predetermined dangerous water level has occurred, is the 'Mowbrey' magnetic float switch'.

The float assembly of this detector carries a permanent magnet which is opposed by a similar magnet in the switch assembly (see Figure 14.16). The adjacent poles of the two magnets are arranged to repel each other through the wall of the switch housing. This principle is employed to change-over switch contacts with a snap action under the control of the water level float.

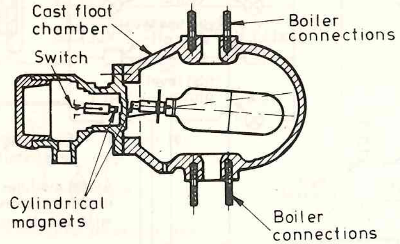


Figure 14.16 Mowbrey float. The magnetic flow switch is made in two types: the pivotal float (as shown in this illustration) and the vertical reciprocating float

These sensors or detectors commonly form a system of water level detection independent of any other mounting for operating audible and visual alarms and for shutting off the fuel supply when the boiler water level gets to a predetermined low or high level.

Single element controls or regulators

As mentioned earlier this mode of control operating from variation in water level alone is normally only used for boilers of moderate evaporation, which operate with small load changes and at relatively low pressures. There are still many such installations in service details concerning some of their feed regulators are described in the following paragraphs.

Generator feed regulator

In this type a generator is used in conjunction with a control valve, the pressure from the generator being piped to a diaphragm-operated feed-control valve, see Figure 14.17; any increase in pressure opens the control valve.

The generator consists of an inner and outer tube, the inner tube being connected to the steam and water space so that a water level is produced in the tube corresponding to the water level in the boiler

drum. The outer tube or jacket forms a closed vessel connected by copper tubing to the diaphragm chamber of the diaphragm-operated feed-control valve. Fins are provided on the outside of the outer tube. The closed space between outer and inner tubes is filled with water when the feed-regulating valve is closed and the diaphragm is in its uppermost position. The generator is set at 30° to the horizontal, the steam connection being lagged and the water connection uncovered.

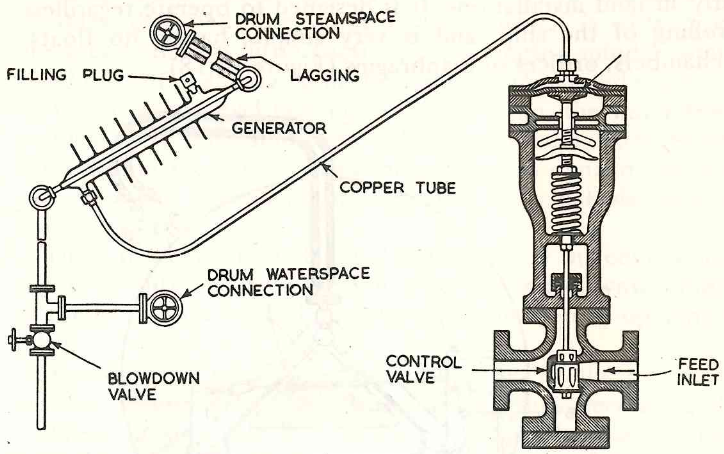


Figure 14.17 Generator feed regulator

Heat is transmitted from the inner tube to the water in the jacket; the quantity depends on the length of the inner tube which contains steam, and this, of course, depends on the water level in the boiler drum. The heat transference from the inner tube to the outer jacket causes some of the water in the jacket to evaporate and form steam, thus creating a pressure in the jacket, which is in turn transmitted to the diaphragm of the control valve, causing it to open against its spring load.

The lower the water level falls in the boiler drum, the greater is the length of inner generating tube transmitting heat to the jacket, which raises the jacket pressure and opens the control valve to a greater extent. When the water level in the inner generator tube rises thus reducing the length which contains the steam and decreasing the heat transference to the jacket, this in turn reduces the jacket pressure and allows the control valve springs to close the valve. The fins on the outside of the jacket increase the cooling rate of the water in the jacket, and so improve the sensitivity of the regulator.

These regulators are of the continuous feeding type, changes in the water level being used as a means of generating steam to apply the necessary pressure to the diaphragm operating the feed-control valve.

Copes regulator

This regulator, also of the thermal type, is extensively used, particularly in land installations. It is designed to operate regardless of the rolling of the ship, and is very simple, having no floats, pressure chambers, orifices or diaphragms (Figure 14.18).

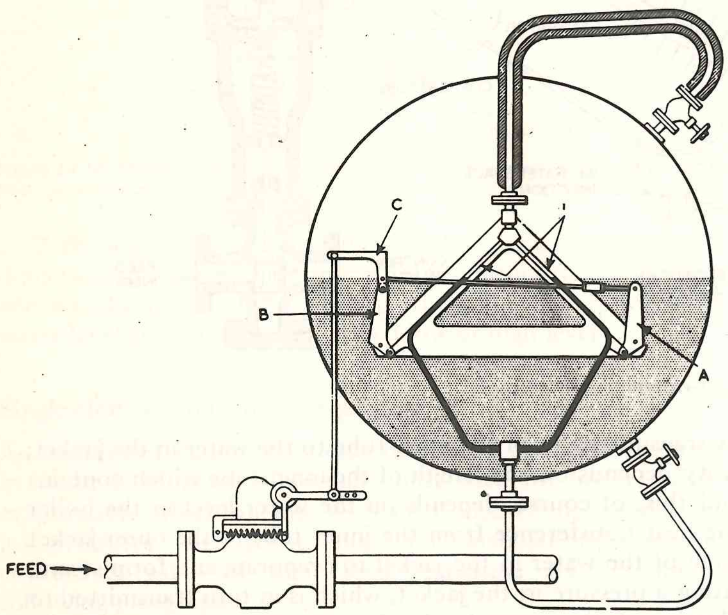


Figure 14.18 Copes thermal regulator

The regulator consists of two stainless-steel expansion tubes inclined at 45° and mounted in a rigid steel frame. Their upper ends joint together in a yoke anchored to the frame, and are connected by a heavily-lagged steam pipe to the steam space of the boiler drum. The lower ends of the tubes are pin jointed to levers, and from there lead back to the water space of the drum. With boilers which have their drums in a fore-and-aft position the regulator is installed on the

vertical centre line of the drum, at such an elevation that for normal working water level, the upper halves of the expansion tubes are filled with steam and the lower halves with water.

In operation, owing to the fact that the steam connection to the drum is heavily lagged, the steam temperature in the tubes will be the same as in the boiler, but as the water connection is unlagged the water temperature in the tubes will be appreciably lower. The levers *A* and *B* magnify the motion caused by the expansion of the tubes *T*, the motions of the levers *A* and *B* are added and further multiplied by being linked together and to a further lever *C*. The lever *C* directly operates the feed-water control valve, which is of a type which operates with very little friction, the actuating spindle rotating in a gland instead of sliding, as in the diaphragm-operated types.

As the water level falls in the boiler drum, the water level in the stainless steel expansion tubes falls correspondingly. More steam and less water in the tubes causes the tubes *T* to expand, resulting in an anti-clockwise movement of lever *A* and a clockwise movement of lever *B*.

These motions are added and multiplied by the connecting link to give *C* an anti-clockwise motion, resulting in a downward movement of the feed-water control operating rod and thereby opening the feed valve.

As the water level rises, the contraction of the expansion tubes has the reverse effect and lifts lever *C*, thus decreasing the feed.

When the ship rolls in a seaway, the water level in one expansion tube will fall while the other rises; the motion of the levers *A* and *B* will thus be in the same direction, and there will be no resultant motion of the lever *C* and the control valve position remains unaltered.

Copes Type P thermostat assembly

A modern version of the Cope's Regulator operating on the same principle is shown in Figure 14.19. This type is frequently used as a level sensor, feeding signals to the level controller of two and three element feed systems.

The thermostat is an inclined stainless steel expansion tube mounted in a rigid channel steel frame. The upper end of the tube is connected to the steam space of the boiler drum; the lower end to the water space of the drum. Thus the water level in the tube always corresponds to the water level in the gauge glass. The water in the lower half of the expansion tube cools by radiation to a temperature lower than that of the steam in the upper half. Because of this temperature differential, the tube contracts as water level rises, and expands as water level lowers. Since the upper end of the tube is fixed with respect to the thermostat frame, the end of the thermostat lever rises with a rising water level and lowers with a falling level. Movement of the thermostat lever is transferred through a bell crank lever to the stem of a pilot valve. This pilot valve is

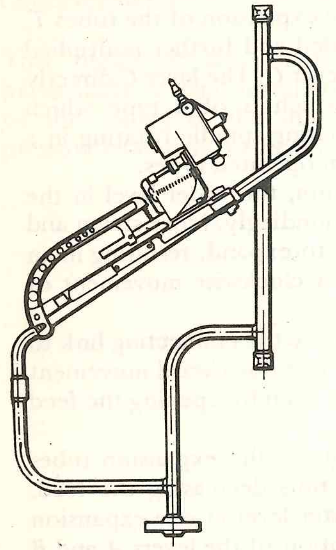


Figure 14.19 Copes Type P thermostat assembly

supplied with constant pressure air, and regulates air pressure in the control line. It is of the pressure compensated type, and does not use air unless the water level is changing. The controlled pressure is always in proportion to the water level in the boiler. The higher the water level, the higher the controlled pressure.

Position of regulators in feed system

In all types of regulator, if the regulator is to follow closely changes in the water level of the boiler drum, it is important that the steam and water connections be kept as short as possible, and be so arranged that the regulator itself is placed so that rolling of the vessel has a minimum effect.

SUPERHEATED STEAM TEMPERATURE CONTROL

Control of the steam temperature is achieved by varying the quantity of steam which passes through the attemperator, the remainder of

the steam passing through the attemperator bypass. The control is by means of two control valves, one in the line to the attemperator and the other in the bypass line (see Figure 14.20).

The temperature after the superheater is measured and used as a measured variable to the temperature controller. The feed forward principle is applied here also, using steam flow as the feed forward signal.

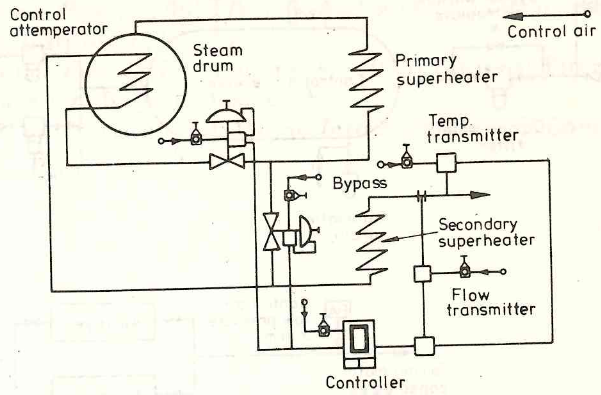


Figure 14.20 Superheated steam temperature control

The modern boiler can maintain its specified superheat temperature down to a low output, and this temperature is maintained constant over a wide range, for further details of methods of superheat control, see chapter 9.

CONTROL AIR SUPPLIES

The air supply for control and instrumentation systems must be clean and dry if problems of contamination, corrosion and subsequent malfunctions are to be avoided. In general air supplies for instrumentation purposes should have a maximum solid particle size of 3.0μ and a liquid content less than 5 ppm at its specified dew point, in the order of −20°C to −40°C. at its working pressure.

To avoid major oil contamination, control air should be supplied from an oil free compressor so that the only oil contained in the supply will be from the induced air (see Figure 14.21).

Entrained water and oil which carry over from the control air compressor is first removed by passing the air through a coarse filter. As the air enters the filter it is given a swirling motion by guide vanes so that liquid particles and heavy solids are thrown outwards to impinge on the side of the bowl and flow downwards to the drain. Further solid particles and liquid are removed as the air leaves the filter through the filter element. At best this mechanical filtration will only remove entrained liquid particles and the air will remain saturated with liquid vapour.

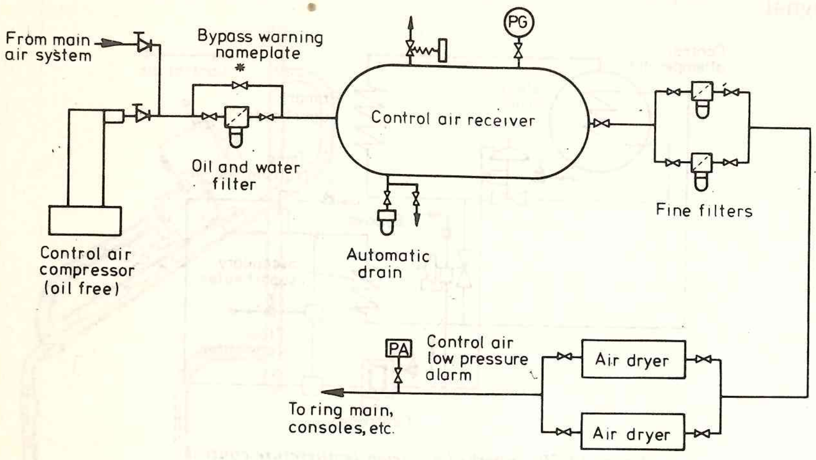


Figure 14.21 Control air diagram

From the filter unit the air is passed to the receiver, and as expansion occurs the dew point is lowered so that further moisture is precipitated out to leave partially dry air. The filter and receiver are usually fitted with automatic drains. Two fine filters are arranged in parallel after the receiver to remove any liquid and solids that may carry over. Only one filter is in use at a time, while the second acts as a standby unit. Driers can be of the refrigeration or absorption type. Drying by refrigeration will remove up to about 96% of the remaining moisture in the air supply.

Absorption driers usually consist of two units, each containing a solid dessicant. One unit is in operation while the other is reactivated. There are two types of absorption driers in common use, one requires heat to reactivate the dessicant while the other does not. In both types a certain quantity of dried air is fed back through the dessicant to remove the moisture. Typical dessicant materials include silica gel and activated alumina.

Filter and drier units which are not duplicated and arranged in parallel should be fitted with by-pass valves to ensure continuity of supply. The operators attention should however be drawn, by means of a warning notice fixed to each by-pass valve, to the dangers of operating a control system with filters and driers by-passed.

Bibliography

1. BS.1523: *Glossary of terms used in automatic and regulating systems, Part I. 1967. Process and kinetic control.* British Standards Institution, London.
2. *National Fire Codes, Volume 8,* (1975) National Fire Protection Association, Boston, Mass, USA.
3. *Code of Procedure for Marine Instrumentation & Control Equipment,* B.S.R.A., (1976).

15 Treatment of boiler water and feed water

by J.D. Skelly and J.H. Lester, Nafloc Ltd. (I.C.I.)

This chapter summarises the various problems that can arise in boilers and boiler feedwater systems.

SCALE

Scale formation in boilers leads to lower efficiency because of reduction in heat transfer rates. Overheating and tube failures may result, and often the high cost of chemical cleaning may be entailed. Typical constituents of scales and deposits in boilers are:

Calcium carbonate.
Calcium sulphate.
Complex silicates of magnesium, iron, sodium, calcium and aluminium.
Calcium phosphate.
Magnesium hydroxide.
Magnesium phosphate.
Iron and copper oxides.

All types of boilers may be affected, from the high pressure water-tube to the low pressure tank-type auxiliary boilers.

CORROSION

The presence of oxygen in the feed water can cause serious effects on the metals of the system. It can give rise to feed line corrosion with the formation of corrosion products of iron and copper and a simultaneous reduction in the effective thickness of the metals used to construct the feed system. The most serious aspect of corrosion in the feed line is that the iron and copper oxides thus formed are carried further through and will tend to accumulate in the boiler, even if adequate blowdown has been regularly carried out. Such oxides, particularly when deposited on generating tube surfaces,

restrict heat transfer and thus lead to the creation of dangerously high tube metal temperatures.

Any oxygen not used up in the feed line corrosion process which reaches as far as the boiler along with the feed water will not always give rise to serious problems, as the bulk of it will be expelled and

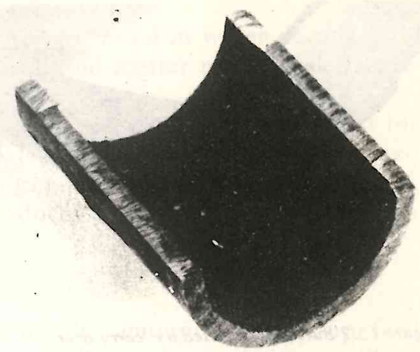


Figure 15.1 Localised pitting can lead to tube failure

carried over with the steam. However, when oxygen attack does take place in the boiler, it does not always occur in the form of general wastage but often as localised deep pitting which can readily lead to tube failure (see Figure 15.1).

'CARRY OVER' AND PRIMING

Any impurities entering with the feed water (together with any corrosion products which may have been formed in the feed system) will eventually concentrate in the boiler. Normal testing will indicate when contamination by, for example, chlorides is taking place, and the correct procedure is then to eliminate the source of the contamination.

This may not always be immediately possible, due perhaps for example to shortage of water. In such cases the impurities in the boiler water will increase and may reach a concentration where 'foaming' might occur. The effects of foam formation can be serious, in that water droplets containing suspended and dissolved solids can be carried over in the steam from the boiler, later to evaporate and deposit their entrained solids in the superheater section and, perhaps, eventually on turbine blades. 'Carry over' can be seriously accentuated by the presence of small quantities of oil (see Figure 15.2).

The term 'Carry over' is the phenomenon of water droplets being carried over with the steam into the steam system. The term 'Priming' relates to contamination of the steam by the injection of gross quantities of water, as compared to the small, though perhaps many droplets in 'Carry over'.

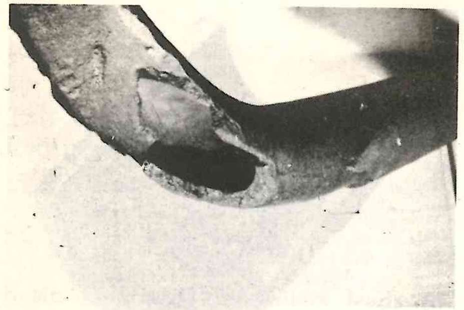


Figure 15.2 Burst tube caused by 'carry over'

To control 'carry over' and priming, good operating practice is essential, whether or not water treatment is in use. Correct chemical treatment of feed water and boiler water, carried out as recommended by the treatment suppliers, should be considered as an aid to maintaining conditions which minimise the aforementioned difficulties rather than as a separate cure.

TREATMENT OF FEED WATER

The total feed flow to any boiler normally comprises a small quantity of make-up water, to replace water lost from the system by leakage or as steam or blowdown, together with the condensate recovered from the steam.

Make-up feed

The quality of make-up feed will vary considerably depending on the class of ship and type of boilers.

Low pressure boilers as found in many motor ships may be using raw shore water, evaporated sea water or evaporated shore water as make-up feed. The quality of shore water varies considerably, the possible constituents being:

Calcium bicarbonate ($Ca(HCO_3)_2$)
Calcium carbonate ($CaCO_3$)

Calcium sulphate ($CaSO_4$)
Magnesium sulphate ($MgSO_4$)
Sodium chloride (NaCL)
Sodium sulphate (Na_2SO_4)

It is the calcium and magnesium compounds which may cause most trouble since they can lead to scale formation.

The water-soluble sodium salts often found in water do not form scale but will increase the dissolved solid matter in the boiler water leading to the need for increased blowdown.

Evaporated sea or shore water is the preferable make-up feed for any boiler because the process of evaporation will have eliminated the bulk of the scale-forming compounds and soluble salts. A correctly operated evaporator produces a water of excellent quality.

Condensate

In a well maintained feed system, the amount of make-up feed required will be minimal and the bulk of the feed water will be returned condensate.

The major problem arising with the use of condensate is the possible pick-up of copper from the copper alloys used for condenser tubes. Corrosion of aluminium brass or cupro-nickel may take place, with the result that copper corrosion products will be returned to concentrate in the boilers. This problem is aggravated by any ingress of sea water to the condensate system.

Total feed water

The total feed water going to the boiler (as mentioned previously) will comprise condensate plus any make-up feed requirements. The latter may be added to the feed water system at different points such as the condenser, atmospheric drain tank, etc. The treatment of the total feed water will vary according to the type and steam conditions of the boiler concerned.

For low pressure auxiliary tank type boilers, as found in most motor ships, treatment of feed water is not normally carried out unless specific corrosion problems arise.

In the case of double evaporation boilers, feed water treatment is necessary on the low pressure side to prevent corrosion. Such corrosion is due to carbon dioxide and oxygen, and it is necessary to carry out two processes; one to eliminate oxygen, either mechanically or chemically, or by using a combination of the two processes; the other to deal with the CO_2. It is not usual to have a system of de-aeration on the low pressure side of such boilers and oxygen removal is therefore normally carried out by chemical means alone.

Depending on the quantity of oxygen to be removed, this may be effected by the use of catalysed sodium sulphite or, alternatively, catalysed hydrazine.

Sodium sulphite will combine with oxygen to form sodium sulphate, which will result in the formation of additional dissolved salts in the boilers.

$2Na_2SO_3$	+	O_2	=	$2Na_2SO_4$
Sodium Sulphite		Oxygen		Sodium Sulphate

Hydrazine, will react chemically with oxygen to form nitrogen and water but will not increase dissolved solids.

N_2H_4	+	O_2	=	$2H_2O$	+	N_2
Hydrazine		Oxygen		Water		Nitrogen

The decision as to which oxygen scavenger to use must be taken after due consideration of the following:

(i) Excess hydrazine in the boiler is not stable and will break down to form ammonia, nitrogen and possibly hydrogen.

$3N_2H_4$ =	$4NH_3$	+ N_2		
$2N_2H_4$ =	$2NH_3$	+ N_2	+ H_2	
Hydrazine	Ammonia	Nitrogen	Hydrogen	

(ii) The use of hydrazine will aid the formation of a protective magnetite layer. Hydrazine reacts with the relatively loose non-protective film of ferric oxide Fe_2O_3 normally found on steel, reducing it to magnetite or black iron oxide. Magnetite forms a tight oxide film that prevents O_2 attack on the underlying ferrous metal.

(Magnetite is itself an O_2 absorber, as indicated by:

$4Fe_3O_4$	+	O_2	=	$6Fe_2O_3$
Magnetite		Oxygen		Ferric Oxide

Thus a large area of boiler surface coated with magnetite can 'neutralise' a lot of O_2, thus preventing O_2 from attacking the ferrous metal.)

$N2H_4$	+	$6Fe_2O_3$	=	$4Fe_3O_4$	+	N_2	+	$2H_2O$
Hydrazine		Ferric Oxide		Magnetite		Nitrogen		Water

(iii) Sodium sulphite does not readily aid such a reaction.

Carbon dioxide in the feed will combine with water to form carbonic acid. This acid can dissolve ferrous metal both in the boiler and the condensate system. The alkalinity of the boiler water will neutralise the carbon dioxide, but depending on operating conditions, the carbonate so formed will decompose liberating carbon dioxide to pass over the steam, dissolve in the condensate and be carried through with the total feed water back to the boiler.

Some method of eliminating the carbon dioxide is therefore essential. The most common method is to use the ammonia formed by the decomposition of excess hydrazine alone or in conjunction with a volatile amine, as both these chemicals, being alkaline in nature and volatile in steam, are capable of neutralising acidic gases such as carbon dioxide.

It is normal to inject the amines in conjunction with hydrazine to the feed water system, either after the de-aerator, or, if no de-aerator is present, after the hot well, in order to minimise losses which might occur through the hydrazine reacting with atmospheric oxygen in the open feed tank. The combined effect of hydrazine and amine will considerably reduce the corrosion in the feed, condensate and boiler system, and will thus prevent formation of excessive corrosion products and oxygen corrosion pitting.

TREATMENT OF FEED TO HIGH PRESSURE WATER TUBE BOILERS

The chemical treatment of the feed water for high pressure water tube boilers is essentially the same as has just been described, plus physical de-aeration to remove most of the dissolved gases as normal practice.

Hydrazine is applied as the oxygen scavenger, coupled with amines for neutralising carbon dioxide, both chemicals being applied as a dilute solution either to the cross-over pipe between the HP and LP turbines or after the de-aerator. It may be argued that one or the other point of application is preferable, but either may be used with satisfactory results. It has been suggested that an effect of adding the hydrazine to the cross-over pipe could be to reduce corrosion of the copper alloys of the condenser tubes, and while this may be so it is also a fact that a de-aerator in such a system would then only be useful as a feed water heater because physical oxygen removal would no longer be required.

The alternative injection of the chemical after the de-aerator will allow the de-aerator to perform its correct function of feed water heating and de-aerating by removing oxygen, carbon dioxide and ammonia, prior to the application of chemicals to remove any traces of oxygen still remaining.

Some ships use both systems, with the normal application being to the cross-over pipe, followed by automatic change-over to injection to the line after the de-aerator when the turbine is shut down.

In practice, it is advisable to try to eliminate the impurities present in feed water prior to entering the boiler, as internal conditioning of poor quality water in a boiler always results in some sludge and possibly scale formation.

The alternative methods of treating the feed water to eliminate scale-formers are either to evaporate the make-up feed water to produce good quality distillate, or to pass the water through a base-exchange unit which will exchange sodium ions for the scale forming calcium and magnesium ions, or to use demineralisation to remove all dissolved solids.

The choice of the systems to be used will depend on the type of boiler, its steam conditions and its ability to tolerate impurities.

TREATMENT OF BOILER WATER

As discussed previously, the feed water may or may not have been treated and, regardless of any treatment for the feed system, some chemical treatment of the boiler water is essential if subsequent corrosion and scale formation problems are to be avoided.

CORROSION IN THE BOILER

Some of the various types of corrosion that have been found in boilers are as follows:

(i) *Caustic cracking.* Caustic cracking is known to be caused by the action of strong sodium hydroxide solution on steel which is under stress. The most common occurrence of this has been in low pressure boilers having riveted seams, where the low residual alkalinity (required to reduce corrosion) present in the boiler water can

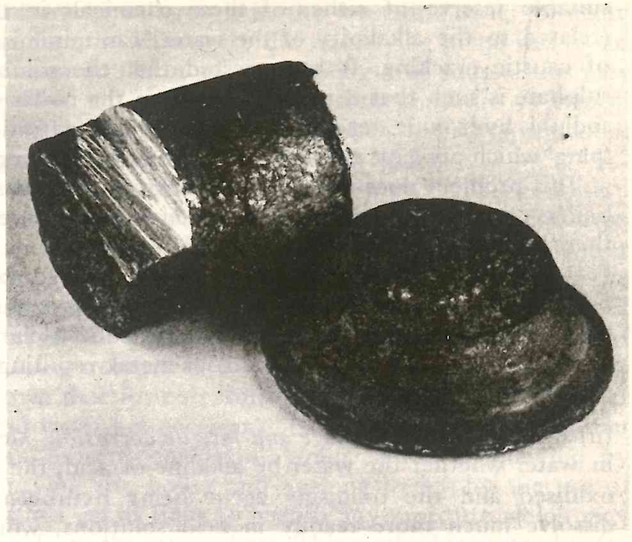


Figure 15.3 Showing how defects in a rivet head may cause it to snap

concentrate locally by evaporation of the water to atmosphere at a leak in the seam. The strong sodium hydroxide thus formed can dissolve ferrous metal within the seam, forming hairline cracks, without any outside indication. The practice, carried out by Surveyors, of hitting rivets heads with a hammer shows up such defects in that affected rivet heads snap off readily (see Figure 15.3).

A condition of caustic cracking could be disastrous in that the apparently sound boiler seam could be riddled with cracks and mechanically very much weakened.

The common method of reducing the possibility of the occurrence of caustic cracking is to use either sodium nitrate or sodium sulphate (see Figure 15.4). It has been found that the maintenance of a

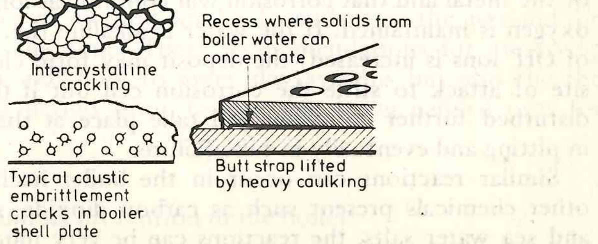


Figure 15.4 Types of caustic cracking

suitable reserve of either of these chemicals in the boiler water (related to the alkalinity of the water) can minimise the possibility of caustic cracking. It is suggested that the solubility of sodium sulphate is such that it precipitates from the boiler water before the sodium hydroxide reaches a dangerous concentration and forms a 'plug' which prevents the sodium hydroxide attacking the metal.

This problem does not normally arise in high pressure water tube boilers or in welded stressed-relieved low pressure boilers, where there are no stressed seams susceptible to leakage.

It is possible for concentrations of sodium hydroxide solutions to occur under any oxide deposits on the heat transfer surfaces of generating tubes in high pressure water tube boilers, and that this solution will also dissolve the ferrous metal, resulting in thinning and subsequent failure of tubes.

(ii) *Pitting, general wastage and fatigue corrosion.* Metals can dissolve in water whether the water be alkaline or acid, the metal becoming oxidised and the oxidising agent being hydrogen ion. Iron will dissolve much more readily in acid solutions, which have a high hydrogen ion concentration. The corrosion mechanism may be represented simply by the equations:

$$Fe \xrightarrow{\text{dissolves}} Fe^{++} + 2 \text{ electrons (at the anode)}$$

$$2 \text{ electrons} + 2H^{+} \longrightarrow H_2 \text{ gas} \quad \text{(at the cathode)}$$

In the presence of oxygen the reaction at the cathode is:

$$O_2 + 2H_2O + 4 \text{ electrons} \longrightarrow 4OH^{-}$$

This indicates that iron corroding in water containing dissolved oxygen (such as condensate) will precipitate the insoluble hydroxide of the metal and that corrosion will continue as long as the supply of oxygen is maintained. If the water is alkaline (i.e. the concentration of OH^- ions is increased) the deposit may form close enough to the site of attack to stifle the corrosion cell but if the deposit is then disturbed further corrosion will take place at that point, resulting in pitting and eventually in tube failure.

Similar reactions can occur in the boiler itself, but due to the other chemicals present such as carbon dioxide, sodium hydroxide and sea water salts, the reactions can be very much more complex.

Corrosion fatigue will be found when a metal in a corrosive medium is subjected to fluctuating or alternating stresses.

Flexing of the metal will result in the loosening of its normally protective oxide film, in which case the underlying metal will try to further oxidise. Continuation of the flexing will loosen the new layer of oxide film and the process will thus continue. A typical example is the necking of combustion chamber side stays in Scotch boilers due to this flexing and oxide reforming action.

Provided water in the boiler is always kept in an alkaline condition corrosion is not a serious problem in low pressure boilers, even without oxygen elimination by mechanical or chemical means, due to the protective action of the sodium hydroxide in reinforcing the formation of the iron oxide film in the system. A major cause of oxygen corrosion in low pressure boilers is inadequate protection of the idle boiler during storage.

It is well known that for corrosion to take place in an idle boiler both oxygen and water are necessary. To eliminate one or the other should therefore prevent corrosion. Water can be eliminated by completely emptying the boiler and keeping it dry by the use of either lime or silica gel in trays to absorb any moisture which may enter the system from the atmosphere. This method is preferable for long-term storage.

The alternative is to remove the oxygen by chemical means. This method is more suitable for the in-service boiler where steam production may be required at short notice. The procedure to follow is to add calculated quantities of either catalysed sodium sulphite or hydrazine to the boiler immediately prior to shutdown to allow adequate time for chemical reaction to take place, and to leave adequate reserves of the oxygen scavenger in the boiler water. The boiler is then filled completely so that with the excess oxygen scavenger present, oxygen cannot exist and therefore corrosion due to the oxygen cannot take place. The normal boiler water alkalinity must be maintained.

The additional benefit of this method of idle boiler preservation is that prior to flashing the boiler up, some water must be removed from the boiler, which reduces the levels of suspended and dissolved matter. The choice of method will be dependent on the user and the circumstances at the time. These recommendations for preserving the boilers apply not only to every day systems but also the the precommissioning period prior to the ship being handed over for normal service.

Scale formation and its prevention in the boiler

The type of feed water used, coupled with the possible pick-up of contamination from condensers, or the necessity to use poor quality make-up feed derived from a shore source, can result in scale formation in the boiler itself.

The salts of calcium and magnesium are the major source of scale problems. It is possible to eliminate these contaminants from the make-up feed water before entry into the system, but the alternative is to use chemicals to modify the scale-formers so that they are precipitated as a relatively non-adherent sludge, which can be blown out of the boiler before any scale forms. It should be stressed that the use of chemicals for treatment in the boiler must be the minimal amount required to prevent problems.

If very impure water is in use or condenser contamination occurs regularly, then the addition of excessive quantities of chemical can accentuate the problem of sludge and carryover. The recommendations of the chemical supplier must be followed closely to ensure that excessive chemical additions are not made and excessive sludge formation does not occur. The common chemicals used to prevent formation of scale are:

(i) *Sodium phosphate.* This is used for precipitating the calcium (lime) salts from solution as calcium phosphate sludge. The important types are:

Di-sodium phosphate Na_2HPO_4
Tri-sodium phosphate Na_3PO_4

(ii) *Sodium hydroxide.* This is also known as caustic soda (NaOH). It is used to precipitate magnesium salts from solution as magnesium hydroxide sludge. Sodium carbonate, or soda ash, (Na_2CO_3) can be used as an alternative source of sodium hydroxide because it is partly converted to sodium hydroxide within the boiler.

These chemicals are normally added as dilute solutions, fed to the boiler either by means of a proportioning pump, or by injection from a pressure pot direct into the boiler system. With either method, the amount of chemical used must be minimal and for high pressure water tube boilers, the solution must be injected very slowly over a long period to prevent foaming and carry over caused by a sudden increase in boiler water dissolved solids. Small amounts of chemical added regularly are much preferable to large infrequent doses.

The use of sodium phosphate and sodium hydroxide to cause precipitation of scale-formers is normal for all classes of boilers, but practice has shown that the excessive use of phosphate, without the necessary blow-down for sludge removal, can produce troublesome deposits on a par with scale formation. Therefore, there are two problems one to prevent scale forming, and the other to minimise sludge. The modern tendency is to use organic polyelectrolytes for the modification of scale-forming constituents, particularly in the case of low pressure boilers.

Polymer treatment

A polymer is a giant molecule formed by the stringing together of a large number of small simple molecules, often of the same kind. The simple molecules are called monomers.

Polyelectrolytes are giant molecules of either natural or synthetic origin, made up of monomers that are ionic in nature, forming ions in solution.

Polyacrylates are ionic polymers of acrylic acid.

Polyamides are polymers made up of monomers called amides, a specific chemical group.

In water treatment specific water soluble polymers are used for coagulation, dispersion and to prevent scale and sludge formation. The action of certain polymers is to prevent scale formation by magnesium and calcium salts but without forming an adherent sludge. One of the most common polymers used in this treatment is a polyacrylate, used in conjunction with either sodium hydroxide or sodium hydroxide/sodium sulphate.

The polymer treatment prevents scale deposition and minimises sludge formation. It may also loosen any scale already present in a boiler. It is therefore preferable to introduce such a treatment to clean boilers only, otherwise troubles might be encountered through the exposure of leakages at places where scale has been loosened, i.e. tube expansions, etc.

Experience to date is proving that this modern treatment is in most ways superior to the old alkali and phosphate treatment for the majority of auxiliary boilers.

Co-ordinated and congruent phosphate treatments

For many years it has been known that sodium hydroxide (caustic soda), under certain conditions, can dissolve boiler metal. It was suggested that the elimination of free caustic soda from boiler water might prevent this problem and as a result, phosphate combinations were used to give a boiler water containing no free sodium hydroxide.

The original method was the co-ordinated phosphate treatment, and this relied on the fact that sodium hydroxide and phosphate could combine together to form tri-sodium phosphate (Na_3PO_4). This, however, partially hydrolyses in water to form some free caustic soda coupled with di-sodium hydrogen phosphate ($NaHPO_4$). Although re-combination of the di-sodium hydrogen phosphate with the caustic soda can take place, it was found that there was always some free caustic soda left, and this therefore defeated the main object of using the treatment.

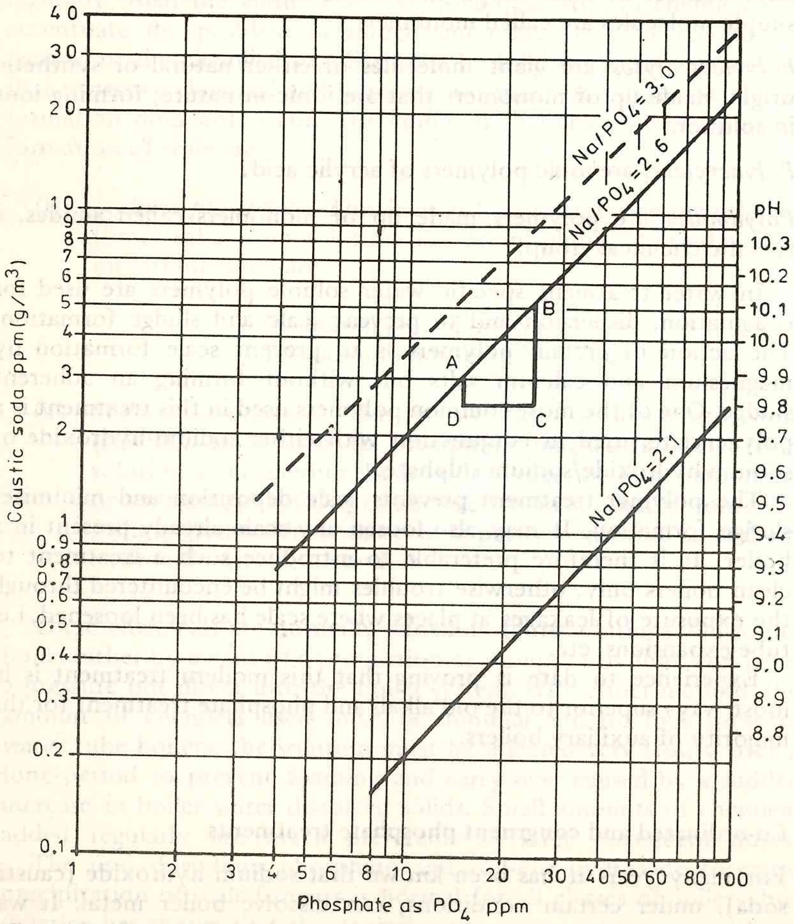


Figure 15.5 Control diagram

A modification called congruent phosphate treatment was therefore introduced. This was based on the use of sodium hydroxide (caustic soda) and sodium phosphate to produce a sodium phosphate with a ratio of sodium Na^+ ion to phosphate $PO_4\equiv$ ion not exceeding 2.6 : 1, instead of 3.1 as in Na_3PO_4.

This resulted in a treatment whereby the formation of free sodium hydroxide (caustic soda) was avoided. The diagram used for control of this treatment is shown in Figure 15.5. The correctly treated boiler water should lie within the area surrounded by A, B, C, D, on the graph thus ensuring that the correct ratio of sodium hydroxide to sodium phosphate is always maintained.

The major problems with this type of treatment relate to the control testing, which must be very accurate, and the possibly serious effect of salt water contamination.

Because of the very low level of alkalinity held in the boiler water, any contamination by sea water will quickly eliminate it and lead to formation of acidic salts from magnesium chloride, with resulting disastrous effects. This can be corrected by using the recommended testing procedures which should in theory be continuous, to ensure that any contamination taking place will be quickly discovered and eliminated. The alternative, testing once every twenty-four hours, can suffice providing the salinometers in the system used for monitoring contamination are in good order and are checked regularly or, better still, are automated to show when trace contamination occurs.

For congruent phosphate treatment monitoring of the pH by a continuous recording meter is strongly recommended; but at the least regular testing with an accurate portable pH meter is necessary. The additional tests required to ensure maintenance of correct conditions are accurate determination of the level of phosphate and of the alkalinities to phenolphthalein and methyl orange. Assuming that these tests can be carried out accurately and the system kept free from contamination, then the congruent phosphate method can be confidently recommended.

If regular accurate testing cannot be ensured and if there is the possibility of contamination, then the congruent phosphate treatment may result in more serious problems than those the treatment was designed to eliminate.

Treatment using amines

Amines as used in water treatment may be classed into two distinct types:

(i) *Neutralising Amines.* These have a similar action to ammonia, NH_3. They are steam-volatile, and are used to neutralise CO_2 in steam, condensate and feed systems. The common amines used are cyclohexylamine and morpholine, or combinations of these.

(ii) *Filming Amines.* These do show a neutralising tendency, but their essential function is to protect by forming a molecular water-repellent protective film on metal surfaces and thus prevent corrosion. Octadecylamine is a commonly used filming amine.

Antifoams

An increase in the levels of dissolved and suspended solids in the boiler water will increase the chances of foaming and 'carry over' in both low and high pressure boilers. If conditions are such that reduction in levels of contaminants cannot conveniently be effected, then 'antifoams' can be of assistance.

Antifoams work by reducing the stability of water films around steam bubbles, thus causing the bubbles to collapse more readily. A common type of antifoam is based on organic compounds of high molecular weight called polyamides.

Some water treatment compounds are formulated to contain small quantities of antifoam, but in cases of severe contamination regular separate additions of straight antifoam are recommended to ensure that sufficient reserves are maintained. Inadequate reserve may allow sudden and severe foaming to occur.

A summary of possible chemical treatments is as follows:

Sodium phosphates	To prevent scale.
Sodium hydroxide	To prevent scale, to minimise corrosion.
Polymers	To prevent scale, to condition sludge.
Tannins/starch	To condition sludge.
Hydrazine/sodium sulphite	To remove oxygen.
Antifoam	To prevent carry over.
Neutralising amines	To neutralise CO_2.
Filming amines	To protect steam/condensate lines.

Blowdown

Adequate and regular blowdown from all boilers is essential, not only to reduce the level of dissolved solids, but also to get rid of the sludge formed by the chemical treatments reacting with contaminants, and any iron and copper oxides entering the boiler from corrosion in the feed and condensate systems. (These oxides are often not detected, as the testing procedure for them is somewhat complicated and not suitable for use as a routine check).

Auxiliary boilers in motor ships are often regarded as 'kettles'; no corrective water treatment for scale prevention or blowdown for sludge ejection being considered necessary. This of course is a fallacy, and the adoption of the procedures recommended, together with occasional complete emptying and rinsing out, will pay dividends in the long run.

Sampling

The importance of correct sampling procedures cannot be overstressed. It is strongly recommended that suitable boiler water sample coolers are provided for both low and high pressure boilers, so that truly representative samples can be easily and safely obtained. Such a sampling system can be used to good effect as a method of continuous blowdown when the boiler is on full load.

CONTROL OF TREATMENTS

The application of chemical treatments must be based on regular and accurate testing of the boiler water. Obviously, the use of the efficient sampling system as already recommended is a necessity to ensure that correct samples are obtained. Testing frequency for all classes of boilers should be daily, with increased frequency when corrective measures have to be taken because the required conditions cannot be maintained or when contamination has been found.

The control must be based on the recommended boiler water characteristics for each particular class of boiler, and the figures stated in BS 1170 : 1968 are an indication of the limits recommended. They are given in Table 15.1.

It should be noted that this table does not include the use of the more modern polyacrylate treatments. The control of the treatment using polyacrylate is normally based on alkali and chloride testing only. Hardness and phosphate testing is not necessary with this modern treatment for low pressure boilers. The recommendations for 'alkalinity to phenolphthalein' will always be of the order 100 to 300 ppm with chloride maximum dependent on the class of boiler, for example 150 ppm for low pressure water tube, and 750 ppm for

Table 15.1 Watertube boilers, recommended boiler water characteristics

Boiler pressure	*EDTA Hardness max.* ppm $CaCO_3$	*Alkalinity to Phenolphthalein* ppm, $CaCO_3$	*Chlorides max.* ppm $CaCO_3$	*Phosphate* ppm, $CaCO_3$	*Dissolved solids* ppm	*Sulphite or hydrazine excess* ppm Na_2SO_3	*Sulphite or hydrazine excess* ppm N_2H_4	*Silica max.* ppm SiO_2
0–15 bar	Nil	50–300	300	30–70	1500	50–100	0.1–0.3	–
15–30 bar	Nil	150–300	150	30–70	1000	50–100	0.1–0.3	–
30–40 bar	Nil	100–150	100	20–50	500	30–50	0.1–0.3	–
40–60 bar	Nil	50–100	50	20–50	500		0.1–0.3	5
60–80 bar	Nil	50 80	30	15–30	300		0.1–0.3	3

1. To convert from chloride as ppm $CaCO_3$ to ppm NaCl, multiply by 1.17.
2. To convert from chloride as ppm $CaCO_3$ to ppm Cl, multiply by 0.71.
3. To convert from alkalinity as ppm $CaCO_3$ to ppm NaOH, multiply by 0.8.
4. To convert from phosphate as ppm PO_4 to ppm P_2O_5, multiply by 0.75.

low pressure fire tube boilers. Full details of treatment and testing procedures are given in the British Standard.

The feed water characteristics for the different systems are given in Table 15.2. Again it must be noted that these are recommended characteristics but in many cases the full range of tests is not always necessary for satisfactory control of treatment.

Table 15.2 Water tube boilers, recommended feed water characteristics

Boiler pressure	*Chloride max.* ppm, $CaCO_3$	*pH*	*Dissolved oxygen max.* ml/litre	*Copper max.* ppm Cu.	*Iron max.* ppm Fe
0–15 bar	5				
15–30 bar	5	8.5–9.5	0.04	–	–
30–40 bar	1.0	8.5–9.5	0.02	–	–
40–60 bar	1.0	8.5–9.5	0.01	0.01	0.01
60–80 bar	1.0	8.5–9.5	0.007	0.005	0.01

1. To convert from chloride as ppm $CaCo_3$ to ppm NaCl, multiply by 1.17.
2. To convert from chloride as ppm $CaCO_3$ to ppm Cl, multiply by 0.71.
3. To convert from oxygen from ml/litre O_2 to ppm (weight for weight) O_2, multiply by 1.5

Note. A change in pH reading of only 1 unit does not sound significant but it represents a change in ion concentration by a factor of 10 (because the scale is logarithmic). Thus, a change of pH from say 7 up to 10 – a numerical difference of only 3 – is equivalent to an ionic concentration change of 10 × 10 × 10.

The actual tests which may be required and with which engineers should be familiar are as follows:

Hardness in boiler and feed water by either EDTA or soap solution test.
Alkalinity to phenolphthalein.
Alkalinity to methyl orange.
Chlorides.
Phosphates.
Dissolved solids.
Oxygen scavenger/sodium sulphite.
Oxygen scavenger/hydrazine.
Silica.
Conductivity.

The use of the shipboard test for determinations of silica does not always give consistent results and (as for iron and copper determinations) it is recommended that the boiler water supplier be consulted and requested to carry out shore side analyses for these impurities.

DESCRIPTION OF pH

All aqueous solutions contain hydrogen ions H^+, and hydroxyl ions OH^-. Neutral solutions such as water contain equal concentrations of these ions.

$$H^+ + OH^- = H_2O.$$

If more H^+ ions than OH^- ions are present, the solution is said to be *acid.* If more OH^- ion than H^+ ions are present, the solution is said to be *alkaline.* The greater the excess of either ion, the stronger will be the acidity or alkalinity.

The measure of the intensity of acidity or alkalinity is given by the pH scale reading.

0	7	14
Strongly Acid	Neutral	Strongly Alkaline

The correct definition is:

$$pH = \log_{10} \left(\frac{1}{[H^+]} \right)$$

where $[H^+]$ means 'the concentration of hydrogen ions in grams per litre'.

Measurement is by use of indicators giving a colour corresponding to the particular pH of the solution under test or by use of a pH meter.

Determination of the alkalinity to phenolphthalein measures the amount rather than the strength and is a more common and useful way of measuring the alkalinity of the boiler water.

INTERPRETATION OF TEST RESULTS AND SUGGESTED ACTION

Boiler water test readings can give considerable information about what is happening in the whole of the feed, condensate and boiler water systems, but the results must be accurate and the appropriate steps must be taken as suggested below.

Boiler water chloride

If the tests show sudden increases in chloride or a faster rate of increase in chlorides as compared to normal, then the following actions may be necessary:

(i) Increase the boiler blowdown frequency until the dissolved solids and therefore chloride levels are below the advised maximum.

(ii) If the chloride is well above the advised maximum the quantity and the frequency of blowdown must be increased to bring the level below the advised maximum.

(iii) If the chloride level is excessive, for example three times the maximum advised figure quoted by the water treatment suppliers, then the level of dissolved solids will be unacceptably high and it is advised that either the boiler be shut down or, at the very least, the steam offtake from the affected boiler minimised, whilst keeping its pressure normal, thereby lessening the possibility of excessive carryover.

Regardless of the procedures taken to eliminate the contaminants present in the boiler water it is vital that the source of the contamination be found and eliminated as soon as possible, because whilst the contaminants are still entering the system the problems of freshening the boiler are being continually worsened. In a two-boiler system it is perhaps preferable to shut down one boiler completely (thus allowing all the contaminants to concentrate in the other) and then, when the source of the contamination has been found and eliminated, to bring the other boiler back into service under normal conditions, whilst the contaminated one is emptied, flushed and refilled as normal.

It is preferable to use fresh water to rinse out the contaminant from a contaminated boiler, prior to filling from the (normally limited) supply of distilled water.

(iv) If the chloride readings change suddenly but all other parameters remain constant, this suggests that test reagents are perhaps not correct and check-testing (of the silver nitrate in particular) is advisable; (e.g. Between 26 and 28 ml of silver nitrate solution of 0.02 N strength should be required to titrate one ml of sea water using potassium chromate indicator, to the correct faint brown end point).

This would indicate a correct solution; any major deviation from 26 to 28 ml would indicate incorrect silver nitrate strength. It is suggested that whenever a new supply of silver nitrate is brought into use a boiler water sample should be divided and used to check the old and the new silver nitrate reagent against the same water sample. Similar results would indicate similar strengths for the old and new reagents.

Boiler water alkalinities

Alkalinity in a boiler may increase for several reasons and the following are possibilities:

(i) Addition of chemical treatment to the boiler.
(ii) Wrong strength reagent for the alkalinity test.
(iii) Alkali from another boiler in the system with perhaps a leaking desuperheater allowing the alkaline water from that boiler to leak back to the feed system and thus back to the other boilers.
(iv) Make-up feed from cement-washed storage tanks, or
(v) Use of shore side water containing alkali.

Some decrease in alkalinity may be observed if:

(vi) Contamination has occurred with the resulting use of some of the alkali to precipitate magnesium; a reduction in phosphate and corresponding increase in dissolved solids and chloride levels should also occur at the same time.
(vii) Water loss from the boiler has occurred either by blowing down or at a sampling point, resulting in a reduction in the level of all the boiler water constituents and not just the alkali.
(viii) Reagent being of incorrect strength.

As in the case of silver nitrate, sulphuric acid can also be tested against sea water. 11.5 to 12.0 ml of sulphuric acid of 0.02 N strength titrating a sample of 100 ml of sea water, using methyl orange indicator, will give the orange/pink end point. Any additional or reduced quantity of acid required to give this correct end point will indicate incorrect strength of reagent.

Dissolved solids

The determination of the dissolved solids level in a boiler water sample is possibly the quickest method of monitoring the increasing or decreasing level of contamination.

Providing the full range of chemical tests are still carried out at regular intervals, and the importance of maintaining some alkali reserve in the boiler water is ensured, then the testing for conductivity or dissolved solids in the boiler water may be used as a quick means of monitoring changes in the system. However, this would normally be for emergency procedures only.

PRE-COMMISSION CLEANING

It is essential that the heating surfaces in new boilers should be free from mill scale and other debris. Pre-commission chemical cleaning is the recommended process for removal of these impurities.

The advice and services of professional chemical cleaning companies should be obtained prior to carrying out the process. A normal precommission clean is as follows:

(a) Alkaline degrease to remove oil and grease residues.
(b) A copper removal process designed to ensure that deposition of any copper present is avoided.
(c) Acid cleaning using either citric or hydrochloric acids to eliminate mill scale and general rust.
(d) Rinse programme using weak citric acid to avoid reprecipitation of the iron oxide. Alternatively a further copper removal process may be needed.
(e) Neutralisation to eliminate excess acid.
(f) Thorough flushing – this is *essential* to eliminate all suspended and dissolved contaminants.
(g) Passivation to obtain a protective magnetite layer on all boiler metal surfaces.

A similar process may be carried out at intervals of say four to five years to eliminate the iron and copper oxides which may have accumulated in the boilers from corrosion of the feed and condensate system.

FUTURE WATER TREATMENT

The continued improvements in boiler feed water and condensate systems, coupled with the higher rating of water tube boilers, will mean increasingly stringent control of the water treatment parameters, and a reduction in the permissible level of chemicals allowable for treatment purposes can be expected.

Alternative treatments are in use in high pressure land boilers using chemicals based on sequestrants of the EDTA (*E*thylene *D*iamine *T*etra *A*cetic *A*cid) type. Monitoring for oxygen elimination and contamination is however more difficult with such treatments than with the congruent phosphate system.

EDTA compound is usually used in the form of its soluble, alkaline, tetra-sodium salt. Two important uses should be noted:

(a) Its use in the determination of the 'hardness' of water using a suitable indicator such as Eriochrome Black T, and
(b) Its use as a scale preventative for water treatment.

The two uses rely on the ability of EDTA to exchange sodium ions for calcium and magnesium scale forming ions and yet to remain water soluble. i.e. there is no precipitation as with conventional phosphate treatment. EDTA will aid scale removal because of its strong tendency to combine with calcium and magnesium ions.

In the future there is the possibility of completely automatic treatment and testing. At the present time, however, this is not likely to be used to any great extent because of the initial installation costs and maintenance requirements.

16 Steam generation and boiler operation

For the past thirty years the vast majority of ships have been propelled by machinery designed to operate by burning oil fuel. Currently there are very few ships still afloat burning coal in their boilers and even these are confined to harbour craft and the like.

Oil fuel is much more convenient to handle afloat than is coal. It presents fewer problems of storage and, in addition, has a higher heating value for a given volume than coal. However, as is well known, the price of oil has escalated rapidly during recent years and this has generated a renewed interest in the use of coal as an alternative fuel not only for economic reasons but also from political considerations.

COAL

Woody fibres under pressure for very many years are slowly converted into peat, then lignite and subsequently into coal. During this time the hydrogen and oxygen content is considerably lowered:

	% Carbon	*% Hydrogen*	*% Oxygen*
Wood	50	6	44
Peat	60.5	6	33.5
Lignite	66.5	5.5	28
Anthracite	91	4.3	4.7

Combustion of coal

When coal, which consists of carbon, hydrogen, oxygen, volatile matter, sulphur and ash, is burnt, chemical reactions and the evolution of heat take place, and it is well to have some knowledge of the nature of these reactions. The heat-producing constituents are the carbon, hydrogen and sulphur. At the beginning of combustion of coal, gases are evolved, containing hydrogen and carbon; these are known as hydro-carbons. These compounds, not including the moisture which is driven off, comprise the volatile matter in the coal, and are heavy, tarry vapours which, in the main, can be burnt, but which, if not ignited, form sooty deposits and dense smoke.

After the volatile content of the coal has been emitted, the fixed carbon content, or coke, becomes oxidized, forming carbon monoxide (CO), and this, provided there is sufficient oxygen or air present, is then further oxidized to carbon dioxide (CO_2). All the oxygen supplied for the oxidation process is normally taken from the air, and as air is a mechanical mixture of oxygen and nitrogen, in the proportions by volume of 20.9–79.1, a large volume of nitrogen, an inert gas, remains after combustion. This nitrogen absorbs some of the heat evolved during combustion and carries it away to the uptake, and thus has rather an adverse effect from the efficiency point of view.

During combustion the hydrogen content of the coal combines with oxygen, forming water in the form of steam, and this steam with its latent heat is also lost in the flue gases. The sulphur content has little effect on the heating value of coal, although its presence is usually noted in fuel analysis. In combination with oxygen it forms sulphur dioxide, and this, with the steam from the hydrogen content, can form a corrosive mixture which is extremely undesirable in boilers. When perfect combustion of coal is taking place, the exact amount of oxygen must be supplied, and must be wholly consumed – this means that all the carbon is converted to carbon dioxide (CO_2), the hydrogen to steam (H_2O) and the sulphur to sulphur dioxide (SO_2) – without excess air.

Air supply

Complete combustion must not be confused with perfect combustion – complete combustion can readily be obtained by supplying excess air, but when this is done, it must not be forgotten that the greater the amount of excess air admitted into the furnace, the greater will be the amount of nitrogen present. As has already been stated, this nitrogen is an inert gas and absorbs heat, carrying it away to the uptake. It will be readily understood, therefore, that if perfect combustion and maximum efficiency are to be obtained, a close control on the air supply must be maintained.

Excess air or, in other words, excess oxygen and nitrogen, are the chief sources of heat loss in combustion. On the other hand, when insufficient air is supplied for complete combustion, the loss due to the presence of the inert nitrogen is small compared to that resulting from incomplete combustion.

In practice, excess air is necessary in the case of both solid and liquid fuels; more so in the case of the former, as the fuel is not so finely divided. The excess air is the mechanical means of obtaining more intimate contact between the oxygen of the air and the fuel. It will be readily understood that, in a coal fired furnace, intimate contact is much more difficult to obtain than in the case of an oil-fired water tube boiler.

Combustion efficiency is the relationship between the amount of air actually supplied for combustion and the amount theoretically required. The amount of excess air required for the efficient combustion of coal is a very variable quantity as, with hand firing, the amount and thickness of fuel, also the condition of the firebars, etc., vary from one fire to another. Oil, on the other hand, finely atomized and intimately mixed with air, can be burnt under more stable conditions, the excess air required being about 10–30%.

Carbon dioxide percentage

The theoretical CO_2 percentage for perfect combustion of coal is 18.6% and oil 15.65%, but for reasons already stated, it is not practicable to obtain these figures, as excess air is always required to burn the fuels efficiently. A low CO_2 percentage does not necessarily mean that the air supply is insufficient, as the same result can be obtained when the air supply is excessive.

From the above it will be apparent that for efficient combustion, a flue gas analysis should show the highest possible carbon dioxide or CO_2 percentage, and that any adjustments to the operating conditions which result in a higher percentage are steps in the right direction. A clear, smokeless funnel is often accepted as an indication of good combustion – this can be correct; on the other hand, the good combustion may be accompanied by 200 or 300% excess air.

Calorific value of fuels

The heating or calorific values of fuels, whether solid or liquid, are specified in mega joules per kilogram, one joule being 0.2388 calories and one calorie being the amount of heat required to raise the temperature of 1 gram of water 1°C.

		MJ/kg (*approx*)
Coals:	Bituminous (Scotch or Lancashire)	30.2
	Anthracite (Welsh)	32.5
	Average coal	29.1
Oil:	Mexican	43.0
	Shale	44.2
	Burma	43.7
	Texas	42.8

It has already been stated that the heat-producing constituents of coal are carbon, hydrogen and sulphur; in oil the same statement applies, the proportions of these constituents being as follows:

	Coal (*per cent*)	*Oil* (*per cent*)
Carbon	80–85	84–87
Hydrogen	3– 4	11–14
Sulphur	0.5– 2	0.5– 1

It will be noted that the percentage of heat-producing constituents is higher in the case of oil than in that of coal and, if the actual heating values of each constituent are substituted, the total calorific values of coal and oil can be compared thus:

Combustible substance	*Heating value MJ/kg*	
Carbon to CO_2	34	
Hydrogen to H_2O	120.5	(assuming water vapour is not allowed to condense)
Sulphur to SO_2	9.3	

If, therefore, 1 kg of coal contains 80 per cent carbon, 3% hydrogen and 0.5% sulphur, the calorific value will be:

$$(0.8 \times 34) + (0.03 \times 120.5) + (0.005 \times 9.3)$$
$$= 27.2 + 3.615 + 0.0465 = 30.86 \text{ MJ/kg}$$

Similarly, if 1 kg of fuel oil contains 84 per cent carbon, 11 per cent hydrogen and 0.5% sulphur, the calorific value will be:

$$(0.84 \times 34) + (0.11 \times 120.5) + (0.005 \times 9.3)$$
$$= 28.5 + 13.25 + 0.046$$
$$= 41.79 \text{ MJ/kg}$$

The above represents the approximate calorific value as found by analysis. In the laboratory this value is determined by burning a known quantity of the fuel in a steel bomb, in the presence of oxygen. The heat generated is absorbed by a known quantity of water surrounding the bomb, and from the temperature rise of the water, the amount of heat generated can be calculated.

Coal firing of Scotch boilers

A good fireman does not take long to find out the best way to obtain satisfactory results from any one class of coal, and it is not proposed to deal at great length with hand firing as this '*modus operandi*' is unlikely to be encountered by today's practising marine engineer.

In general some of the points to be observed are:

1. Keep firebars and bearers in good condition, especially side bars, to prevent air passing up the furnace sides.
2. Keep bridges in good order so that no air can pass through them from the ash pits into the combustion chambers.
3. When steaming see that the fires are kept level and of an even thickness. Unless this is done, there will be bright hollows with too much air and dark mounds with insufficient air.
4. Keep ash pits clear, and when they have a dull appearance, slice the fires to lift the clinker obstructing the bars.
5. In forced-draught installations see that all furnace front air valves are in efficient working condition – i.e., the top valves which supply air for completing the combustion of gases produced in the fuel bed, and the side valves controlling the air supply beneath the firebars.
6. Keep furnace doors shut, except when firing, in order that the passage of cold air through the furnaces, with consequent mechanical straining of the boiler through sudden cooling, is prevented as far as possible.
7. Remember that soot is an efficient insulating medium, and therefore clean the heating surfaces of boiler, superheater and air-heater at every opportunity.
8. Avoid the use of excess air.

Mechanical firing of coal

In the 1930s many coal-burning vessels were equipped with mechanical stokers.

The advantages claimed for the mechanical stoker over hand firing were:

Saving in fuel.
Steadier steam supply.
Reduction in stokehold personnel.
Less mechanical straining of boiler due to more constant thermal conditions.
Increased evaporative capacity for the boiler.

Stokers for Scotch boilers

A type of stoker which was fitted to Scotch boilers employed a mechanically-operated shovel, fed from a hopper on the smoke-box front; this shovel threw coal on to each zone of the furnace in rotation. Preheated air for combustion was supplied to the furnace through hollow, trough-shaped firebars, these bars being made to reciprocate and propel the fire-bed slowly forward towards the combustion-chamber end of the bars.

The speed of travel of the fire-bed was such that, by the time the fuel reached the far end of the bars, combustion was complete and the ash fell over into the ash-pit, to be raked out, through a swing door, at regular intervals by firemen.

Stokers for water tube boilers

In the case of water tube boilers, several designs of mechanical stoker have been used with satisfactory results in marine installations. Naturally, the marine engineer waited until a design had been proved ashore before installing it aboard ship.

The two designs of stoker most usually employed in conjunction with water tube boilers were the Erith-Roe and Taylor. In both of these designs the coal used had to be small and was fed from hoppers into several rams, which situated along the furnace front and driven from a crankshaft, forced the fuel into the bottom of the fire-bed, the propagation of combustion being downwards. The fire-bed was propelled forward by reciprocating bars and, on reaching the far end of the inclined furnace, the accumulated ash dropped periodically from a hinged plate into a pit, from where it could be withdrawn without admitting air to the furnace. Combustion air suitably preheated was admitted through the furnace bed, a secondary supply also being provided above the fire. The amount of fuel burnt was

controlled by admitting more or less combustion air, and not simply by increasing the stoker speed.

These stokers were known as 'underfed' types, and as such had an advantage, inasmuch as the fire-bed was always radiant, never being damped on the surface by unburnt fuel.

Currently there is a project receiving active consideration for the construction of two 75 000 dwt coal fired, steam propelled bulk carriers intended to operate on relatively short hauls of about seven days. This allows an arrangement whereby only a minimum amount of what would normally have been valuable cargo space, being re-allocated to bunker space. The design features a mechanical grate fed by rotary spreaders consuming lump rather than pulverised coal. One of the problems yet to be overcome with this type of installation is that of obtaining the equivalent of a high turn down ratio when the engines are manoeuvring. This could, of course, be achieved by arranging for alternative firing using oil fuel. In spite of this disadvantage, there are strong indications that such a project would prove to be sufficiently economic to make it a practical solution in the very near future.

Other methods of using coal in modern marine water tube boilers are under consideration. The use of a fluidised bed — a turbulent bed of inert particles such as coal ash onto which the solid coal is fed — has the advantage of achieving maximum heat transfer from the fuel whilst maintaining minimum possible metal temperatures in the heating surfaces and on the bed structure. In this system the inert particles forming the bed are kept turbulent by blowing an evenly distributed stream of air up through the bed thus maintaining the temperature of the bed sufficiently low so as to avoid the particles sintering. Water tubes forming part of the generating bank of the boiler are immersed in this fluidised bed.

The use of pulverised coal has also been proposed, but here the initial cost of the pulverising mill and the additional space required for this equipment together with the inherent dangers associated with pulverising process, and the difficulty of storing all but the smallest quantities of this form of fuel, seem to put it at a disadvantage.

More encouraging, perhaps, are the efforts being made to burn coal and coke slurries efficiently. Such liquid fuels can be processed at plants ashore and handled and burnt on board ship in the same manner as oil. These processed fuels are, as yet, only available in limited quantites at a very few depots in the world, and future development depends on these fuels being made available on a world-wide basis at economic cost.

OIL BURNING

A normal oil-burning installation consists essentially of settling tanks, two fuel-oil units comprising suction filter, pressure pump with attached air vessel, discharge filter and heater (see Figure 16.1). Each fuel-oil unit is capable of supplying fuel for generating the steam required for all purposes at sea. The second unit is maintained

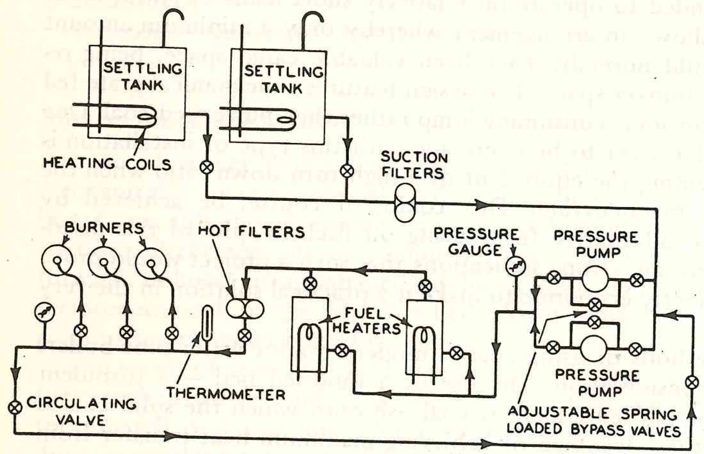


Figure 16.1 Basic arrangement of an oil burning installation

as a stand-by. The hot fuel from these units is delivered to the boiler fronts through a pressure line, which is fitted with a circulating valve and return line to the suction side of the fuel units.

An emergency pump and paraffin or electric heater are also fitted for lighting up when no steam is available.

Settling tanks

It is usual to fit two settling tanks, each having a capacity sufficient for about twelve hours steaming. Any water in the oil is allowed to settle to the bottom of these tanks, to be drawn off at regular intervals.

The tanks are fitted with level indicators and also steam-heating coils for use in cold weather, when the oil is very viscous, and to expedite the separation of any water present. The drains from these steam-heating coils are usually led back to an observation tank, so that it can be readily seen whether the condensate is free from oil, thus ensuring that the coils are not leaking. The tanks are used

alternately, the one not in use being kept full ready for the change-over.

Filters, heaters and pressure line

From the settling tanks the oil is drawn by the pressure pump through a suction filter and then forced through the heater and discharge filter to the pressure line for the burners. An adjustable, spring-loaded relief valve is fitted between the discharge and suction ends of the pressure pump, so limiting the discharge to any set pressure. The hot filters are usually of a type which can be cleaned by turning an external handle, thus avoiding any danger from hot oil escaping when cartridges are removed for cleaning.

The temperature to which the fuel is heated at the heaters, for efficient atomisation, is normally between 90°C and 130°C, but the temperature at the heater is not a criterion, as it must not be forgotten that the atomising end of the burner, being practically in the furnace, also heats the oil. The amount of heating at this point depends on the steaming conditions.

It is essential that the oil should not be heated more than is necessary to reduce the viscosity sufficiently to ensure efficient atomisation, as, if the temperature is raised too high, there is a danger of the oil 'cracking' and depositing asphalt or carbon in the heater tubes. If efficient atomisation cannot be obtained at, say, a maximum temperature at the heater of 130°C a higher fuel pressure should be tried.

ATOMISERS

There are six types of atomisers in common use, namely:

Simple pressure jets.
Spill type pressure jets.
Variable orifice type pressure jets.
Spinning cup atomisers.
Steam assisted pressure jets.
Ultrasonic.

In the simple pressure-jet types (Figure 16.2), the pressure head of the oil fuel is converted into velocity head as it passes through small tangential holes in the atomiser tip. In addition, the holes impart a swirling motion to the oil, the discharge from the nozzle being broken up into a fine mist by centrifugal force.

The operating range or 'turn down' of such burners is limited, and with a view to obviating changes in tips, sprayer plates, etc., of individual burners, to cater for different steam outputs, the following types have been developed.

Spill burners

The spill-type burner uses a simple pressure atomiser as in Figure 16.2 but in addition a leak off is provided from the swirl chamber Figure 16.3.

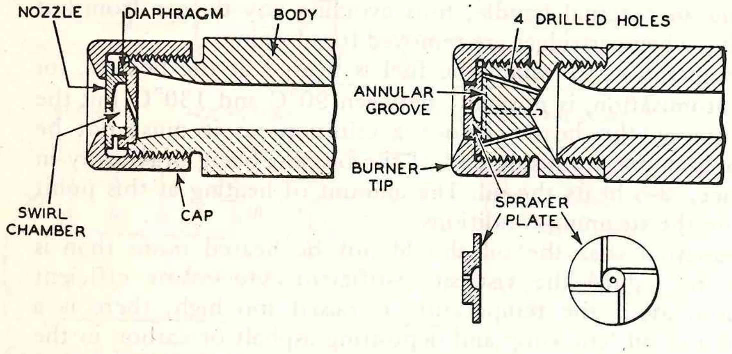


Figure 16.2 Burner atomiser

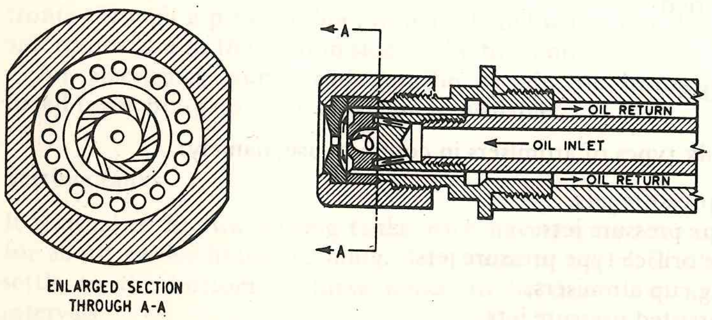


Figure 16.3 Spill-type burner
The oil enters centrally and spill oil leaves through annular passage in burner body

By increasing the amount of leak off, the amount of oil that is delivered to the furnace is reduced without seriously impairing the atomisation.

Variable orifice burners

The variable orifice burner utilises variations in fuel pressure to increase or decrease its output. The arrangement is illustrated in Figure 16.4 from which it will be noted that an increase of oil-fuel

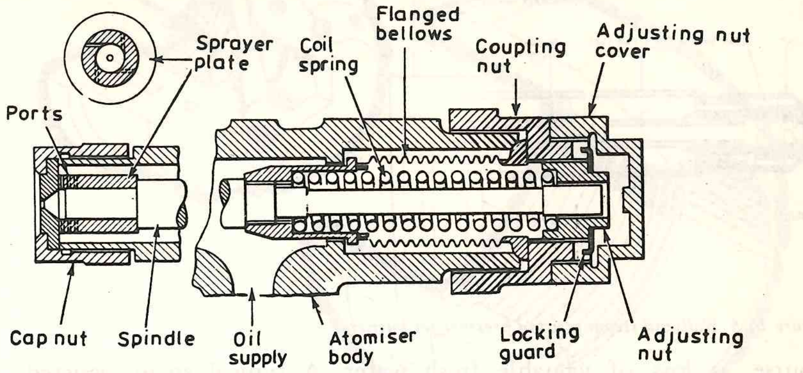


Figure 16.4 Variable orifice burner
An increase in oil pressure forces the spindle to the right, against action of the coil spring, uncovering an increased number of tangential holes in the sprayer plate

pressure acting on the larger-diameter portion of the spring-loaded assembly will force the valve-spindle assembly to the right, against the spring loading. This causes the valve spindle to uncover additional tangential ports in the sprayer plate supplying oil to the swirl chamber.

Spinning cup burners

In this method of atomisation the oil fuel is delivered through a tube to the back end of a cup which is rotating at high speed. The oil film is spread evenly by centrifugal force over the cup surface until it reaches the rim where it meets swirl air, which is delivered there, in the opposite direction of rotation.

This swirl air breaks down the oil into a stream of very fine droplets, and an adjustable air guide enables the shape of the flame to be varied from long to short and bushy.

Steam-assisted pressure jet atomisers

Low-pressure steam is used in this type of atomiser to increase the effectiveness of fuel pressure as a means of obtaining atomisation.

These atomisers have several advantages, it is claimed that their use results in a cleaner boiler, they require lower fuel pressures and are easy to flash up, but they have one notable disadvantage, namely they absorb anything up to 1% of the steam output and this, of

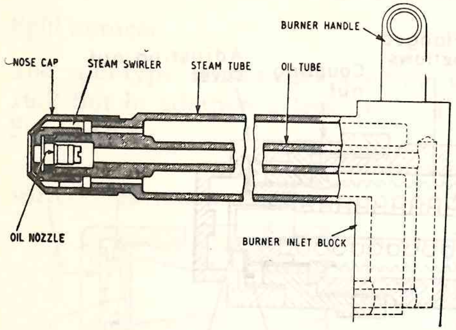


Figure 16.5 Wallsend steam assisted pressure jet burner

course, is loss of valuable fresh water. A typical steam assisted pressure jet burner is shown in Figure 16.5 and two current types in general use are described below.

Skew jet atomiser

This atomiser and its associated venturi register (Figure 16.6) are manufactured by CEA Combustion Limited. A combination of skew jet atomiser, swirler and matched aerodynamically designed venturi provide a very stable flame pattern.

The venturi air register is designed to maximise available fan pressure and give full register flow excluding internal eddies (see Figure 16.7). Each register is complete with its own airslide and is designed for positive open and shut operation without operator adjustment.

It will be seen that the oil and steam/air after mixing issues from the atomiser in a series of conic tangents. The advantage of this method is that the atomiser induces fuel reversals inside the fuel cone sufficient to establish flame stability over a wide turndown range. The mixing chamber ratio results in steam/air economy.

The atomiser is housed in a sprayer body which allows for differential expansion between oil and steam supply tubes, and can be removed while the boiler is in operation. Mechanical interlocks ensure oil and steam/air are shut off before the sprayer body can be removed, a gas flap ensures that no furnace gases are emitted to the

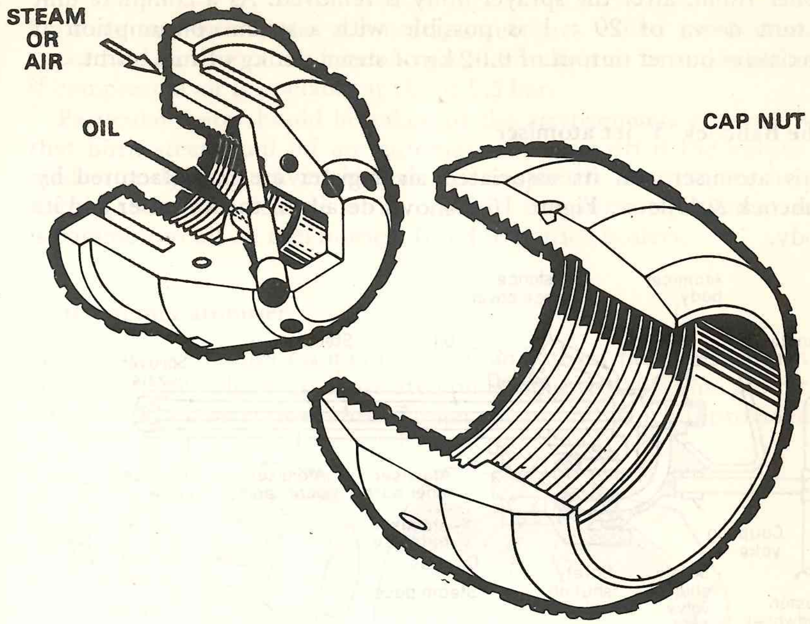


Figure 16.6 Section of skew jet atomiser

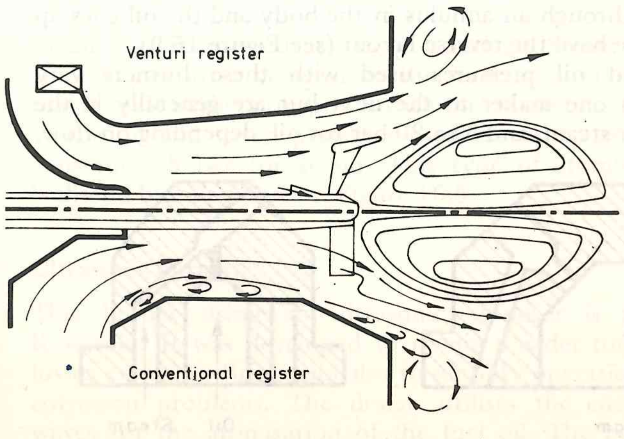


Figure 16.7 Showing venturi register and conventional register

boiler room, after the sprayer body is removed. As a complete unit a turn down of 20 : 1 is possible with a steam consumption at maximum burner output of 0.02 kg of steam per kg of fuel burnt.

The Babcock 'Y' jet atomiser

This atomiser and its associated air register are manufactured by Babcock & Wilcox. Figure 16.8 shows details of the atomiser and its body.

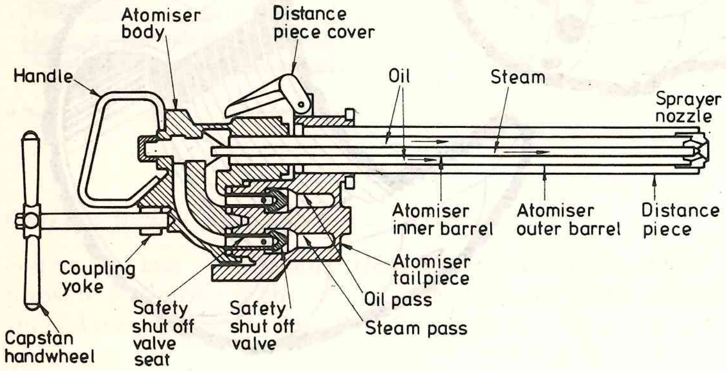


Figure 16.8 Babcock and Wilcox 'Y' jet atomiser

It will be noted that as in the case of the skew jet atomiser the steam (or air) enters one arm of a Y and the oil the other, but in this case the exit holes are not 'skew'd', and also whereas in the skew jet the steam passes through an annulus in the body and the oil goes up the centre, here we have the reverse layout (see Figure 16.9).

The steam and oil pressures used with these burners vary considerably from one maker to the next but are generally in the range of 10 bar for steam, and 3 to 20 bar for oil, depending on flow.

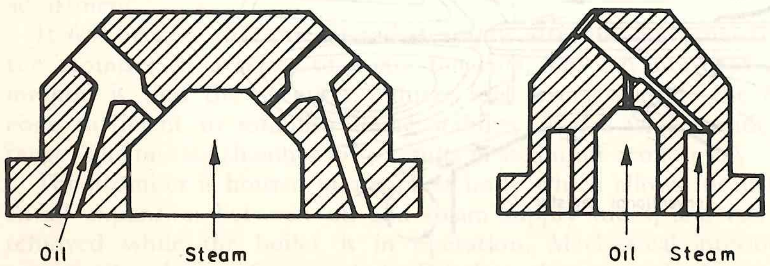


Figure 16.9 Section view of 'Y' jet and skew jet atomisers (left) 'Y' jet, (right) skew jet

Lighting up with these atomisers, sometimes called internal mix types because the oil and steam mix internally can be accomplished if compressed air is available at about 5.5 bar.

Particular note should be taken of the arrangements for ensuring that both steam and oil are automatically shut off if the burner is inadvertently withdrawn without the respective stop valves being tightly shut. This feature is, of course a statutory requirement and is common to all oil fuel burners fitted to marine boilers.

External mix atomiser

As the name implies no mixing of oil and steam takes place within this atomiser which is illustrated in Figure 16.10. The atomiser consists of a conventional pressure jet tip around which is provided a

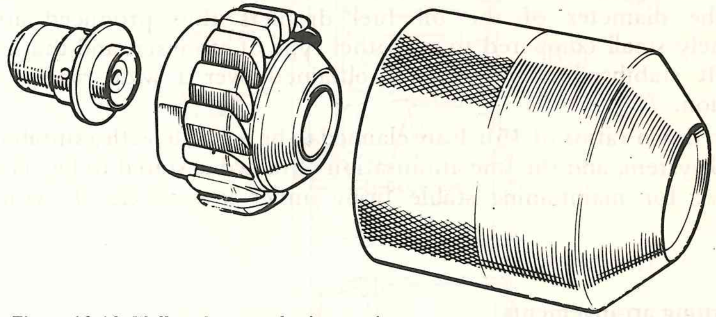


Figure 16.10 Wallsend external mix atomiser

steam (or compressed air) supply passage. Steam issues through an annular gap after being given the right amount of swirl to ensure that its exit angle corresponds with the oil spray cone angle.

The oil and steam pressures used are up to 36 bar for oil and a constant 1.8 bar for steam. This type of atomiser is used in the Wallsend burner shown in Figure 16.5.

Ultrasonic burners

This burner using an ultrasonic atomiser is manufactured by Kawasaki. It was developed to obtain a wider turndown ratio with lower excess air firing, and also to simplify operation and reduce acid corrosion problems. The design utilises the energy of ultrasonic waves for the atomisation of the fuel oil. The burner atomiser, as shown in Figure 16.11, consists of an annular steam nozzle, a resonator, and oil nozzle with holes.

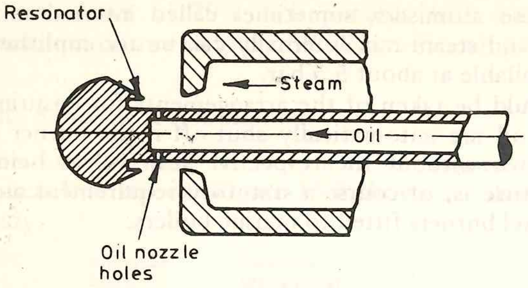


Figure 16.11 Typical atomiser construction — ultrasonic burner

The ultrasonic vibrations ranging from 5000 Hz to 20 000 Hz are produced by a high speed flow of steam or air impinging on the resonator edge located in front of the oil nozzle holes. It is claimed that the diameter of the oil fuel droplets thus produced are extremely small compared to any other type of atomiser, and that as a result stabilised combustion is obtained over a wide range of operation.

Turn down ratios of 15 : 1 are claimed to be possible with a suitable control system, and the fine atomisation obtained is stated to be very effective for maintaining stable firing under low excess O_2 conditions.

Oil burning arrangements

The working pressure in the fuel line to the burners varies in different types of installation, ranging from 1.05–1.125 bar for spinning cup burners to 31.5–35 bar for spill types.

A circulating valve connecting back to the pressure pump suction is fitted at the end of the pressure line to the burners, and when this valve is open, the oil circulates through the line and back again to the pressure pump. This valve is very necessary when starting-up the installation, so that the cold oil can be circulated through the heater and the line to the boiler fronts, until the temperature is high enough for efficient atomisation.

Furnace fittings

Furnace front fittings vary, for obviously their arrangement will be different for boilers employing the double-fronted system of forced draught to that when single fronts and natural draught are used.

In the main, these fittings consist of burner, air director for giving the air a conical swirling motion, a master air-supply check, a secondary air check regulating the supply of straight unswirled air around the burner (which controls the angle and length of the flame) and, most essential, a blue glass window for observation purposes when making flame adjustments. A typical arrangement for a Scotch boiler is as shown in Figure 16.12.

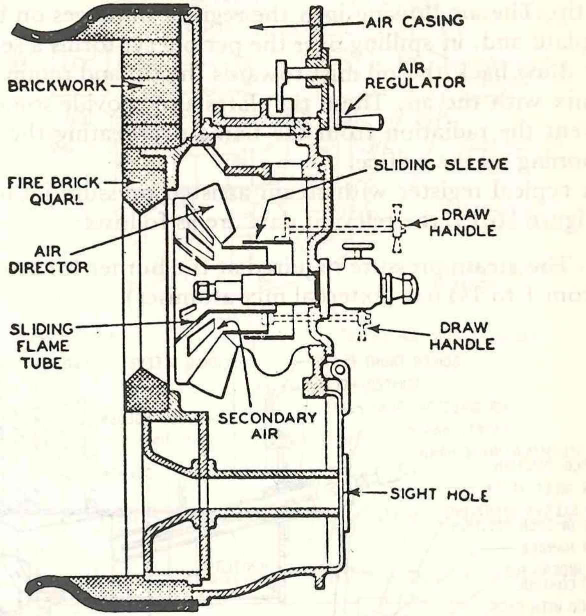


Figure 16.12 Typical arrangement of Scotch boiler furnace front fittings

The oil pressure line to the burners is normally made of heavy scantling seamless-steel tubing with flanged and bolted joints, the whole row of piping being placed in a readily visible position.

Water tube boiler registers

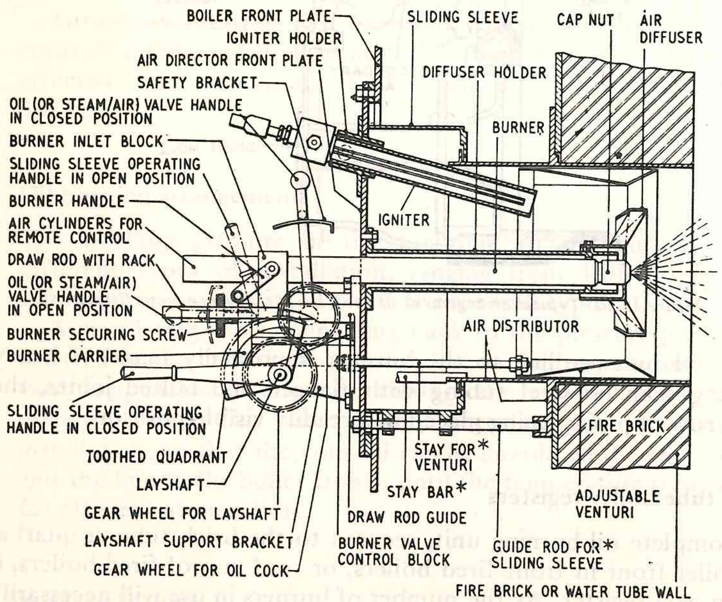
The complete oil burning unit, secured to the brick tube or quarl at the boiler front in front fired boilers, or roof in roof-fired boilers, is known as a register. As the number of burners in use will necessarily have to be varied, especially during manoeuvring, means have to be provided for shutting off the air supply to the burners when they are not in use.

There are many different arrangements for effecting this, sliding tubes, hinged flaps, etc. The air supply is given an angular rotation or 'swirl' by means of vanes as it passes into the furnace in order to assist in mixing the air and oil – this is normally done by shaped vanes, although in some designs the vanes and shut-off device are combined.

Stability of the flame is achieved by the use of tip plates, i.e., an annulus located close to and concentric with the outlet orifice of the tip. The air flowing into the register impinges on the back of the tip plate and, in spilling over the periphery, forms a series of vortices that draw back the oil mist towards the tip and retain it long enough to mix with the air. These tip plates also provide some cooling air to prevent the radiation from the flame overheating the burner tip and carboning up the orifice.

A typical register with steam assisted pressure jet burner is shown in Figure 16.13; the relevant data are as follows:

1. The steam pressure required at the burner for atomisation varies from 1 to 1½ bar (external mix atomiser).



* FOR TRUE POSITION SEE FRONT ELEVATION

Figure 16.13 Wallsend burner and FD air register. Showing sectional view of air director with burner in position

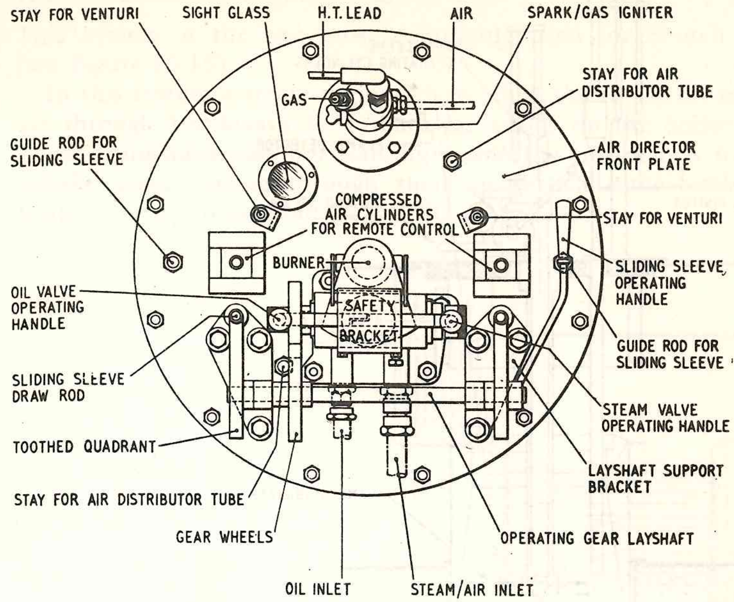


Figure 16.13 (continued) Front elevation of Wallsend burner

2. Atomising steam pressure need not be altered to suit variations of burner output.

3. The burner will operate satisfactorily though a 'turn down' or output range of 15 : 1.

4. The burner cannot be removed from its carrier without first shutting both oil and atomising steam valves.

5. The oil valve operating handle cannot be moved to the open position unless the atomising steam valve is already open, and similarly the atomising steam valve cannot be closed unless the oil valve has already been closed.

6. When the oil valve is closed and the atomising steam valve is open the steam acts as a coolant. Under these conditions the burner will not become overheated from the furnace and can be left in position ready for immediate use.

Most of the large steam-turbine tankers either under construction or completed are steamed by roof fired boilers with remote-controlled registers (see Figure 16.14).

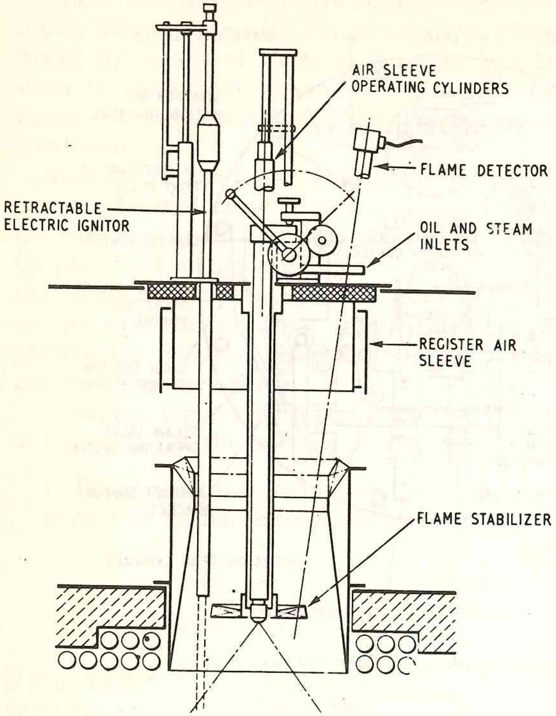


Figure 16.14 Steam-assisted pressure jet burner in remotely operated register for roof firing

DRAUGHT

The amount of draught required varies with each type of fuel and with the rate of combustion, the best setting being found by experiment. In the early days of marine boilers, natural draught obtained by the use of a high funnel was the general rule. It was soon found, however, as boiler ratings increased, that natural draught had its limitations.

The adoption of forced draught for coal burning with closed ash pits showed that 50% more fuel could be efficiently burnt per unit of grate area, this enabled boiler sizes to be reduced with a correspon-ding increase in a vessel's cargo-carrying capacity. This has been maintained over the years with ever-increasing forced draught pressures.

Howden's forced-draught system

This system is the one most commonly used for Scotch boilers (see Figure 16.15).

In this system a steam-engine-driven fan in the engine room forces air through trunkways to furnace air valves on the boiler fronts. These trunkways pass horizontally across the smoke box tops, the uptake gases passing through them in vertical tube banks, thus heating the air from about 27° –93°C.

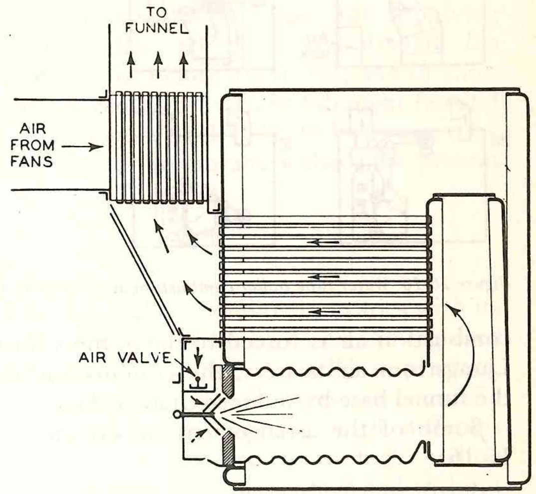


Figure 16.15 Howden forced-draught system

At the front of each boiler the furnace is provided with air valves for controlling the air supply above and below the firebars for coal burning, and to the burners when oil burning. Control valves are provided in the trunk-ways of multiple-boiler installations so that the air supply can be regulated, and any one boiler isolated as required.

In addition to supplying heated air which accelerates combustion, increased boiler efficiency is also obtained as the combustion air, in being heated, extracts waste heat from the uptake gases, thus lowering the funnel temperature.

Water tube boiler combustion air arrangements

In water tube boilers the combustion air supply arrangements vary from the simplest case where a forced draught fan supplies air direct to the burners, to the high efficiency system in which the

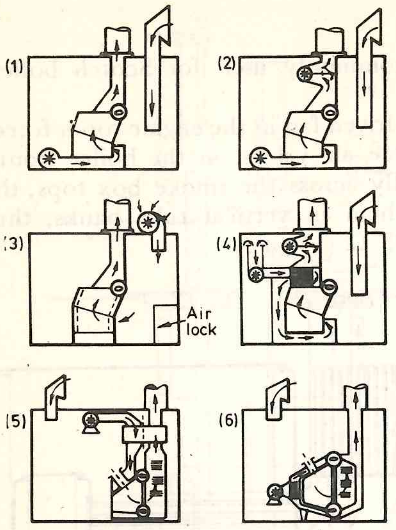


Figure 16.16 Water tube boiler combustion air arrangements

combustion air is forced to the burners through both bled steam and Ljungstrom air heaters, the combustion gases then being drawn to the funnel base by induced draught fan.

Some of the arrangements in common use are shown in Figure 16.16:

1. Forced draught fan direct to double front casing.
2. Forced draught fan as above in conjunction with an induced draught fan in the uptake.
3. 'Closed' stokehold forced draught.
4. Double cased boiler forced draught with or without induced draught.
5. Membrane walled top fired boiler with forced draught through Ljungstrom air heater.
6. Double cased tangent-tube-walled top fired boiler with forced draught though bled steam air heater.

The first method, simple and cheap to install, has two main drawbacks:

(a) The actual casing of the boiler is exposed, which means that there is the possibility of gas leaks into the boiler room;
(b) The boiler casing is more liable to distortion through over-heating than in the case of method (4), as the cooling effect

of the combustion air passing through the double casing is not present.

The apparent advantages of a purely induced draught system have not been developed to any extent, largely due to mechanical trouble with the fan and its power unit, which of necessity have to work under adverse conditions. The closed-stokehold forced-draught system was at one time extensively used by the Admiralty, but this system is rarely encountered in merchant vessels, and is complicated by the fact that air locks have to be used.

The systems most extensively employed today for supplying combustion air to water tube boilers are by forced draught fan through a bled steam air heater as in Figure 16.16 (6), and in cases where slightly more efficiency is required by forced draught fan and Ljungstrom gas air heater as in Figure 16.16 (5). In both cases the boiler may be either double cased or membrane walled, the present tendency favouring the latter.

Air requirements for combustion

The amount of air required by the fuel for combustion varies with its composition. Theoretically, for oil 13½–14½ kg of air are required per kg of fuel and for coal, about 11 kg/kg. Actually in practice, with coal firing, 8-—100%, and with oil 10–4%, excess air is usually required for combustion, this percentage varying with different conditions. A smokeless funnel accompanied by a high carbon dioxide (CO_2) percentage, low oxygen (O_2) percentage and without carbon monoxide (CO) is the ideal.

In the absence of gas-analysis apparatus, assuming all burners are clean and oil is at the correct temperature, it is considered good practice to reduce the excess air from the smokeless funnel state until a light-brown haze is obtained. It is usual to fit air heaters in the path of the flue gases, as apart from extracting heat from these gases, which would otherwise be wasted, the preheated combustion air so obtained accelerates the rate of combustion in the furnace. In addition, the effect of cold air impinging on the boiler surfaces is avoided and boiler efficiency improved.

AIR HEATERS

Tubular air heater

The type of air heater most frequently used with Scotch boilers is undoubtedly the ordinary tubular type. This uses thin steel tubes expanded at their ends into steel tube plates, the gases passing on one side of the tube walls and the combustion air on the other (Figure 16.17). In Scotch boiler installations it is usual for the uptake gases to pass through and the combustion air to pass around the outside of the tubes; whereas in early water tube boiler practice, when this type of heating element was used, the reverse arrangement was generally employed; the tubes were placed horizontally instead of vertically.

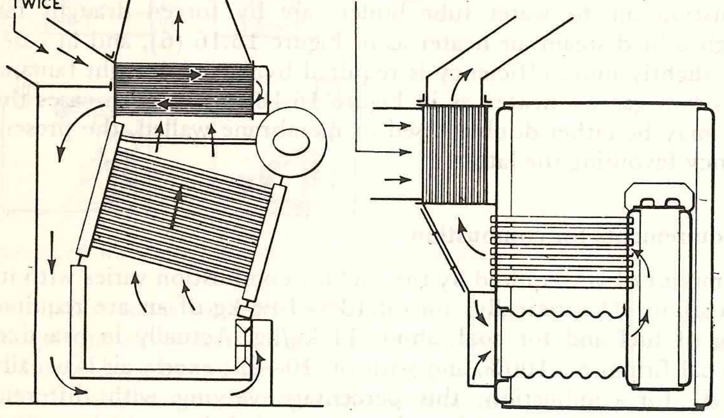


Figure 16.17 Tubular air heater

An arrangement which was commonly used is shown in Figure 16.17 from which it will be noted that the air makes several passes through the heater tubes, and on emerging at the heater outlet passes down through the boiler double-casing side, across the bottom and up to the front, thus absorbing further heat which would otherwise have been lost by direct radiation.

Ljungstrom air heater

An entirely different type of air-heater which is used in modern water tube boiler installations is the Ljungstrom air heater shown in Figure 16.18. In this heater a drum slowly revolves on a vertical axis inside a cylindrical casing. Openings at the top and bottom of this casing are so arranged that on one side of the vertical centre line flue gases enter and leave, and on the other side the combustion air does likewise. The drum, open at top and bottom, is fitted with thin sheet-steel plates and vanes, these being fitted so that there is a free

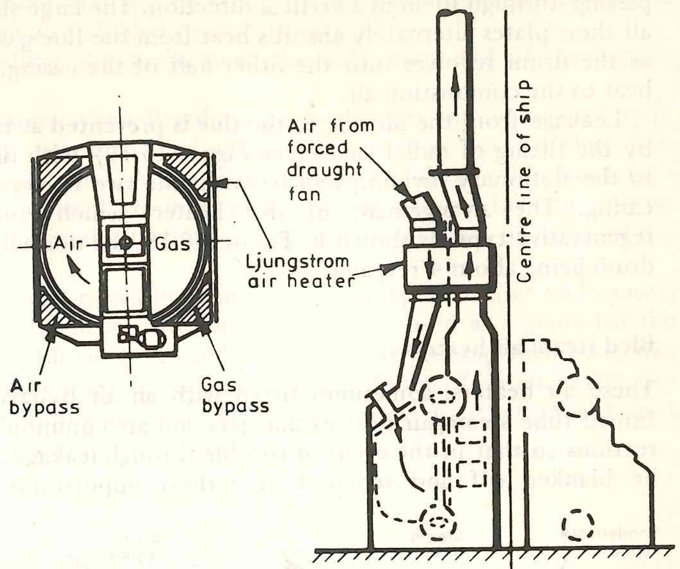


Figure 16.18 Ljungstrom air heater
Typical passenger liner draught arrangement

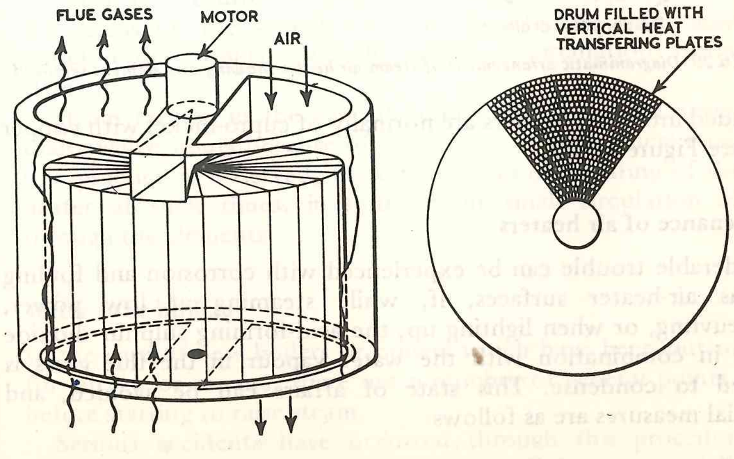


Figure 16.19 Arrangement of the Ljungstrom air heater

passage through them in a vertical direction. The large surface area of all these plates alternately absorbs heat from the flue-gases, and then, as the drum revolves into the other half of the casing, imparts this heat to the combustion air.

Leakage from the air side to the flue is prevented as far as possible by the fitting of radial vanes (see Figure 16.19), with fine clearances to the stationary dividing wall between the two halves of the heater casing. The arrangement of this heater, which is known as a regenerative type, is shown in Figure 16.19, the normal speed of the drum being about 4 rev/min.

Bled steam air heaters

These air heaters, sometimes fitted with an air bypass, are simply finned tube steam/air heat exchangers and are commonly built up in sections so that in the event of trouble through leakage a section can be blanked off and renewed at earliest opportunity. The tubes

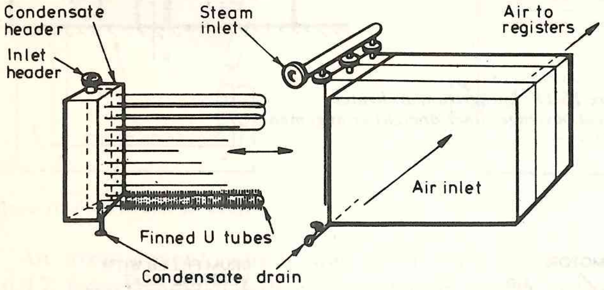


Figure 16.20 Diagrammatic arrangement of steam air heater showing one element removed

expanded into steel headers are normally of cupro-nickel with copper fins (see Figure 16.20).

Maintenance of air heaters

Considerable trouble can be experienced with corrosion and fouling of gas air-heater surfaces, if, while steaming at low power, manoeuvring, or when lighting up, the acid-forming sulphur dioxide (SO_2) in combination with the water vapour in the flue gases is allowed to condense. This state of affairs can be avoided, and remedial measures are as follows:

1. The fitting of an air bypass on the heater.

2. Preheating the air entering the gas air heater by passing it through a small bled steam air heater.
3. Enamelling the surfaces at the cold inlet end of the heater.

Soot blowers when fitted to gas air heaters should be used only when really necessary and when the heater is hot, so that condensation is avoided. A sooty air heater can, on the other hand, be a source of potential trouble, as a soot or carbon fire can release enough heat actually to burn out the thin steel tubes or plates of the heater.

Under normal operating conditions, a dirty air heater will cause a rise in funnel temperature, and this can be used as a guide for the frequency of blowing. A sudden unusual rise accompanied by sparks from the funnel would indicate the possibility of an air heater fire and, provided they are of the steam type, *immediate* action with soot blowers should smother the fire.

RAISING STEAM

Scotch boilers

In the case of Scotch boilers fitted with smoke tube superheaters, the normal practice is to open all header drains before setting the fires away, when steam is showing, the steam-to-superheater valves are opened, and after the superheater has been well blown through, the drains on the superheater inlet headers are shut, leaving the outlet-header drains open to create a circulation through the elements.

Steam raising, in the case of Scotch boilers, should never be less than twelve hours because of the danger of mechanical straining. If this practice is observed, there will be no overheating of the superheater at such times, in spite of the small circulation of steam through the elements.

Water tube boilers

In the case of new boilers or boilers which have been out of service for survey or repairs, there are a number of general points to note before starting to raise steam.

Serious accidents have occurred through this procedure being casually carried out, under divided responsibility – especially in the case of new installations – and it is important therefore that the procedure is the responsibility of a experienced qualified engineer.

Prior to filling the boiler, a thorough examination should be made, both internally and externally with particular reference to the following:

Internally

(a) All tubes should be proved clear – oily waste and tube cleaning gear have on occasions been left in tubes.
(b) Apertures in drum ends leading to water gauges, etc., should be examined – tools have been found obstructing these passages.
(c) Internal surfaces should be free from scale and oil – this also includes oil from tube expanders, if these have been used.
(d) Internal fittings should be secure i.e. perforated plates, feed pipes, internal steam pipes, baffles, etc.

Externally

(e) All refractory should be in good order – particularly any protecting drum surfaces.
(f) All valves, safety valves and cocks should be in good operable condition and shut.
(g) Manhole and handhole door joints should be in good condition and properly tightened.
(h) Superheat control valves (dependant on arrangement) should be correctly set to ensure that all initially generated steam flows through the superheaters.

On completion of the foregoing and prior to filling the boiler, the following valves and cocks should then be opened: boiler, superheater and economiser vents, superheater header drains, steam raising circulating valves, water level steam and water isolating valves and cocks, pressure gauge cocks, water level alarm gear isolating valves, and feed check valves.

It should also be ascertained that the following are shut: water level gauge drain cocks, water wall and economiser drain valves, running-down and blow-down valves.

The boiler can then be filled with distilled de-aerated water to a level just above that which causes the low water level oil fuel cut out to operate.

With regard to the actual light-up, especially in the case of new installations, the responsible engineer fully appreciating the

possibility of furnace explosions should not proceed further unless he is fully satisfied from the purging aspect that all sequential controls and safety devices are fully operable. The automatic start-up sequence of the first burner will include a pre-start purge period and the correct operation of the sequence controller of this burner should always be verified when this burner is put into service.

In all cases, the manufacturer's instructions, when available, should be followed, as these based on experience specify the safe firing rate for preventing overheating of any pressure parts, especially superheater elements.

A typical 'Cold light-up procedure' as detailed by Foster Wheeler for their ESD III boiler is given below.

It will be seen from this procedure chart that uniform heating and a satisfactory controlled firing rate are obtained by specifying:

1. The position and size of the light-up burner.
2. The fuel oil pressure and through-put.
3. The maximum rate of temperature rise of the boiler water i.e. saturation temperature.

The lighting up procedure assumes that steam is available for fuel heating and auxiliary services. When steam is not available, the light up has to be effected using diesel fuel (Ship's with turbo-generators carry this fuel for their emergency generator), forced draught fans being electrically driven are still available.

ESD III main boiler 'cold' light-up procedure

The following instructions and the diagram (Figure 16.21) must be displayed in the control room.

The 'cold' boiler light-up burner firing rate is restricted in accordance with the curves to prevent any damage by overheating the boiler pressure parts – especially the superheater elements.

1. Light-up on any *one* of the four centre burners and burn oil at a rate of 340 kg/hr. for a period of approximately one hour. *Wing burners must not be utilised during this light-up period.*
2. Increase the firing rate to 454 kg/hr. for the second hour.
3. Increase the firing rate to the maximum allowable light-up rate of 680 kg/hr. This should be sufficient to attain the stand-by steaming condition of 64.5 bar after approximately 2½ hours.

Note. When required to raise the boiler evaporation rate *after* the light-up procedure this maximum limit can be automatically removed by introducing a second burner.

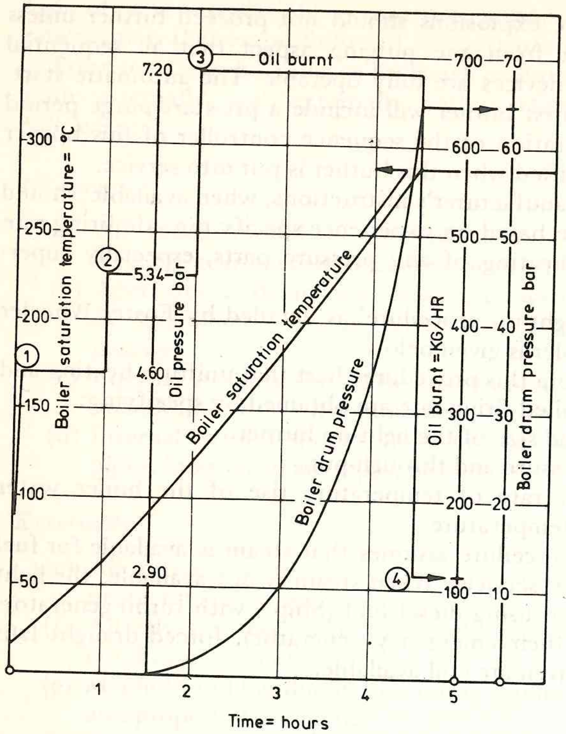


Figure 16.21 Typical lighting up chart for Foster Wheeler ESD III boiler

4. The aforementioned steaming conditions should now be maintained by utilising the maximum boiler burner turndown (90:1) rate of 116 kg/hr.

LAYING-UP BOILERS

During idle periods precautions have to be taken to protect boiler internal surfaces against corrosion. Two methods are in common use dependant on the length of lay-up.

For short periods up to say a maximum of one month, the boiler, superheater, desuperheater and economiser, with all valves and cocks shut, are completely filled with hot distilled de-aerated alkaline water – daily checks subsequently being made to ensure that fullness and alkalinity are maintained.

In the second method, used when longer lay-ups are envisaged, the boiler, superheater, desuperheater and economiser are completely dried out using heating stoves in the drums and hot air through the tubes. When dry all valves and cocks are shut tight, all doors replaced (using new joints) and the boiler hermetically sealed – trays of a drying agent such as 'silica gel' usually being inserted before sealing up. (See also BS 1170).

In the case of auxiliary boilers which operate under intermittent steaming conditions corrosive conditions are likely to occur both internally and externally unless precautions are taken during their off periods.

A method frequently used, always assuming steam is available from another source is to embody simmering coils in their water drums. The use of such coils enables a slight pressure to be maintained in the off duty auxiliary boiler, thus eliminating the risk of air ingress, and the gas side is kept warm and dry.

FEED-WATER SYSTEMS

The condensed steam from the propelling machinery is returned to the boilers by means of a feed-water system. This water, as formed, is not returned straight to the boilers for the following reasons:

(a) The low temperature of the condensate is liable to cause mechanical straining of the boiler.

(b) Any oil from cylinder lubrication in the case of steam reciprocating engines has to be removed before the water is fit for feed purposes.

(c) Means have to be provided for de-aerating the feed, otherwise oxygen will be liberated in the boiler, causing corrosion of the boiler surfaces.

(d) Some means of allowing for variation in the working water level in the boilers must be provided, and this is usually done by fitting a feed tank which will accommodate extra feed or excess water when required. In addition, the drains from auxiliary machinery can be conveniently led to this tank.

(e) External feed-water treatment to counteract impurities is generally necessary.

Simple feed system (reciprocating machinery)

In the case of the relatively simple feed systems, used on cargo vessels fitted with Scotch boilers utilising moderate steam pressures, the arrangement is shown in Figure 16.22. From this it will be noted that a wet air pump of the Edwards type, two feed pumps (one as stand-by), a feed-filter tank fitted with float operating the steam supply to the feed pumps and an exhaust feed heater complete the installation.

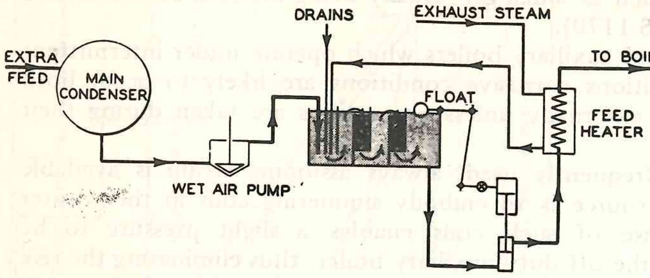


Figure 16.22 Sample feed systems for Scotch boiler cargo vessel

This arrangement is often improved by the fitting of a direct-contact feed heater, in which case one of the two feed pumps draws the condensate from the feed-filter tank and delivers it to this heater, which is normally situated at the top of the engine-room. In the direct-contact heater the condensate is raised in temperature by intermingling with exhaust steam, and at the same time any air released from the feed is vented to the main condenser. The de-aerated feed is then drawn from the direct contact feed heater by

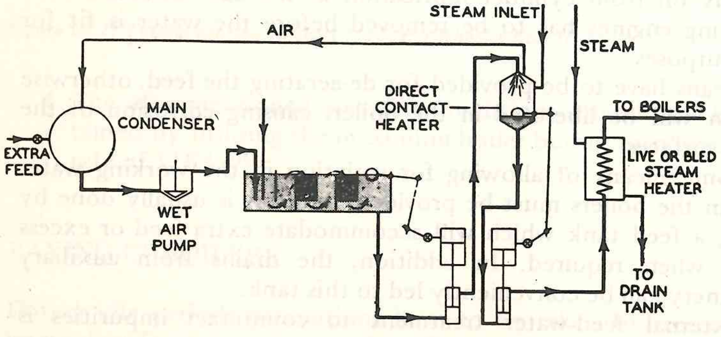


Figure 16.23 Sample feed system with direct-contact feed heater

the second of the two feed pumps, which discharges it, either direct or through a further live or bled steam heater, to the boiler check valves – this arrangement is shown in Figure 16.23. It will be noted that both pumps are under automatic float control.

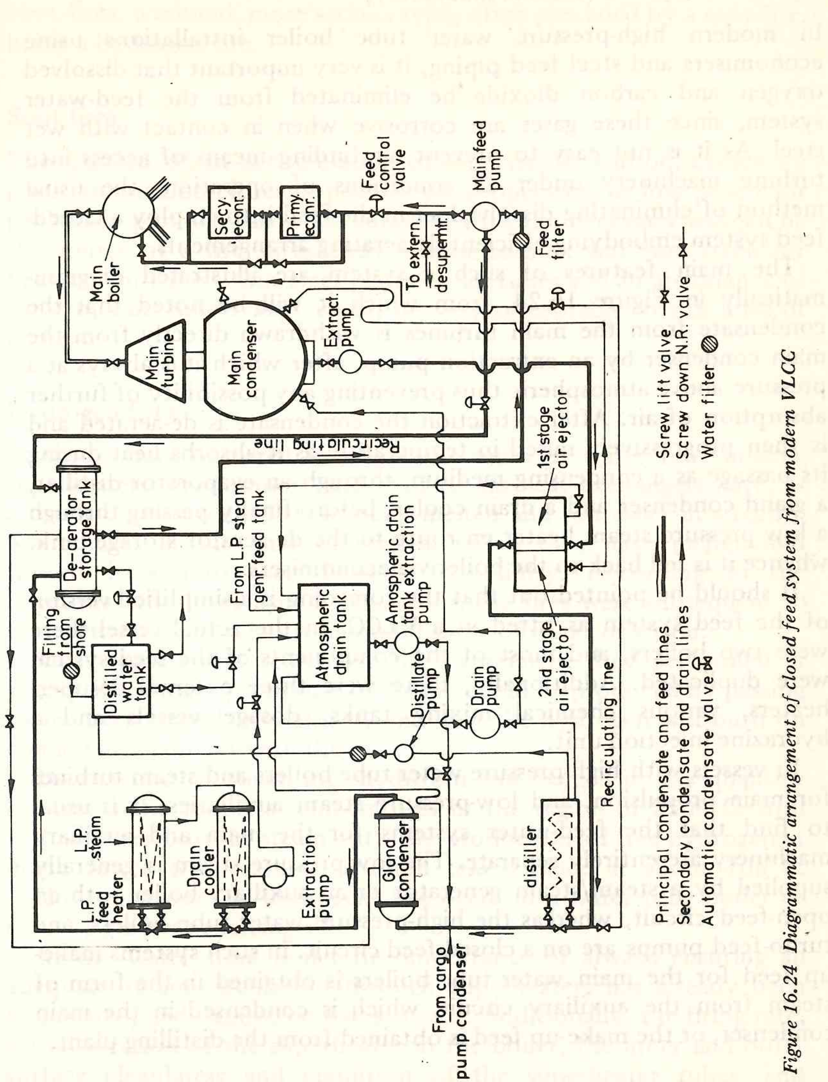


Figure 16.24 Diagrammatic arrangement of closed feed system from modern VLCC

Closed-feed system (turbine machinery)

In modern high-pressure water tube boiler installations using economisers and steel feed piping, it is very important that dissolved oxygen and carbon dioxide be eliminated from the feed-water system, since these gases are corrosive when in contact with wet steel. As it is not easy to prevent air finding means of access into turbine machinery under all conditions of operation, the usual method of eliminating dissolved air in the feed is to employ a closed-feed system embodying efficient de-aerating arrangements.

The main features of such a system are illustrated diagrammatically in Figure 16.24, from which it will be noted that the condensate from the main turbines is withdrawn directly from the main condenser by an extraction pump, after which it is always at a pressure above atmospheric thus preventing any possibility of further absorption of air. After extraction the condensate is de-aerated and is then progressively raised in temperature as it absorbs heat during its passage as a condensing medium, through an evaporator distiller, a gland condenser and a drain cooler, before finally passing through a low pressure steam heater en route to the de-aerator storage tank, whence it is fed back to the boiler via economisers.

It should be pointed out that the foregoing is a simplified version of the feed system as fitted in a VLCC. In the actual vessel there were two boilers, and most of the components of the feed system were duplicated. Additionally, there were three external desuper-heaters, various chemical mixing tanks, dosage vessels and a hydrazine injection unit.

In vessels with high-pressure water tube boilers and steam turbines for main propulsion, and low-pressure steam auxiliaries, it is usual to find that the feed-water systems for the main and auxiliary machinery are entirely separate. The low-pressure steam is generally supplied by a steam/steam generator or an auxiliary boiler with an open-feed circuit, whereas the high-pressure water tube boilers, and turbo-feed pumps are on a closed-feed circuit. In such systems make-up feed for the main water tube boilers is obtained in the form of steam from the auxiliary circuit, which is condensed in the main condenser, or the make-up feed is obtained from the distilling plant.

FIRES IN AIR HEATERS, SUPERHEATERS, ECONOMISERS AND EXHAUST GAS HEAT EXCHANGERS

These heat extracting units are all situated in the path of combustion gases and under certain conditions, fortunately rare, can experience disastrous fires. These fires are of two types, the commonest being soot fires, a second, more serious type, often preceded by a soot fire, being a hydrogen fire.

Soot fires

The ignition of an accumulation of soot, rich in carbon, caused by poor combustion either in port or when operating at low power for prolonged periods, can when supplied with the necessary oxygen be the source of a fire sufficiently intense to melt and burn steel. Air heaters, with their thin steel plates or air tubes and an abundance of oxygen, can, unless kept clean, be very susceptable to this kind of damage.

Hydrogen fires

Instances have occurred in which the tubes of water tube boilers, superheaters, economisers and exhaust gas heat exchangers have, as a result of an intense fire, literally melted and run away in streams. Sometimes, in the case of vertical tubes, they have melted and flowed back into their headers to solidify. According to the engineers who investigated these cases, the fires were subsequent to the overheating of tubes which were short of water or steam.

Most readers will remember the experiment they performed at school when they found that hydrogen could be produced by passing steam over heated iron filings, and that the hydrogen will burn on coming into contact with the air.

Dissociation of steam into hydrogen and oxygen in any quantity by *heat alone* requires temperatures in the region of 2500°C. Iron will however burn in steam with the production of free hydrogen at much lower temperatures, ignition taking place at about 700°C.

How then does a 'hydrogen' fire occur in a water tube boiler or exhaust gas heat exchanger?

In the water tube boiler the importance of always ensuring an adequate steam circulation through superheaters has already been mentioned, and cannot be overstressed. Additionally, the firing rate, actual location of the superheater in the boiler, the inner and outer surface cleanliness and condition of the superheater tubes, and possible maladjustment of the burner equipment causing 'flaming through' screen tubes, can all influence the likelihood of severe overheating of these tubes.

When overheating of a superheater due to insufficient steam circulation is very severe, the tube material may ignite at about

700°C and, burning in the steam, produce free hydrogen. The iron will continue burning independently of any supply of oxygen from the air, and the hydrogen produced by the reaction will burn on coming into contact with air. This means that once such a fire has started there are likely to be two fires burning simultaneously, one, iron burning in steam and the other, hydrogen burning in air, the combined fire being self supporting and probably lasting until the supply of steam is exhausted.

The conditions necessary for the initiation of a hydrogen fire fortunately rare are generally accepted to be as follows:

1. Tube metal temperatures of over 705°C.
2. Tubes with some steam content (usually quiescent or of poor circulation).
3. The presence of a catalyst in the form of a carbon ash.

The extreme importance of adequate steam circulation was vividly demonstrated in one case where one of the two D type main boilers of a VLCC burnt out. In this incident, subsequent to a tube burst and reduction of steam pressure in one boiler, the NR stop valve shut and, before low water level shut off the fuel, a hydrogen fire started in its steam starved superheater. This white hot fire spread throughout the boiler melting and burning most of the tubes, and also initiated a soot fire in the air heater. Waterwall and screen tube headers were subsequently found to be blocked solid with plugs of steel which had formed when the molten boiler tubes had run back into their holes.

In the foregoing incidents with water tube boilers the source of heat responsible for the overheating has been the boiler burners. Such fires do, however, occur in finned tube exhaust gas heat exchangers and boiler economisers, where the source of heat is flue gas with a temperature much too low to cause ignition. Investigation of such cases has indicated that if perchance during a soot fire; the unit concerned *is not being circulated*, the intense heat of the soot fire, rich in carbon, may initiate a hydrogen fire and that this, as in the case of boiler superheater fires, once started, is self-supporting until all steam is exhausted.

It is important, therefore, that boiler economisers and exhaust gas heat exchangers are kept clean on the gas side to prevent soot fires, and that if defective are either bypassed on the gas side, or if not bypassed have their defective sections properly blanked off, *drained and vented.*

Furnace explosions

Furnace explosions or on a lesser scale 'blow backs' generally occur when volumes of oily vapour and air, present in a furnace in explosive proportions, are ignited, although sudden admission of air to a fuel-rich burner flame may well produce the same result. These explosions should not occur in boilers fitted with automatic sequential controls, as these, apart from controlling the fuel to air ratio also ensure adequate purging before ignition.

Even in the best designed systems, however, automatic light-up failures do occur, and it is then, when going over to manual control, often in a hurry, that the wrong action is sometimes taken, resulting in an explosion. Failure to obtain ignition at the first attempt must be followed by adequate purging.

A typical incident but fortunately without serious result, was an occasion when visiting an old vessel to adjust safety valves of a vertical boiler which had been converted from coal to oil firing. The donkeyman made two attempts with a lighted torch to ignite the burner and on the third succeeded with a roar which blew the ash pit door out forcibly and painfully across many shins!

Such explosions in water tube boilers with their large capacity furnaces can, however, be a much more serious occurrence, often involving the loss of lives. These explosions usually occur when steaming conditions are not stabilised, as for instance during a vessel's fitting-out period when steam is intermittently required for testing auxiliaries. At such times the operation of the boiler is sometimes a divided responsibility, and may well be under manual control without all its safety devices completely installed.

Boiler operation should always be the responsibility of one qualified engineer who fully appreciates, from the furnace explosion aspect, the vital necessity of adequate pre-ignition purging, and who is aware of the possibility, especially with membrane walled boilers, of a serious furnace explosion pulling tubes out of drums and disgorging the boiler contents into the engine room.

17 Fire-fighting appliances

The importance of being familiar with and maintaining in efficient working condition all fire-fighting appliances aboard ship cannot be too highly stressed. It must be pointed out that the use of hot oil under pressure presents a potential fire risk, continual attention being necessary in the use of hot-oil equipment. A limit of 60°C. is specified for the flashpoint of fuel oil, and this is an effective precaution, but when such oil is heated and pressurized for combustion purposes it becomes potentially very dangerous.

By the Merchant Shipping Acts, owners and masters of British ships are bound, under penalty, to comply with the Department of Trade requirements regarding, *inter alia,* the provision of fire-fighting appliances. These Rules are published in booklet form obtainable from Her Majesty's Stationery Office and entitled '*The Merchant Shipping (Fire Appliances) Rules 1965*' and also *The Merchant Shipping (Fire Appliances) (Amendment) Rules, 1974*'.

Ships classed with Lloyd's Register of Shipping are also required to comply with the requirements of Part 6, Chapter 4 of Lloyd's Rules and Regulations. The requirements of Lloyd's Register of Shipping for fire-extinguishing equipment in the machinery spaces of motorships and steamships having oil-fired boilers are described in the following pages.

General

All ships of 1000 tons gross and over are to be provided with *at least* two hydrants in the machinery spaces, complete with hoses each with jet and spray nozzles, so that at least two jets of water, not emanating from the same hydrant, and one of which is from a single length of hose, may be directed on any part of these spaces.

In smaller ships, one hydrant, hose and combined nozzle will be accepted. The hoses are to be of sufficient length to permit an effective spray to reach any part of the engine room and boiler room.

In ships of 2000 tons gross and over a hydrant complete with hose and nozzle is also to be provided in the shaft tunnel adjacent to the engine-room watertight door.

Provision is to be made for stopping, from positions outside the machinery spaces, ventilating fans for these compartments, also other fans or blowers situated within the compartments, and for closing as far as practicable all openings to the machinery spaces. The engine-room skylights are to be capable of being shut from deck or from a safe position outside the machinery space.

Precautionary arrangements regarding oil leakages

Gutterways are to be fitted at the base of bulkheads between boiler-rooms and oil compartments, leading to the bilges.

Drip trays or gutterways with suitable drainage arrangements are to be provided for all oil tanks which do not form part of the hull structure, at pumps, valves and elsewhere where there is a probability of leakage. Drip trays are also to be fitted under oil-tight decks, except if these are completely welded when the drip trays need be fitted only over boilers. Pipes conveying heated oil under pressure are to be of seamless steel having flanged couplings and placed in sight above the platform in well lighted parts of the stokehold or engine room. The flanges are to be machined, and the jointing material, which is to be impervious to oil heated to 150°C is to be the thinnest possible so that the flanges are practically metal to metal. The scantlings of the pipes and these flanges are to be suitable for at least 14 bar working pressure, or the pressure to which the relief valves are adjusted, whichever is the greater.

Every oil-fuel suction pipe from a storage, settling and daily service tank situated above the double bottom is to be fitted with a valve or cock secured to the tank. In the case of fore-peak tanks, these valves are to be fitted on the tank side of the bulkhead.

In the engine and boiler spaces such valves and cocks are to be capable of being closed locally and from positions which will always be accessible in the event of fire taking place in these spaces. Instructions for closing the valves or cocks are to be indicated at the valves and cocks and at the remote-control positions.

In the case of very small tanks consideration will be given to the omission of remote controls.

Every oil-fuel suction pipe which is led into the engine and boiler spaces from a tank situated above the double bottom outside these spaces is to be fitted in the machinery space with a remote-controlled valve, except where the valve on the tank is already remote controlled.

All valves and cocks forming part of the oil-fuel installation are to be capable of being controlled from readily accessible positions, which, in the engine and boiler spaces, are to be above the working platform.

Valves or cocks are to be interposed between the pumps and the suction and discharge pipes in order that any pump may be shut off for opening up and overhauling.

Oil-fuel valves are to be so constructed as to prevent the possibility of any cover being slacked back or loosened when operating the valves. The valves and cocks are to be fitted with legible nameplates.

Where the filling pipes to deep oil tanks are not connected to the tanks near the top, they are to be provided with non-return valves at the tanks or with valves or cocks fitted and controlled as in the case of the outlet valves or cocks on these tanks.

Open drains for removing the water from oil tanks are to be fitted with cocks or valves of self-closing type, and suitable provision is to be made for collecting the oily discharge.

Boiler insulation and air circulation in boiler room

The boilers are to be suitably lagged. The clearance spaces between the boilers and tops of the double-bottom tanks and between the boilers and the sides of the storage tanks in which oil fuel or cargo oil is carried are to be adequate for the free circulation of air necessary to keep the temperature of the stored oil well below its flash point.

Where water tube boilers are installed, there should be a space of at least 760 mm between the tank top and the underside of the pans forming the bottom of the combustion spaces.

Smoke-box doors are to be shielded and well fitting, and the uptake joints made airtight.

Funnel dampers

Dampers which are capable of completely closing the gas passages are not to be fitted to inner funnels of ships equipped for burning fuel only. In ships burning oil or coal alternatively, dampers may be retained if they are provided with a suitable device whereby they may be securely locked in the fully open position.

Control of pumps

The power supply to the oil-fuel transfer and unit-pressure pumps and to the cargo-oil pumps is to be capable of being stopped from a position that will always be accessible in the event of fire taking place in the compartment in which they are situated, as well as from the compartment itself.

Precautions against fire

Settling and daily service oil-fuel tanks and oil fuel filters are not to be situated immediately above boilers or other highly heated surfaces.

Oil fuel pressure pipes are to be led, wherever practicable, remote from heated surfaces and electrical appliances, but where this is impracticable, the pipes are to have a minimum number of joints and are to be led in well-lighted and readily visible positions.

Short sounding pipes to oil-fuel tanks are not to be situated adjacent to boilers or to electric generators or motors.

Water-service pipes and hoses are to be fitted in order that the floor plates and tank top or shell plating in way of boilers, oil-fuel apparatus or deep storage tanks in the engine and boiler spaces can at any time be flushed with sea-water.

So far as is practicable, the use of wood is to be avoided in the engine rooms, boiler rooms and tunnels of ships burning oil fuel.

Drip trays are to be fitted at the furnace mouths to intercept oil escaping from the burners and under all other oil-fuel appliances which require to be opened up frequently for cleaning or adjustment. The arrangements are to be such that a burner is shut off and that the oil cannot be turned on unless the burner has been correctly coupled to the supply line.

For alternately fired boilers using exhaust gases and oil fuel, the exhaust-gas inlet pipe is to be provided with an isolating device and interlocking arrangements whereby oil fuel can only be supplied to the burners when the isolating device is closed to the boiler.

The open ends of air pipes to oil-fuel and cargo oil tanks are to be situated where no danger will be incurred from issuing oil or vapour when the tank is being filled and each opening is to be furnished with a wire-gauze diaphragm of incorrodible material which can be readily removed for cleaning or renewal.

Air pipes from lubricating oil-storage tanks may terminate in the machinery space, provided the open ends are so situated that issuing oil cannot come into contact with electrical equipment or heated surfaces.

The closing appliances fitted to tank air pipes are to be of a type which will prevent excessive pressure coming on the tanks.

In machinery spaces and tunnels where it is not always practicable to extend the sounding pipes above the bulkhead deck, short sounding pipes extending to readily accessible positions above the platform may be fitted, provided those to oil-fuel and lubricating-oil tanks are not situated adjacent to boilers or electric generators or motors, and are fitted with cocks having parallel plugs with permanently attached handles so loaded that, on being released, they automatically close the cocks.

Short sounding pipes to tanks other than oil tanks are to be fitted with shut-off cocks or with screw caps attached to the pipes by chains.

Tank-sounding devices of approved type may be used in lieu of sounding pipes. These devices are to be tested, after fitting on board, to the satisfaction of the Surveyors.

Oil-burning steamships

In spaces where main or auxiliary oil fired boilers are situated, or in spaces containing oil fuel units or settling tanks, a cargo ship is to be provided with any one of the following fixed fire-extinguishing installations:

1. A pressure water-spraying system.
2. A fire-smothering gas installation.
3. A fixed foam installation, supplemented, if necessary, by a fixed or mobile arrangement for pressure water or foam spraying to fight fire above the floor plates.
4. A fixed system discharging Halon 1301

The fixed installation is to be of type (2) or (4) above in all cases where the flash point of the fuel is less than 60°C. (Closed cup test) or where the methane gas is used as the fuel for the propulsion of methane tankers.

In each case, if the engine and boiler rooms are not entirely separate, or if fuel oil can drain from the boiler room into the engine-room bilges, the combined engine and boiler rooms are to be considered as one compartment.

There are to be at least two approved portable extinguishers discharging foam or other approved medium suitable for extinguishing oil fires in each firing space in each boiler room and each space in which a part of the oil-fuel installation is situated. In addition, there is to be at least one extinguisher of the same description with a capacity of 9 litres for each burner, however the total capacity of the additional extinguisher or extinguishers need not exceed 45 litres for any one boiler room.

In each firing space there is also to be a receptacle containing at least 0.28 m^3 of sand, sawdust impregnated with soda or other approved dry material, and a scoop for distributing this material. Alternatively, an approved portable extinguisher may be substituted.

Foam apparatus

The foam apparatus is to be capable of discharging foam to a depth of 150 mm over the largest area on which oil fuel is liable to spread in the event of a leakage of oil fuel.

Where the boilers are situated in an upper part of the machinery space, the above requirement applies also to the flat on which the boilers are situated.

Where the upper parts of the machinery spaces contain oil-fuel tanks and appliances, additional fire protection is to be provided by fitting a foam extinguisher of 45 litres capacity, or a CO_2 extinguisher of 16 kg capacity, having a hose on reel capable of reaching any surface of the upper machinery space on which escaping oil would be liable to fall.

CO_2 fixed installations

When carbon dioxide is used as the extinguishing medium in cargo spaces, the quantity of gas available is to be sufficient to give a minimum volume of free gas equal to 30% of the gross volume of the largest cargo compartment in the ship which is capable of being sealed.

When carbon dioxide is used for an extinguishing medium for spaces containing boilers or internal combustion type machinery, the quantity of gas carried is to be sufficient to give a minimum volume of free gas equal to the larger of the following, either:

40% of the gross volume of the largest space, the volume to include the casing up to the level at which the horizontal area of the casing is 40% or less of that of the space concerned;

or

35% of the entire volume of the largest space including the casing;

The above mentioned percentages may be reduced to 35% and 30% respectively for cargo ships of less than 2000 tons gross;

provided that if two or more spaces containing boilers or internal combustion type machinery are not entirely separate, they are to be considered as forming one compartment.

When carbon dioxide is used as an extinguishing medium both for cargo spaces and for spaces containing boilers or internal-combustion-type machinery the quantity of gas need not be more than the maximum required either for the largest cargo compartment or machinery space. The volume of gas is to be calculated at m^3/kg 0.56.

When carbon dioxide is used as the extinguishing, medium for spaces containing boilers or internal-combustion-type machinery the fixed piping system is to be such that 85% of the gas can be discharged into the space within 2 minutes.

The gas cylinders and main controls are to be located in a cool and well-ventilated position, not likely to be made inaccessible by fire. Provision is to be made for changing the cylinders and checking their contents by weighting or other approved means. Operating instructions are to be displayed at the controls.

Systems in which refrigerated liquid carbon dioxide is stored in bulk are permitted. Duplicate refrigerating units are required, one of which is to be operable from two sources of power, one of which is to be the ship's emergency source of electrical power.

Fixed pressure water spraying systems for engine and boiler rooms

Fixed pressure water-spraying systems for boiler rooms with oil-fired boilers and engine rooms with internal combustion type machinery are to be provided with spraying nozzles of an approved type.

The number and arrangement of the nozzles are to be such as to ensure an effective distribution of water in the spaces to be protected. Nozzles are to be fitted above bilges, tank tops and other areas over which oil fuel is liable to spread and also above oil-fuel settling and service tanks, heaters, pumping units, purifers and other main fire hazards in the boiler and engine rooms.

The system may be divided into sections, the distribution manifolds of which are to be operated from easily accessible positions outside the spaces to be protected and which will not be readily cut off by an outbreak of fire.

The system is to be kept charged at the necessary pressure and the pump supplying the water for the system is to be put automatically into action by a pressure drop in the system.

The pump is to be capable of simultaneously supplying, at the necessary pressure, all sections of the system in any one compartment to be protected. The pump and its controls are to be installed outside the space or spaces to be protected. It must be impossible for a fire in the space or spaces protected by the water-spraying system to put the system out of action.

Special precautions are to be taken to prevent the nozzles from becoming clogged by impurities in the water or corrosion of piping, nozzles, valves and pump.

Halon systems

Fixed systems using Halon 1301 (bromotrifluoromethane) are required to be capable of providing rapidly, and in any case within 20 seconds, a concentration of about 5% based on the gross volume of the protected space at 20°C.

The storage vessels should preferably be positioned outside the protected space; however, they may be fitted inside that space provided that the charge is uniformly distributed throughout the space in a suitable number of storage vessels, that the total required charge of Halon is capable of simultaneous release by means of a device attached to each storage vessel and that each release device is actuated by a suitable medium (such as electricity, carbon dioxide or nitrogen) delivered to it by at least two separate routes from a position which would be readily accessible with a fire in the protected space. A suitable alarm is required to be provided to give automatic warning of the release of the charge so that the space may be safely evacuated.

Means are also required for automatically stopping ventilation fans supplying air to the protected spaces before the release of the Halon. Unlike carbon dioxide, Halon 1301 does not have a high vapour pressure and requires another gas to propel it from the storage vessel to the protected space. Nitrogen is acceptable for this purpose, although other gases will also be considered.

Means are required for checking the level and pressure of the Halon in the storage vessels.

Fire-fighting appliances in spaces containing internal-combustion-type machinery

Where internal-combustion engines or gas turbines are used, either (1) for main propulsion purposes or (2) for auxiliary purposes associated with a total power not less than 746 kW in cargo ships of

1000 tons gross and over, and all passenger ships, the spaces containing such machinery are to be provided with the following arrangements A and B:

A. either 1. A pressure water-spraying system.
or 2. A fire-smothering gas installation.
or 3. A fixed froth installation supplemented, if necessary, by a fixed or mobile arrangement for pressure water or froth spraying to fight fire above the floor plates.
4. A fixed system discharging Halon 1301.

B. There is to be in each engine space one approved foam-type extinguisher of not less than 45 litres capacity or equivalent and also one approved portable foam-type extinguisher for each 746 kW of the engines or part thereof. The total number of portable extinguishers so supplied is to be not less than two and need not exceed six.

For cargo ships of under 1000 tons gross arrangement B only is required.

For cargo ships of under 150 tons gross the provision of a 45 litres extinguisher may be waived.

Fire fighting appliances in spaces containing steam machinery

Provision is to be made for extinguishing lubricating oil fires in spaces which are separated from boiler rooms by watertight bulkheads when these spaces contain propulsion turbines or enclosed forced lubricated engines using superheated steam. Equipment not less effective than that detailed in B above is to be provided.

FIRE EXTINGUISHERS

The extinguishers required for use in the machinery spaces of ships burning oil as fuel are to be of a type discharging foam, CO_2 or other approved medium suitable for extinguishing oil fires.

Portable extinguishers are to have a minimum capacity of 9 litres or equivalent and a maximum capacity of 13.5 litres or equivalent.

The extinguisher capacities mentioned in these Rules refer to the quantity of fluid contained in the extinguishers.

Portable extinguishers are to be fitted in readily accessible positions, and a notice plate is to be provided stating that on no account are discharged extinguishers to be replaced in their holders until they have been replenished.

One extinguisher is to be fitted in the vicinity of the entrance door to the space in which it is intended to be used.

A spare charge is to be provided for each portable fire extinguisher which can be readily recharged on board. If this cannot be done, duplicate extinguishers are to be provided.

The makers of portable and fixed fire-extinguishing appliances are to furnish a certificate stating the nature and quantity of the fire-extinguishing medium. In the case of fixed foam or gas fire-extinguishing systems the makers are to state whether the quantity supplied is adequate to give the required depth of foam or gas concentration.

If considered necessary, the Committee of Lloyd's Register of Shipping may require the makers to produce evidence from a recognised independent testing authority regarding the suitability of their appliances.

Acceptable equivalents

136 litres froth extinguisher — 45 kg CO_2 extinguisher.
45 litres froth extinguisher — 16 kg CO_2 extinguisher.
Portable froth extinguisher — 4.5 kg CO_2 extinguisher.

The foregoing requirements are for machinery spaces only, and give some indication as to what is required for a vessel as a whole. The question of fire-fighting appliances is continually under revision, minor modifications and additions being made.

18 Water tube boiler surveys and repairs

Lloyd's Register of Shipping in common with other classification societies require all water tube boilers whether main or auxiliary to be surveyed periodically.

At these surveys, the boilers, superheaters, economisers and air-heaters are to be examined internally and externally and, where considered necessary, the pressure parts are to be tested by hydraulic pressure and thickness of plates and tubes, are to be ascertained to determine a safe working pressure.

The principal mountings on boilers, superheaters and economisers are to be opened up and examined and the safety valves adjusted under steam to a pressure not greater than 3% above the approved working pressures of the respective parts. The remaining mountings are to be examined, if considered necessary by the surveyor. Collision chocks, rolling stays and boiler stools are to be examined and maintained in efficient condition.

The oil-fuel-burning system is to be examined under working conditions and a general examination made of fuel-tank valves, pipes, deck control gear and oil-discharge pipes between pumps and burners. At survey time, the future safe and also efficient working conditions of the boiler can be investigated, the latter from the economical operation aspect being especially important to the owner's representative.

There are various types of water tube boiler, each having from one to five drums. The most usual is the two-drum type which is normally specified for new turbine installations.

In view of this one type tendency, it is proposed to utilise this as the basis for the following discussion on surveys, one of the main objects of which is to stress how ill treatment in service shows up in the form of characteristic boiler defects which, when allowed to develop, will necessitate repairs being effected.

A thorough conscientious examiner in any walk of life knows the value of working to a definite routine and, in the case of boiler surveys, where it is of the utmost importance that nothing is missed, this is essential.

The total heating surface of each individual boiler embodies generating, superheating, feed and/or air heating surfaces, and the extent of these varies from one installation to the next. Initially, therefore, at any survey, unless the boiler in question is known to the surveyor, it is practically essential to make a brief scrutiny of the boiler arrangement plan, noting particularly the designed superheat temperature and the method utilised for its control.

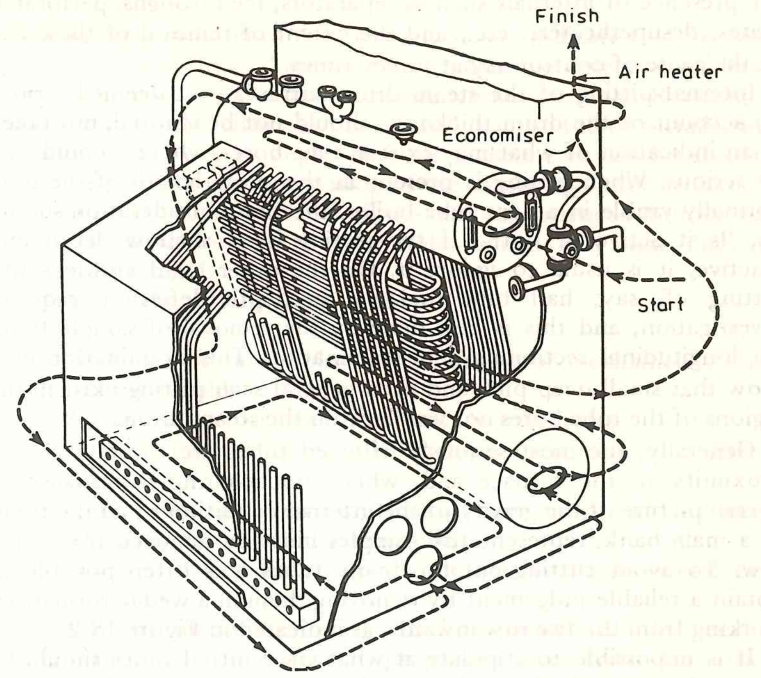


Figure 18.1 Routine examination of D-type water tube boiler

If the designed superheat temperature is above 400°C it is worth while bearing in mind that special steels, utilising more advanced welding techniques, have been embodied in the construction of the superheater and its mountings.

The method of superheat control should also be ascertained as each normally embodies its own form of additional and essential equipment, the examination of which could be overlooked.

The layout of the boiler unit having been ascertained, a convenient survey procedure is as shown in Figure 18.1. Assuming the boiler has been cleaned and prepared for survey, it is proposed to follow this circuit, enumerating and commenting on possible defects at the various stages.

STEAM DRUM INTERIOR

Access to steam drums is often rendered extremely difficult due to the presence of internals such as separators, feed troughs, perforated plates, desuperheaters, etc., and the extent of removal of these can be the cause of controversy at survey times.

Internal pitting of the steam drum surfaces, not deemed serious on account of the drum thickness, should not be ignored, but taken as an indication of what may exist in tube bores, where it could well be serious. When pitting is present in the short length of the bore normally visible in a bent tube boiler, the first consideration should be, 'Is it active or not?'. If the pitting is of shallow depth and inactive, it is usual to ignore it. On the other hand visible active pitting of, say, half tube-thickness in depth definitely requires investigation, and this is best done by the removal of sample tubes for longitudinal sectioning and examination. This examination may show that small deep pits, and even general scab pitting exist in the regions of the tube bores not visible from the steam drum.

Generally, the most seriously affected tubes are those in closest proximity to the furnace and, when endeavouring to visualise an overall picture of the gravity of the internal condition of all the tubes in a main bank, representative samples must be removed from each row. To avoid cutting out too many tubes it is often possible to obtain a reliable judgement by removing them in a wedge formation, working from the fire row inwards, as indicated in Figure 18.2.

It is impossible to stipulate at what stage pitted tubes should be renewed, so much depending on the nature of the pitting – it is

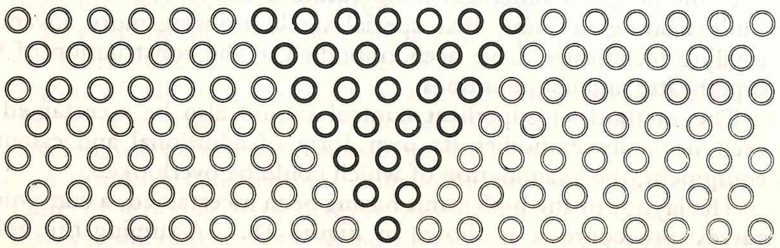


Figure 18.2 Representative tube removals

comparatively easy to judge the depth of isolated pits, but general scab pitting is a different matter. However, when there is less than 50% tube wall thickness remaining in representative sectioned tubes, every consideration should be given to the early renewal of the tubes in question.

Retubing

Should the condition of representative tubes indicate that failures are imminent and immediate renewals advisable, every consideration should be given to the materials and labour available. Retubing of a water tube boiler either in part or full, can be full of pitfalls, and to entrust such work to unproven boilermakers can well be disastrous.

In all cases proper supervision of the whole operation from cutting out to final hydraulic test is vital – an inexperienced 'burner' can in minutes cause damage to tube holes which may take days, even weeks, to rectify.

Some of the pitfalls are as follows:

1. Grooving of tube holes when burning or mechanically cutting out tube stubs.
2. Flame cuts across ligaments between tube holes.
3. Tube holes out of round (often an indication of a distorted drum).
4. Tube holes and their serrations (if any) not properly cleaned to bright metal before inserting tubes.
5. Ends of tubes not properly cleaned to bright metal before inserting.
6. Ends of tubes not entering tube hole parallel to hole bore.
7. Insufficient tube length projecting into drum for efficient belling – minimum length should be 6 mm, and belling included angle not less than 30°.
8. Makers expanding sequence not adhered to – in a row of tubes, particularly straight tubes, some increase in tube length occurs on expanding and, unless allowed for, this can result in built-in stresses.

In cases where careless boilermakers have damaged tube holes, provided the boiler drum is of steel having a tensile strength not less than 520 N/mm^2 and that welders experienced in this type of work are available, it is usual to grind out the defects to a U preparation, crack test and then build up with light runs of electric welding using suitable electrodes and some preheat. Each run of welding is crack tested as deposited, and on completion of welding and machining of holes to original size, the job is subjected to a final crack detection test.

Repairing cracks

It should be pointed out that the foregoing welded repair of tube holes only applies to minor abrasions of the tube hole bores, and if cracking is found in the ligaments between holes a much more serious situation is presented.

Provided these cracks are in *isolated ligaments* and the boiler drum is of steel having a tensile strength not exceeding 520 N/mm^2, the following is considered an acceptable technique for welded repairs:-

1. Welding to be carried out by welders approved for Class 1 welding, under strict supervision, using low hydrogen electrodes, and to the surveyor's satisfaction.
2. Welding zone to be preheated to 100°C minimum.
3. In the case of 'through' cracks it is always preferable that a 'balanced' technique be used i.e. welding alternately from both sides to avoid as far as possible distortion and locked up stresses.
4. Before commencement of welding all cracks to be proved eliminated by crack test.
5. After welding the complete weld to be covered by asbestos blanket and allowed to cool slowly.
6. A magnaflux test to be made of completed weld after grinding off in preparation for radiography.
7. A 100% radiograph to be obtained to Class 1 standard for the surveyor's approval.

It should be clearly understood that repairs to all pressure parts of boilers should only be carried out under the direction and survey of the responsible authority e.g. Government or Classification society surveyor and in cases of cracking of boiler drums, other than isolated cracking in ligaments, it may be prudent to refer the matter to the authority headquarters for further consideration.

Tube and desuperheater pipe failures

Tube failures can occur at very inopportune moments, renewals are costly and a ship may be delayed; it is of the utmost importance, therefore, when active pitting is present, that its cause is established and obviated. In most cases, having established the cause and satisfied oneself regarding the internal condition of the tubes, it is an advantage to chemically clean the boiler so that any oxide scabs

covering pits are removed, prior to re-steaming the boiler under corrected water treatment conditions. While examining steam drums internally attention should be paid to the condition and fastenings of any fittings not removed for access purposes – internal pipes to desuperheaters, internal feed pipes, low-water alarms and in particular steam driers.

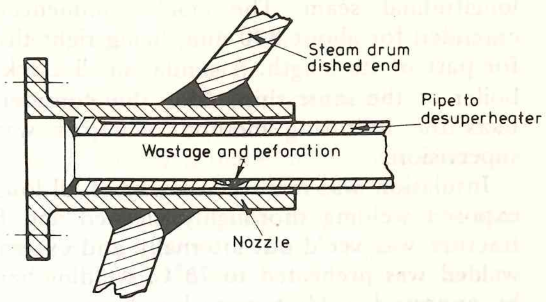


Figure 18.3 Defect in desuperheater pipe

Desuperheater pipe connections, fixed at their ends and operating under continually varying temperature conditions, should be checked for soundness, particularly adjacent to the drum end; perforation of such pipes means boiler contents passing through into the desuperheated steam line.

A typical example of this type of defect is shown in Figure 18.3 and repair by the renewal of the defective portion is the obvious remedy.

Faults following stress relief

Several incidents have occurred where attachments have been welded on to steam drums after stress relief, and eventually cracking has developed in way of these welds of such a serious nature as to necessitate the renewal of the drum (see Figure 18.4).

All such welds should be carefully examined, and ground smooth for crack testing if there is any doubt as to their integrity – the possibility that such bars have been welded to the drum after it was

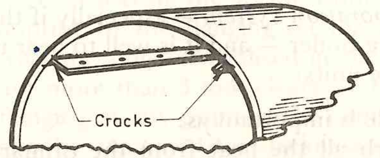


Figure 18.4 Cracking of boiler drum after welding of attachments

stress relieved should always be borne in mind as, should this have been done, a stress concentration could be produced which, under fluctuating working conditions may well initiate cracking, especially if any under-cutting is present.

In one such case, serious cracking was discovered along the weld attachment of an angle bar supporting a steam strainer adjacent to a longitudinal seam. The crack commenced at undercutting and extended for about 800 mm, being right through the shell thickness for part of its length. A similar small crack was found in the other boiler of the same ship. After due consideration of all the relevant facts the following method of repair was adopted, under strict supervision.

Insulation was removed in way of all longitudinal seams, and the exposed welding thoroughly cleaned and fully radiographed. The fracture was vee'd out internally and externally, and the area to be welded was preheated to 75°C. Welding began on the inner surface by approved welders using low hydrogen electrodes. To lessen the possibility of distortion and built-in stresses the balanced welding technique was used where practicable, i.e. alternate welding from inside and outside, the inner root run being cut out and surfaces crack tested prior to commencement of outside welding – preference always being given to downhand in lieu of overhead welding.

On completion of welding the welds were ground flush and fully radiographed. Stress relieving was then carried out at a temperature of 580°–620°C for a period of 1½ hours and the welds subsequently allowed to cool slowly. Hydraulic testing was carried out on completion.

Dual evaporation boilers

In the case of dual evaporation boilers where there is no controlled feed to the primary side, the steam drum and tubes are worthy of special scrutiny at survey times. One case of overheating resulted in the steam drum lower half being discoloured and bulged outwards about 10 mm, the generating and main bank tubes being badly distorted, slack in their holes, and pushed about 5 mm into the drums.

It is not always immediately obvious that a water tube boiler being surveyed forms part of a *dual evaporation system* – especially if the secondary drum is remote from the boiler – and it is well to bear in mind the following features of these units:

1. The secondary evaporation side is important as:
   (a) If dirty it will not absorb all the heat from the primary side with the result that production of l.p. steam falls off and a pressure build up with lifting of safety valves could occur on the primary side – although a primary side pressure limiting switch is fitted which should shut off fuel.
   (b) A fracture in the high pressure evaporating elements in the secondary side drum could result in immediate loss of water in the boiler.
2. The primary side (i.e. actual boiler) is designed to operate as a 'closed' system without any normal regulated feed, being initially filled to working level with high purity water.
3. Any loss of water on the primary side through leakages or lifting of safety valves *if noticed* is made up by switching on a small permanently connected high pressure feed pump.
4. It will be apparent from the foregoing that the operational efficiency, at all times, of the low water alarms and oil fuel shut off arrangements are of vital importance for this type of boiler.
5. Distortion of a boiler drum is not always evident, and in cases where continuous trouble has been occurring with leakages at tube expansions, out-of-round tube holes through drum distortion should be suspected. In all cases a straight edge together with a trammel will quickly check circularity along the length of a drum. If distortion is present its magnitude together if possible with details of drum material should be referred to the authority responsible for consideration, before any repairs are commenced.
6. The safety valves on the secondary side are adjusted in the normal manner.
7. The safety valves on the primary side are regarded as alarm valves and their setting is accomplished by lowering the secondary side water level – this, by decreasing the amount of water in contact with the high pressure steam heated evaporating elements in the secondary drum, restricts the heat flow from primary to secondary, and so creates the necessary pressure build up for setting the primary side safety valves.

All drum openings to mountings should be sighted – it has been known for tools to be 'planted' in passages leading to gauge glasses.

After leaving the steam drum the fit of the door, as shown by the imprint of the flanging on the door joint should be verified; this, with the door centralised in the opening, should show that there is not more than 3 mm clearance between spigot of door and manhole flanging at any point of the opening. The door studs and nuts should also be examined for slackness and stretched threads, also the door

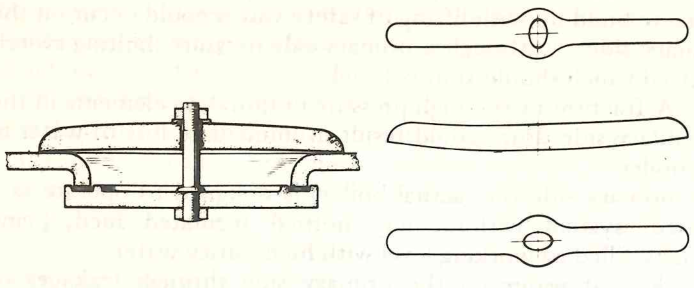


Figure 18.5 Door dog distortion

dogs for distortion – ovality of the holes in the dogs is a sure indication of distortion through overtightening, it not being uncommon in the lighter construction dogs used on lower pressure boilers to find the holes so oval that the dogs bind on the studs (see Figure 18.5).

STEAM DRUM EXTERIOR

On leaving the steam drum and prior to examining the upper mountings, all internals removed for access should be checked and, if necessary, arrangements made to have desuperheater coils tested etc.

The feed regulator, feed check valves, water-gauge fittings and drum safety valves are then examined, particular attention being given to the securing arrangements of seats in valves, of cover to valve chests, and of valve chests to drum nozzles. The importance of verifying that both means of ascertaining the drum water-level are in good order, and readily readable from platform level, cannot be too highly stressed. In a recent case of tube trouble through water shortage, a leaking joint above the top of a gauge glass causing a pressure drop and rise in water-level in the glass, was cited as the cause. The other gauge glass in such an instance would be showing the correct, but lower level, and presumably the operators worked to the glass showing the higher level for fear of priming.

At this juncture it is well to remember that the majority of water tube boiler emergencies are caused through water shortage and, on this account, to make a special examination of the low water oil fuel shut-off and alarm arrangements. Present day classification rules call

for 'Each fired boiler to be fitted with two systems of water level detection which are to be independent of each other and of any other mounting on the boiler. Both systems are to operate audible and visible alarms and shut off automatically the fuel supply to the burners when the water level falls to a predetermined low level'.

It is usual for one of the systems to be activated by a constant leg water level transmitter, the other by a float operated magnetic switch, and verification of their efficiency either by low water simulation or other means, *should be routine* – not forgetting that sticking floats in magnetic switches and leaking valves in water level transmitters can and have occurred.

In the days of riveted drums, external wastage through leakages at riveted seams and at riveted-on mounting pads sometimes occurred, but with present-day solid-forged or all-welded drums, having mountings bolted to nozzles welded into the drum there is little, if any, likelihood of this occurring.

It is well, when sighting the top of the steam drum to take a look at the longitudinal top joint of casing to drum as, in some earlier designs, this joint, which has to cater for the longitudinal and upward movement of the drum relative to the casing, gave considerable trouble through gas leakages. Later designs have dispensed with sliding joints, the casing being welded to the drum casing bar, and the flexibility of the casing allowing for any drum movements.

At this point the possibility of serious defects being initiated through indiscriminate welding on to the outside of finished all-welded and stress-relieved steam drums, is worthy of mention. Several incidents have occurred where attachments have been welded on to boiler steam drums and Scotch boiler shells after stress relief,

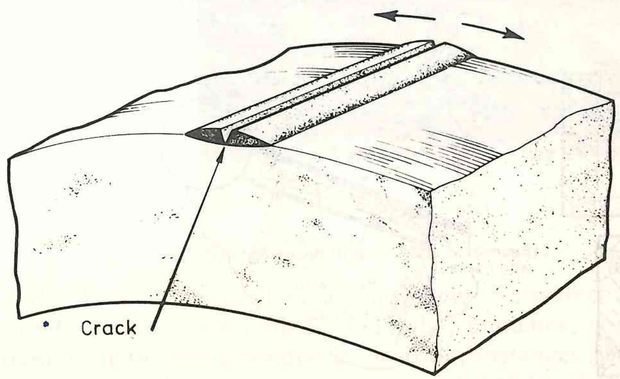


Figure 18.6 Base run cracking in welds

and eventually cracking has developed in way of these welds, of such a serious nature as to necessitate the renewal of the drums in question. This is specially important where high manganese/carbon steel (1.3–1.5% Mn) is used for drums.

The manufacture of welded boiler drums to Lloyd's Register Class I requirements by a number of approved firms, is a specialised process the final operation of which is stress relief (see Chapter 11). To put down light runs of welding on to the cold, thick, unyielding section of a boiler drum is asking for such runs to crack as they suddenly contract on cooling (see Figure 18.6). These cracked runs, possibly at the root of an attachment fillet, can easily pass unnoticed and be covered up by succeeding runs, which as the heat in the zone builds up, do not crack.

Thus, we have on completion a weld which appears sound, but has a crack at its root and has stresses locked up within it, tending to propagate that crack.

To suggest that, at boiler surveys, one should meticulously look for cracks in welded seams and weld attachments would be unreasonable, although one should nevertheless be alert to such possibilities; special attention can however be given to the possible after effects, when repairs involving welding on to boiler parts which it is not practicable to stress-relieve, are being considered.

Whilst at steam drum level consideration should be given to the condition of any dampers. Dampers, often used for superheat control, can be a vital component operationally, especially in reheat boilers which normally use them for both superheat control and also for diverting the combustion gases away from the reheater during manoeuvring and in port. Burnt and distorted dampers can and have caused serious operational difficulties, especially in some boiler

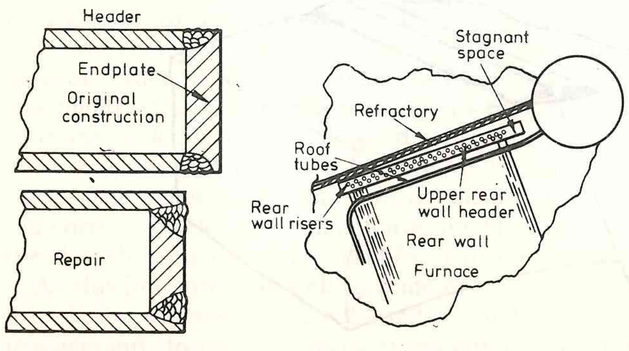


Figure 18.7 Welding in new end plate

designs where they operate at high temperatures, and they should be sighted at survey times.

Before dropping down and proceeding with the superheater examination, attention should be given to the waterwall upper headers. It is not usual for any defects to occur here but specimen doors, always including the end ones, should be removed to allow an internal examination to be made.

In one design of D-type boiler the upper rear wall header, sloping upwards, extended at it's upper end beyond the tube holes, resulting in an uncirculated stagnant pocket being formed which in one case became holed through corrosion. A satisfactory repair was effected by cutting back the header and welding in a new end plate, (see Figure 18.7).

SUPERHEATERS

Following the suggested survey routine in Figure 18.1 an examination is then made of the superheater headers internally and externally, together with the safety valves and main stop valve. The internal examination of the headers of present-day superheaters is usually straightforward and without much cause for comment. Boiler priming is usually shown by deposits at the inlet end of the headers and in the associated superheater tubes, such deposits can cause pitting (Figure 18.1), overheating and distortion.

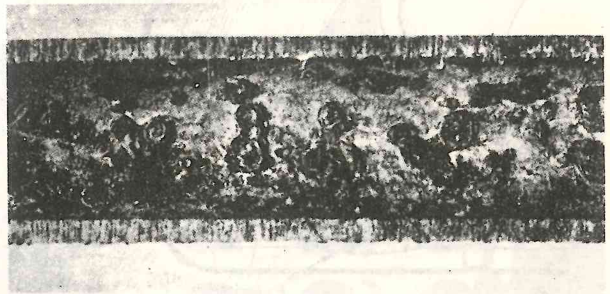


Figure 18.8 Pitting in superheater tubes

The headers themselves are normally fabricated from square or round section thick-walled steel tube, branches, ends and internal division plates being welded in position. Instances of fractures in the welding of such attachments have revealed themselves in service or at surveys, and it is well to give some attention to all welds which are

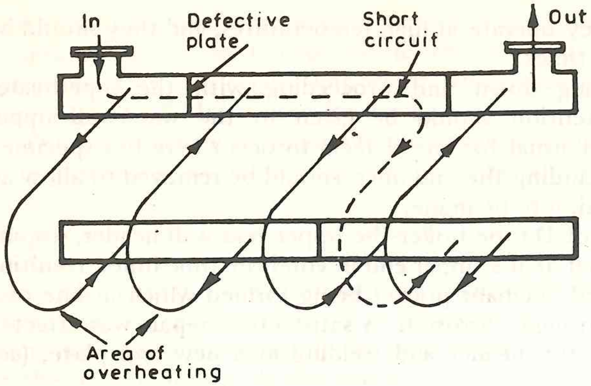


Figure 18.9 Short circuiting of steam in superheater

visible, especially those securing division plates, as, if these plates are adrift or ineffective, short circuiting of steam and serious overheating of parts of the superheater can be caused (Figure 18.9).

Steam short circuiting, through gaps in the attachment welds of division plates to headers, has also been known to cause erosion of such a depth as to necessitate building up the grooves by electric welding (by no means an easy task through the small access hole) before re-welding the division plate itself to the header (Figure 18.10).

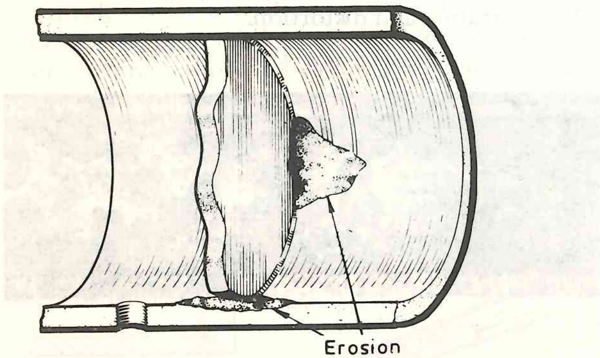


Figure 18.10 Erosion in superheater caused by short currenting steam

In the case of boilers using attemperators as a means of superheat control special attention should be given to the superheater header section coupled to the attemperator (see Figure 18.11). Several cases of severe thermal cracking of the inside of these headers have occurred necessitating their renewal (see Figure 18.12).

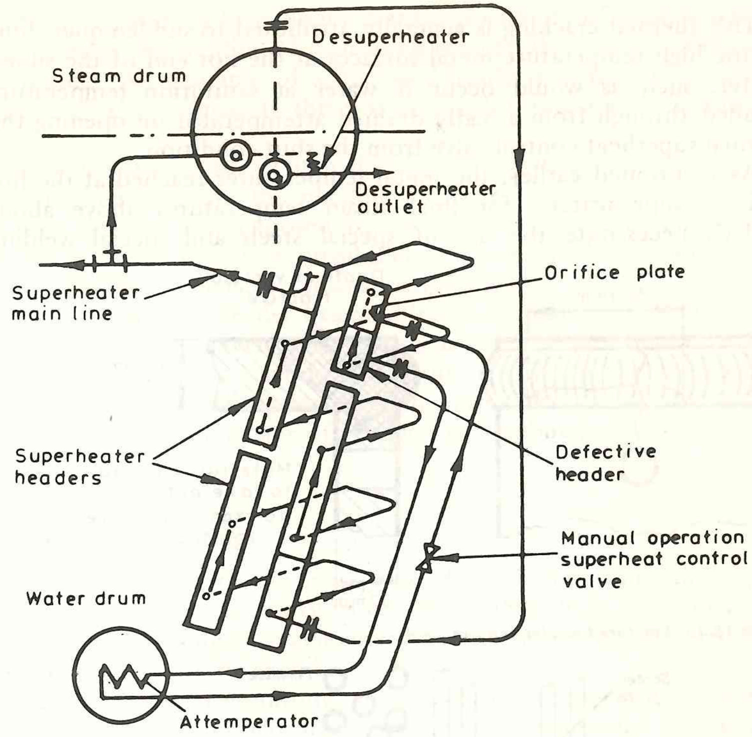


Figure 18.11 An attemperator being used as boiler superheat control

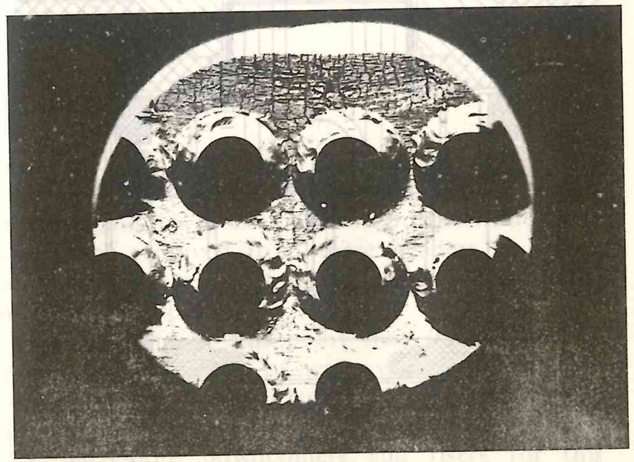


Figure 18.12 Cracked header superheater

This thermal cracking is generally attributed to sudden quenching of the high temperature metal surfaces at the hot end of the superheater, such as would occur if water at saturation temperature flooded through from a badly drained attemperator on opening the manual superheat control valve from the shut condition.

As mentioned earlier, the metal temperatures reached at the hot end of superheaters, for final steam temperatures above about 400°C) necessitate the use of special steels and special welding

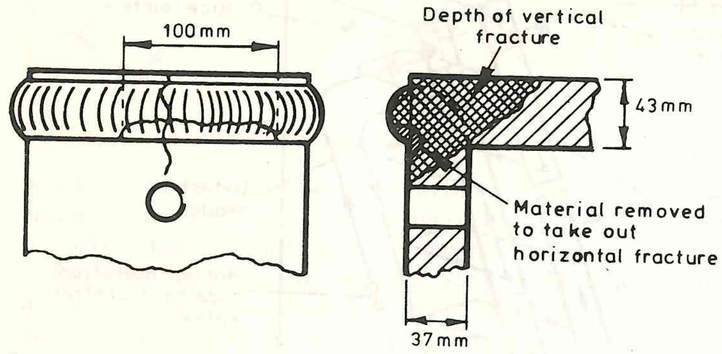


Figure 18.13 Fractured header end cap weld

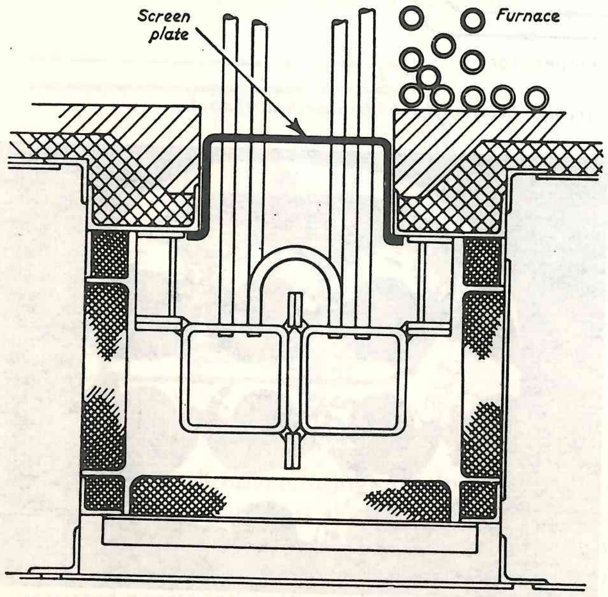


Figure 18.14 Superheater header screen plates

techniques, there is little doubt that the possibility of hidden defects occurring in the welding of such steels is more likely than in ordinary mild steel. An example of a fractured header end weld is shown in Figure 18.13; fortunately this was revealed during a boiler hydraulic test.

Such instances can occur without previous intimation and can in part be attributed to the possible presence in weld attachments of hidden defects, not exposed by the normal testing methods used during construction. This possibility is more likely in welded units utilising some of the earlier heat-resisting steels.

The superheater header examination is not complete without the efficiency of the 'screen' plates being ascertained (see Figure 18.14); these plates of heat-resisting steel, through which the superheater tubes pass, screen the headers from the direct heat of the furnace and help to prevent the escape of products of combustion into the boiler room.

Superheater mountings

Before passing on to the rear parts of the boiler itself, the superheater mountings, i.e. safety valves, stop valve, drain and vent valves and also the closing arrangements for inspection hole and hand hole openings remain to be examined.

Defects in boiler mountings could well be the subject of a separate exercise. Defects in closing arrangements are usually scored and distorted seatings, either of which if not noticed and rectified can quite easily cause serious delays through an enforced shut-down, when raising steam after a survey.

WATER-WALL HEADERS AND CASING

The furnaces of modern water-tube boilers are invariably completely water-walled, but earlier D types fired from the front only had water-wall tubes lining the side and rear walls, and roof. Sufficient doors or handhole plugs should be removed from these headers at survey times to enable an accurate assessment to be made of the internal condition of the headers and tubes.

It is well to bear in mind at this point that the method of connecting upper and lower headers of water-walls to the boiler drum varies – in some designs all the circulation is effected through tubes which in turn form part of the floor and roof of the furnace, whereas others use large-bore downcomers and risers for this purpose. Whilst examining the tubes entering the bottom headers it should be borne in mind that cases of side-wall tube failure have been attributed to deposits accumulating at mid-length of water-wall headers fitted with downcomers at each end (see Figure 18.15).

When the internal condition of the waterwall tubes and headers, also roof and floor tubes (if fitted), has, from the cleanliness, pitting and corrosion aspect been ascertained, attention should be

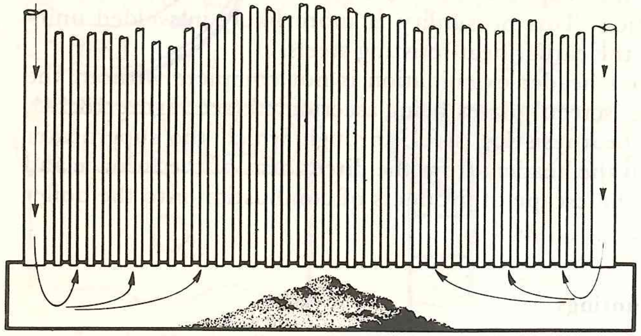


Figure 18.15 Mid-length deposits in water-wall header

transferred to the casing. The casings of water tube boilers of the present time are either of double, or single membrane walled type. In the case of the former, refractory failures followed by cracked or burnt inner casings result in leakage of combustion air into the furnace.

This is a serious state of affairs, but much more serious and occasionally responsible for complete shut-down are refractory failure and overheating of the casings of earlier single-cased boilers. In such cases, it is possible for the leakage of furnace gases through sprung seams and burnt casings to render the boiler room uninhabitable.

A striking example of this is shown in Figure 18.16 which shows slagging up of a header-type watertube boiler, the rise in pressure and concentration of heat in the lower parts of the boiler eventually making their release around a soot blower opening.

Before leaving the outside of the boiler a quick glance should be given to the flatness of the furnace casings, especially if they are of membrane construction – any distortion through a minor furnace explosion may not be so noticeable when inside the furnace, and whereas the pressure parts may not be damaged in a double cased tangent tube design, this of course is not the case with membrane walls.

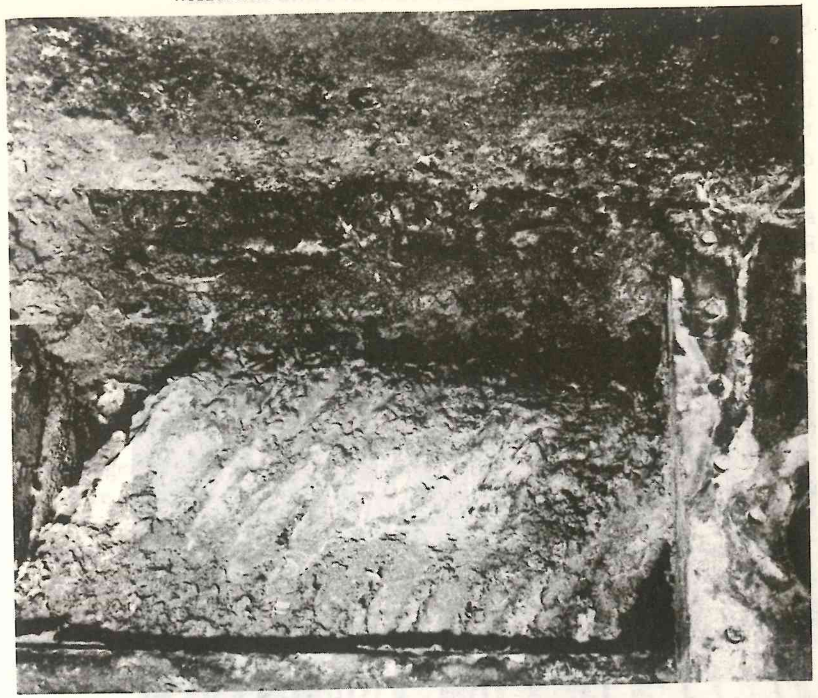


Figure 18.16 Slagging of superheater

Before leaving side and rear wall headers, the drain valves fitted to these headers should be examined, as the use of these valves after shut-down serves to clear the headers of unwanted deposits.

From the side-wall header and side casing, the next convenient step in the survey is the furnace.

FURNACE AND SCREEN AND WATER-WALL TUBES

After entering the furnace, it is well to pause in the middle of the floor and get an overall impression of the general condition. Look at screen tubes, water-wall tubes, roof tubes, refractories, quarls, soot blowers, and then glance through the screen tubes at the superheater supports and superheater tubes, always bearing in mind that an unreported shortage of water as a rule results in a general distortion of the furnace tubes.

Screen tubes

There are normally three rows of screen tubes and as their name implies they should screen the superheater from the radiant heat of the furnace – overheating of these tubes is usually shown by distortion from their correct position and on occasions by swelling.

Looking on to the face of the main bank it is easy to see which screen tubes are distorted out of their correct position, as shown in Figure 18.17, and with a torch as the only illumination in the

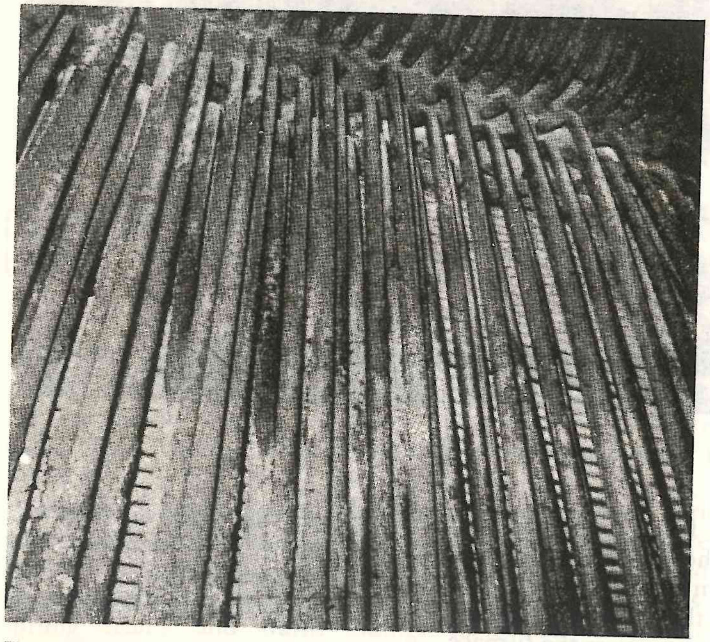


Figure 18.17 Distortion of screen tubes

furnace, it is a simple matter to shine a beam sideways across the face of the bank and pick out those tubes which are sagging inwards towards the furnace (see Figure 18.18).

To state, in writing, how much a tube should be allowed to sag before renewal is required would be rash as so much depends on circumstances – a single distorted tube in a bank requires different consideration to a generally distorted tube bank. A figure of 15 mm in a length of 300 mm has been advanced as a maximum permissible deviation, but the position of the tube, its condition, probable cause of distortion, etc would need to be considered when making such decisions.

In view of the foregoing, when deciding whether or not distorted tubes are fit for further service, it is well to consider their proximity to the flame envelope, and also to make a special examination of any tubes which appear to have been subjected to flame impingement through some derangement of the oil burning equipment.

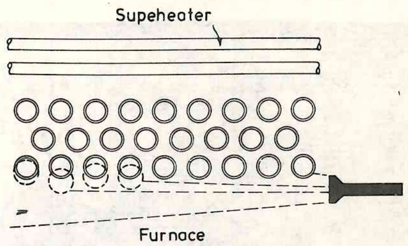


Figure 18.18 Checking for distorted tubes

Leakages at the top expansions of screen tubes are usually shown by white stains down the outside of the tubes, and these should be noted for re-expanding.

While making an examination of the screen tubes in the furnace, it is convenient to assess the ease of passage of the gases through the superheater, from the cleanliness aspect, and also to examine the furnace end of the superheater supports, which often as not are only visible through the screen tubes.

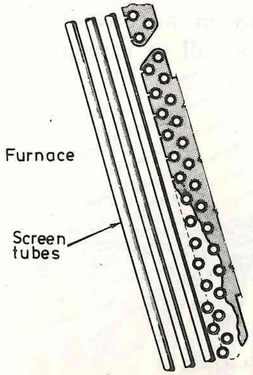


Figure 18.19 Burnt superheater support plates

In some of the earlier designs fitted with heat-resisting steel support plates, it is sometimes found that the furnace side of these plates has entirely burnt away leaving one leg of the superheater U-tubes unsupported (see Figure 18.19).

Screen tubes, when exposed to excessive heat for prolonged periods, caused maybe through restricted circulation or through flame impingement, can alter their material structure and develop high temperature creep cracks or, on account of rapid thermal cycling, can fracture circumferentially through fatigue, a typical example of which is shown in Figure 18.20.

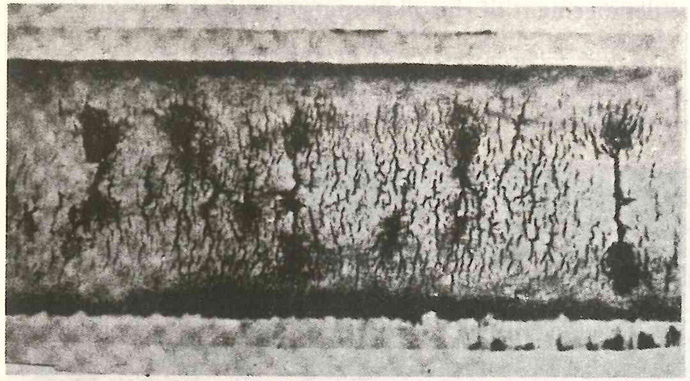


Figure 18.20 Circumferential thermal fatigue fractures in screen tube bores

The D type boiler has been taken as the 'pattern' for this chapter on boiler surveys. Whilst discussing screen tubes, between which all furnace gases pass *en route* to the superheater, it is worthwhile to consider their counterparts in the external superheater type boilers.

In these boilers the superheaters are housed in a convection section separated from the furnace section by a wall or screen of

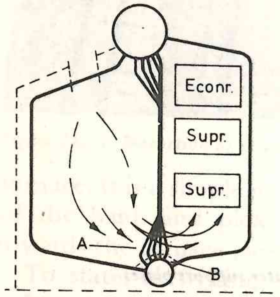


Figure 18.21 External superheat boiler

tubes which is gastight except for a space at the bottom where the tubes are staggered to give a gas passage between them (see Figure 18.21). All the furnace combustion gases have to pass through this passage, *en route* to the superheater, and these tubes A and the refractory B in way of them protecting the water drum should always be the subject of careful scrutiny.

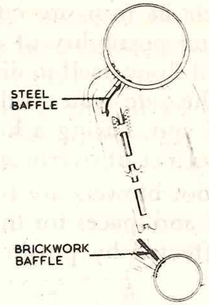


Figure 18.22 Baffles above and below superheater

Baffles are attached to the rear screen tubes, above and below the superheater (see Figure 18.22). This confines the path of the furnace gases to the superheater. The condition and attachment of these baffles should be verified, as short-circuiting gases can cause local overheating of parts of the superheater and loss of superheat.

Water-wall tubes

The observations made regarding screen tubes apply equally to water-wall tubes, but, in addition, as these tubes terminate in headers

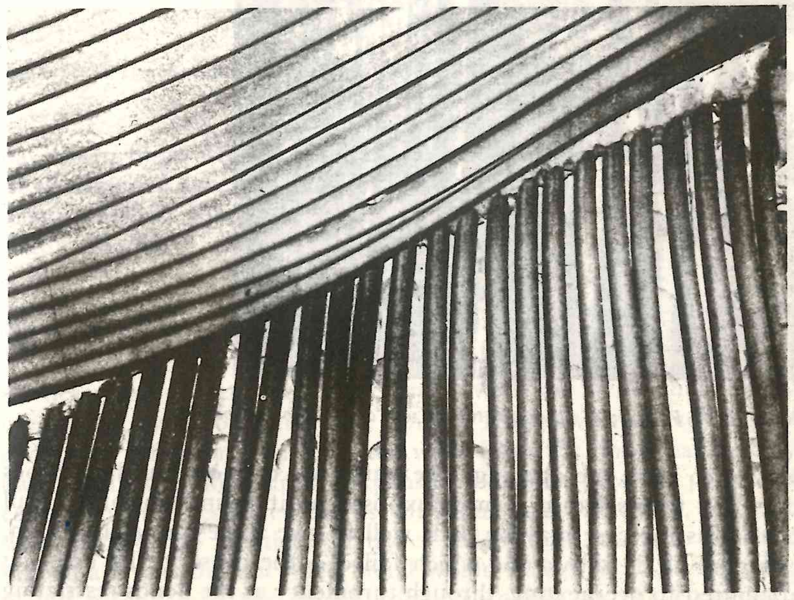


Figure 18.23 Sagging roof tubes