hope that this might provide a solution, which would be even better than the others.

Until that very much greater knowledge of fuels, impurities, etc, referred to above, was available, the author considered the use of additives much the same as betting on horses.