which in turn are connected back to the boiler drums, there is a greater possibility of overheating through restricted circulation. This could show itself in distortion or swelling of tubes.

The side water-wall tubes pass up and over to form the furnace roof and, having a horizontal portion, are among the first to show the effect of overheating through water shortage (see Figure 18.23).

Soot blowers are fitted in various positions in the furnace walls or roof and spaces for them have to be provided through the tubes. This is effected by putting local bends in the two tubes either side of a

Figure 18.24 Fracture of water wall tube in way of soot blower opening

blower to form the opening. The outer two of these four bent tubes thus find themselves in a more exposed position in front of the wall or roof as the case may be. It is well to give these special attention.

Figure 18.24 shows one which failed – the cause in this case was attributed to overheating, through turbulence at the bends restricting circulation in the tubes.

It is of interest to note that although on this occasion fuel was shut off immediately, water shortage and heat in the brickwork were sufficient to cause overheating and distortion of the roof tubes.

At this juncture a point worth remembering is that if an unreported water shortage has occurred, the first tubes to overheat will

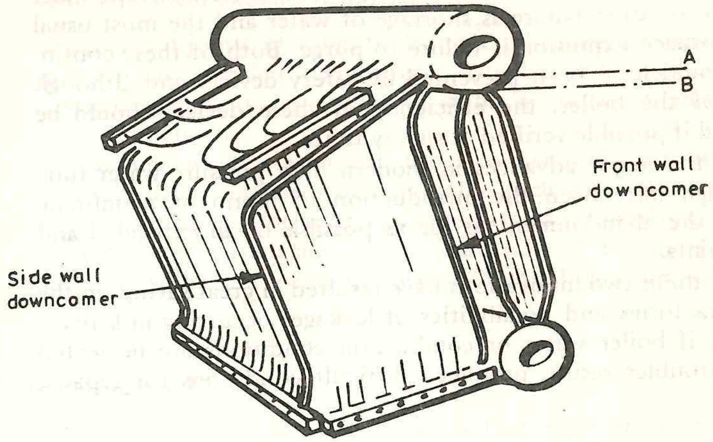


Figure 18.25 Uncovering of downcomers stopping circulation

have been those whose circulation stops first i.e. the ones fed by the downcomer A which has the highest water exit level from the steam drum – often the downcomer feeding the furnace side wall (see Figure 18.25).

MEMBRANE WALLS

As described earlier, membrane water walls are being increasingly used in all types of water tube boilers. They have resulted in great savings in refractories and, as the walls form the boiler casing they have eliminated differential expansion between pressure parts and casing which necessitated the use of sliding seals. However, there are disadvantages in practice, firstly a failed tube must be repaired immediately as the uncooled metal would otherwise burn and gases would escape into the engine room; secondly, in the event of a furnace explosion, serious damage is more likely with membrane walls as there is the likelihood of a much greater pressure build up before release i.e. in tangent tube designs with refractories and a thin metal casing these can deform and split under furnace explosion conditions whereas the much stronger membrane may after distorting pull the tube anchorages out of the boiler drums with disastrous results.

One might say what has this to do with boiler surveys? The most usual cause of tube failure is shortage of water and the most usual cause of furnace explosion is failure to purge. Both of these contingencies should have been prevented by safety devices and although not part of the boiler, the efficiency of these devices should be queried and if possible verified at survey times.

Two of the major advances in modern high pressure water tube boiler design have been the introduction of mono or membrane walls, and the abandonment as far as possible of all expanded and gasketed joints.

Whereas these two innovations have resulted in great savings in the use of refractories and possibilities of leakages occurring in service, they have, if boiler water or combustion conditions are neglected and tube troubles result, produced difficult conditions for repairs.

Membrane or mono walls

Membrane or mono walls were introduced for land power stations and are being increasingly used in marine boilers. Originally, experience gained when making the lower parts of furnaces sufficiently tight to hold liquid ash, proved that this could be done by welding in steel strips between the floor tubes. Further development of this technique resulted in completely gastight furnace wall panels being constructed by welding together either finned tubes or

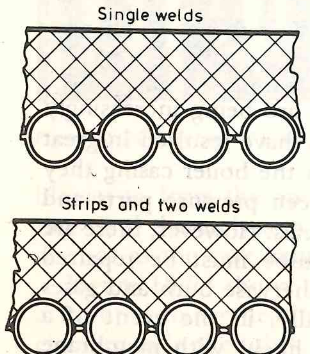


Figure 18.26 Methods of welding membrane walls

normal tubes with steel strip inter spaced between them (see Figure 18.26).

In both methods the longitudinal welds are done by an automatic process and panels of the required size are built up ready for installation in the boiler in one piece.

Abandonment of expanded and gasketed joints

The expanded joints of tubes to drums and headers are rapidly being superseded by welded connections. The boiler drum and header construction embodying a series of stubs, on to which all tubes are butt welded on site.

In boilers where expanded tube connections are used it is necessary to have a series of handholes, each with its own gaskets, along each header, for tube expander access. Nowadays, with the welded-on stub arrangement the multitude of handholes can be dispensed with, and one or two cleaning holes are all that is necessary.

Operating conditions

It will be apparent from the foregoing that with boilers embodying these advance features it is more important than ever to operate them under proper conditions, particularly with regard to feed water treatment.

A tube failure at sea in a boiler of this type, is difficult to repair owing to the welded construction and lack of handholes. In the case of vessels with a single main boiler this type of failure would produce an emergency situation.

Temporary repairs to membrane or mono walls at sea (ships' personnel)

The method of tube repair used in an emergency at sea would depend principally on whether a competent welder and machine are available. If not, the suitable plugs or expandable blind nipples for each of the failed tubes, should be available and also a supply of protective refractory to prevent subsequent burning through of the casing in way of the blanked-off tube.

(a) *Welded repairs.* Welded repairs are usually of a patch nature and have the advantage that as the tube remains in use it is not necessary to protect it with refractory. A butt welded patch is preferable, but as this, and also any internally fitted patch, are liable, in the hands of an unexperienced welder, to result in weld splatter entering the tube bore, it is safer for a quick temporary repair to rely on an external, fillet welded patch. For repairs of this nature the defective part of the failed tube is cut back to sound material and then a patch piece, preferably cut from a tube having bore equal to the outside diameter of the failed tube, is fillet welded over the removed section of the failed tube – the overlap being kept small to prevent subsequent overheating when in service (see Figure 18.27). Subject to a satisfactory hydraulic test on completion such a repair should allow the vessel to reach a port where permanent repairs can be effected.

(b) *Mechanical repairs*. If a welded repair is impracticable the tube may be plugged at both ends providing the tube is subsequently protected by refractory to prevent local burning of tubes and possibly the boiler casing.

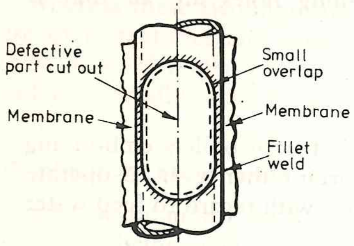


Figure 18.27 Fillet welded patch

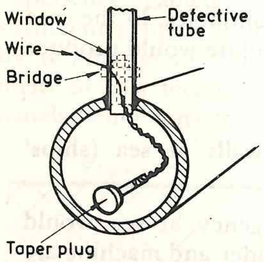


Figure 18.28 Plugging using taper plugs

Various mechanical plugging methods have been devised by the boiler designers, but lack of internal access and the high temperature appertaining at shut down, can make this an extremely unpleasant and/or lengthy operation. Two methods are described below:

Method 1. Windows are cut in the tube about 62 mm from its extremities through which wires with taper plugs attached can be pulled (see Figure 18.28) the taper plugs having been inserted into the headers via the inspection doors. The plugs are pulled into

position through bridge pieces inserted across the windows, and are then pulled up solid by nuts.

After both ends of the tube have been plugged in this manner the whole length of the defective tube and the boiler casing behind it are shielded from the furnace heat during subsequent steaming by a thick shield of plastic refractory.

Method 2. Again windows are cut at each end of the tube through which blind nipples are inserted and subsequently expanded (see Figure 18.29).

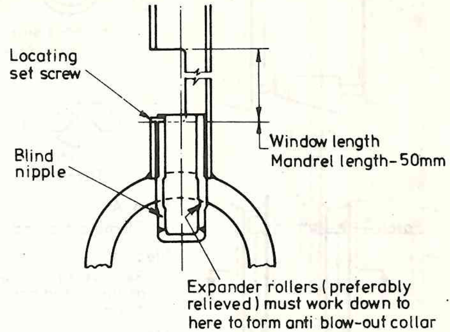


Figure 18.29 Alternative method of plugging showing blind nipple expanded in position

It will be appreciated that in this method boiler pressure tends to blow the plugs out whereas in *Method 1* boiler pressure tightens the plugs in the hole. It is important to ensure therefore that with this method the expander rollers project down the bore of the nipple beyond the header or drum thickness so that an internal anti blow-out 'collar' is formed on the nipple during expanding; as a double precaution special 'stepped' rollers can be used to form this collar.

As in *Method 1*, the whole length of the failed tube has subsequently to be shielded from the furnace heat.

Repairs to membrane or mono walls in port

The type of repair whether accepted as permanent or semi-permanent will depend largely on the availability of welders skilled in this type of work. The following paragraphs describe the various methods used for making permanent repairs.

Inserting a new section

The obvious and most straightforward permanent repair consists of cutting out the defected length of tube along with part of its adjoining membranes and butt welding in a new section. This repair entails the services of skilled welders, the removal of casing and refractory in way of the repair, and accurate weld preparation (see Figure 18.30).

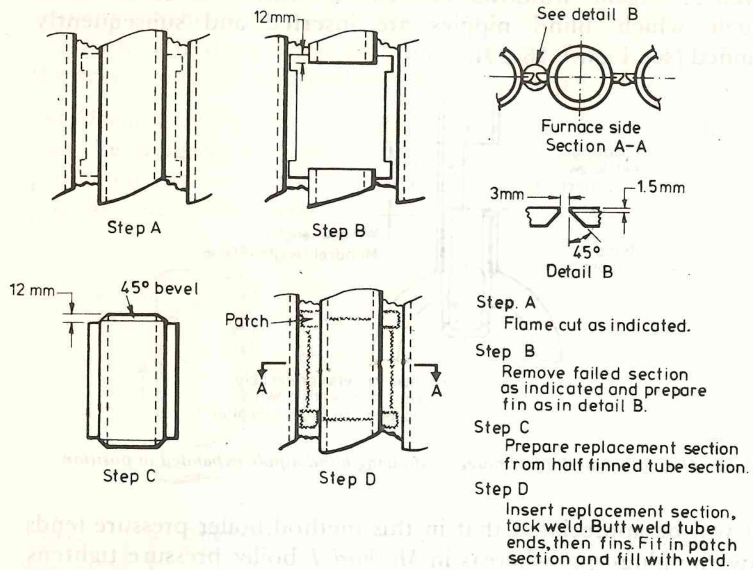


Figure 18.30 Inserting new tube section

It is important to note that unless welders skilled in the type of repair are available, the surveyor should insist that the welders being employed do a preliminary procedure test to his satisfaction.

Fish mouth tube replacement method

This method, when carefully executed, is also acceptable as a permanent repair and has the advantage that as all welding is done from the furnace it is not necessary to disturb the boiler casing and refractory.

The defective part of the tube along with part of its adjoining membranes are burnt out, as in the previous method. The replacement piece of tube is prepared with its' top and bottom ends cut off at 45° (see Figure 18.31) to give access when the replacement is in

position for welding, from the furnace, the rear part of the two circumferential butt welds.

When these rear parts of the circumferential welds have been satisfactorily completed, wedge-shaped pieces of tube are welded into the two windows, and the circumferential butt weld then

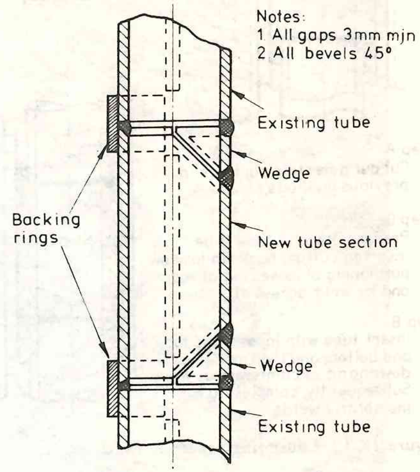


Figure 18.31 Fish mouth tube replacement method

completed working from the outside (see Figure 18.31). The membranes are subsequently closed by welding as in the previous method.

The configuration of the wedge pieces can be varied to suit tube diameter and access required and, if necessary, backing rings may be used.

The loose ring method

In ports where it is doubtful whether the experience of the welders justifies their employment on the previous two methods of repair, it is possible by this 'loose ring' method, to make an acceptable repair of a semi-permanent nature using down hand welding.

In this method (see Figure 18.32) access has to be made all round the tube and loose rings with cupped upper surfaces are slid into position in way of the butts to be welded, so that an inexperienced welder has a better chance of making a butt cum fillet joint. In all other aspects the repair is as in the previous two cases.

In view of the extra metal thickness in way of the rings and

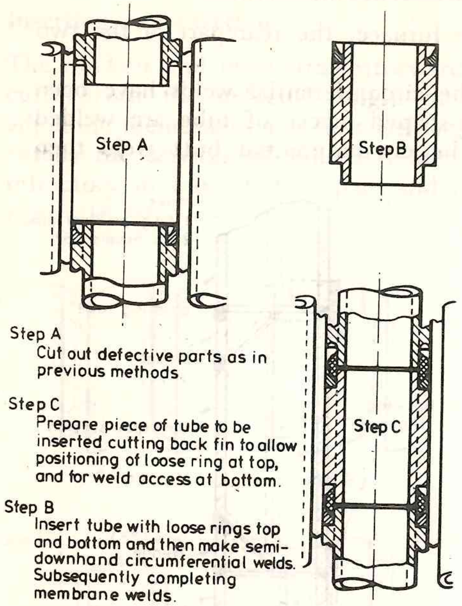


Figure 18.32 Loose ring repair method

possible build up of weld metal this repair could subsequently be the subject of overheating in service, and on that account the repair should only be regarded as semi-permanent.

Testing

On completion of any of the foregoing repairs whether temporary or permanent, the boiler should be subjected to a working pressure hydraulic test. In the case of the repairs effected in port the welds should be crack detected and, if possible, X-ray detection equipment should be used.

REFRACTORIES

There is perhaps a tendency when surveying water tube boilers to think too much of potential dangers through deterioration of pressure parts, and not to pay enough attention to the heat retaining envelope.

The furnace, except for the gas outlet side, is normally completely bounded by refractories, all wall refractories except the front being

Figure 18.33 Front wall defects

screened by tubes. The front wall with its quarls receives the full radiant heat of the furnace and on this account usually deteriorates more rapidly. Figure 18.33 shows what can happen, spalling of the brickwork, mis-shapen quarls and badly burnt registers.

Spalling and slag formation result in floor build-up which, if allowed to proceed too far, will interfere with efficient combustion through flame impingement.

Probably the most important refractory material in the furnace is that installed to protect the front part of the water drum in way of, and particularly below, the screen tubes; failure of this refractory and subsequent exposure of the drum to the direct heat of the furnace has on occasion resulted in circumferential thermal fatigue cracking similar to that shown in Figure 18.34, the seriousness of which necessitated drum renewal.

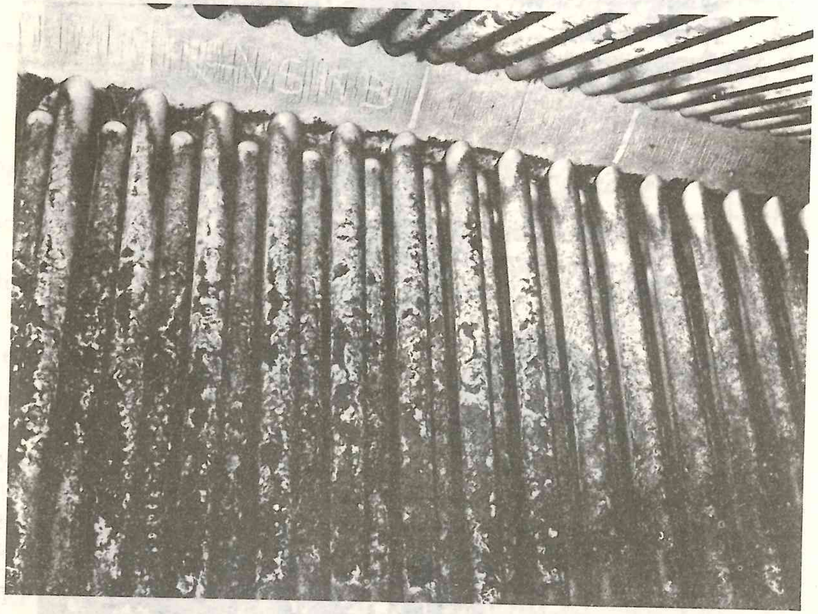


Figure 18.34 Thermal fatigue cracking of boiler drum

Before leaving the furnace it is always well to 'spot-light' the underside of the steam drum – if this should be visible. Figure 18.34 shows the underside of a steam drum unshielded by refractories which after many years' service was found to be seriously affected by circumferential thermal fatigue cracking.

Air casings

When leaving the furnace, the bottom of the air casing should be sighted for accumulations of fuel oil, which on occasion occur through spillage and leakage, and which are a potential source of danger. Downcomers and risers usually pass through the air casings and, if of the expanded type, they should be examined for leakage where they enter the drums.

Water drum

Normally, the internal examination of the water drum produces little of note in the way of defects. If, however, internal pitting, corrosion or deposits were observed in the tubes, at either the steam drum or header examinations, then the lower parts of the tube bores need special attention from inside the water drum.

It is well at this point to verify that it is the duty of a responsible official to prove a clear way through the boiler tubes before the boiler is closed up for further service.

Water drums normally have a manhole door at each end, and the remarks made regarding the fit of the steam-drum door apply here also.

Drum ends should be carefully examined prior to leaving the drum – diligent scrutiny of a drum end by a Surveyor during a survey revealed serious cracking around the manhole which could well have had very serious consequences. In this instance the drum end, instead of being flanged inwards to take the door, was fitted with a welded-in solid compensatory ring (see Figure 18.35), thus transforming the normally flexible end into one with very limited

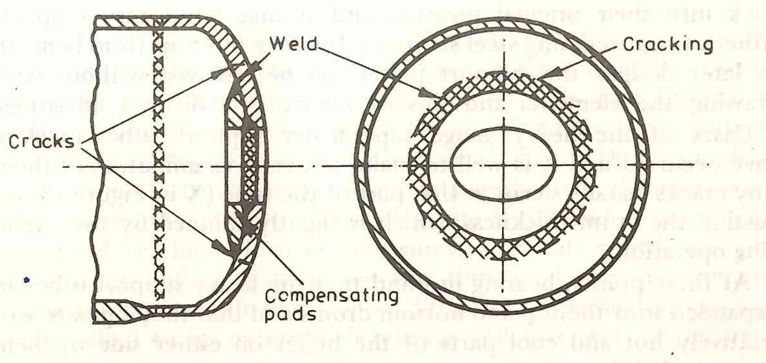


Figure 18.35 Fractures in drum end

flexibility, and having a severe stress concentration in the region where the relatively thin dished portion joins the solid welded-in compensating ring.

Subsequent investigation in this case revealed the cracking to have penetrated through 60% of the end-plate thickness. As a repair the drum end was burnt off and after suitable weld preparation and under strictly controlled conditions, a replacement conventional end with flanged-in manhole was welded-on, *in situ*, with local preheat and stress relief.

SUPERHEATER WALK-IN SPACE

Following the internal examination of the water drum, it is convenient to enter the superheater walk-in space, and it is probably here that, even in the most carefully tended boilers, one is most likely to find defects.

The problem of supporting horizontal superheater elements has always been a difficult one, and there are many different designs of supports and materials used for the purpose. At the present time it is usual to find the elements supported by heat-resisting steel spectacle plates, which to some extent are cooled, through being attached to special heavy section boiler tubes fitted for that purpose. As mentioned earlier, these spectacle plates, situated immediately behind the screen tubes, are apt to burn away and leave the superheater elements unsupported on one leg, with the result that the inclination given to the elements for self-draining purposes is lost.

When this state of affairs is found to exist, provided the tubes are otherwise sound, it is usual to endeavour to lever the elements back into their original position and arrange temporary supports, either of heat-resisting steel strip or refractory built up from beneath. In later designs the support plates can be renewed without withdrawing the elements and this of course is a distinct advantage.

Cases of the heavy gauge superheater support tubes cracking have occurred and it is well to make a special examination of them. Any cracks usually occur in that part of the tube (X in Figure 18.36), outside the drum thickness, which is slightly thinned by the expanding operation.

At these points, bearing in mind that the heavy support tubes are expanded into the top and bottom drums and that they operate with relatively hot and cool parts of the boiler on either side of them, bending fatigue stresses can be expected (see Figure 18.36). On

occasions, such stresses, superimposed on locked-up stresses present in the tubes, through having been originally expanded while in malalignment with their tube holes, have been responsible for fractures.

The recognised successful repair in such cases is to cut out the fractured part of the tube, insert and lightly expand a new piece in correct alignment, butt weld it to the support tube, locally stress-relieve and then finally complete the expanding and belling.

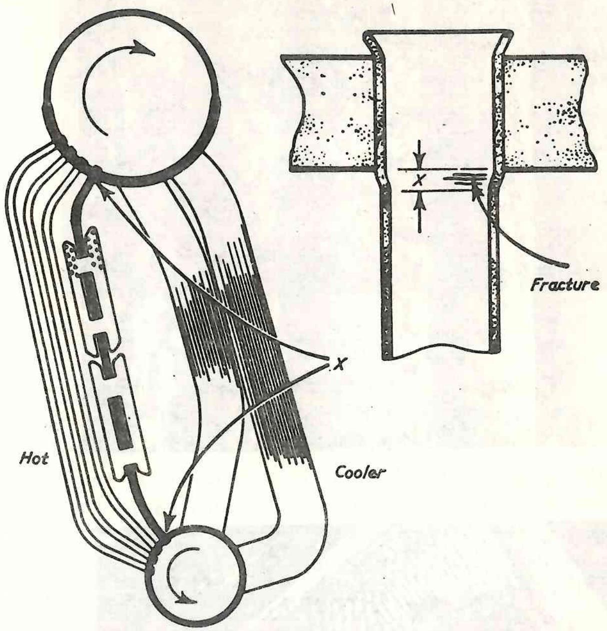


Figure 18.36 Location of possible cracking in support tubes

In respect of boilers with external superheaters troubles are still encountered with element supports, even in those boilers with their superheaters situated in lower temperature zones (see Chapter 9). Element supports should always be examined at boiler surveys.

Build-up of deposits, as shown clearly in Figure 18.37 is undoubtedly the most troublesome defect in superheaters, if not in water-tube boilers as a whole. These deposits if allowed to accumulate can produce high furnace pressures, loss of superheat, poor combustion and a general deterioration in boiler performance.

The subsequent safe working condition of a superheater is to some extent allied to its external cleanliness and this must therefore be considered during surveys. In the case of those that have been

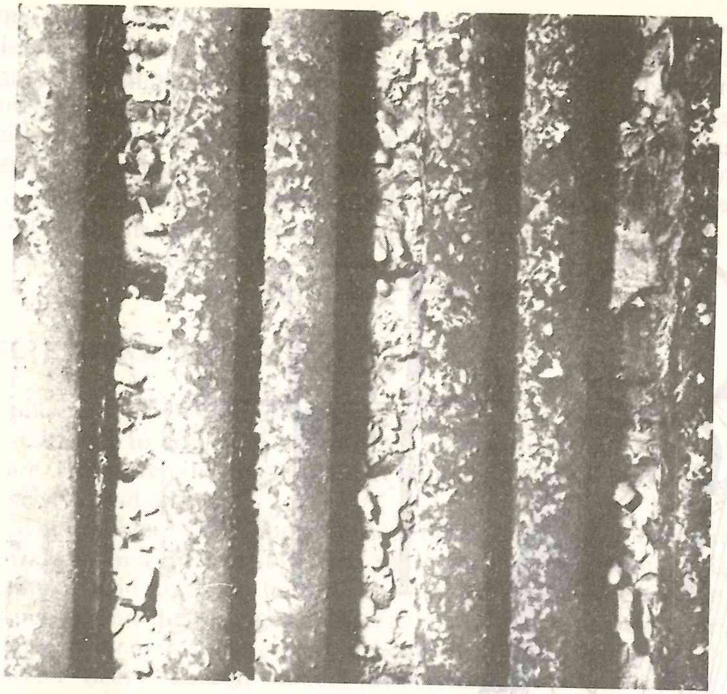


Figure 18.37 Slagged-up superheater

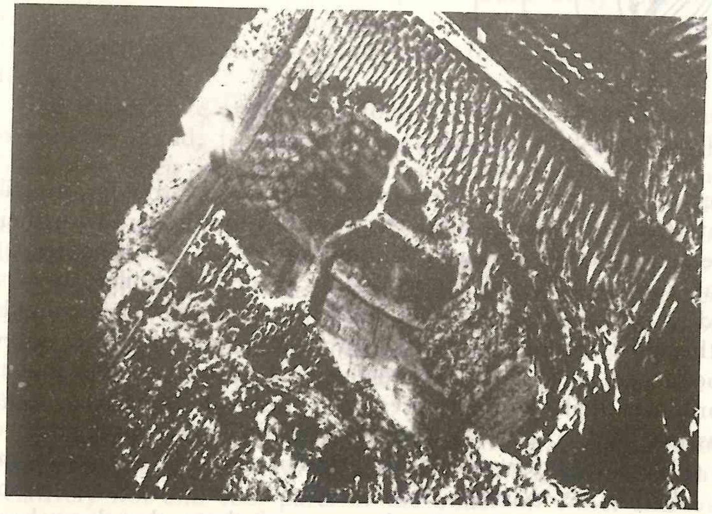


Figure 18.38 A burnt-out water tube boiler

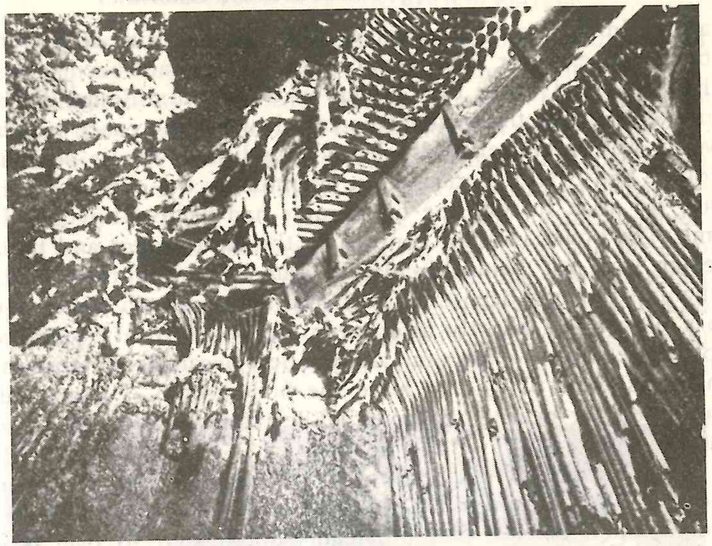


Figure 18.39 A burnt-out water tube boiler

operating in a dirty condition special attention should be paid to those parts through which there is still a gas path, as these have probably been operating at excessive metal temperatures.

Superheater tubes, even under normal conditions, operate at higher temperatures than boiler tubes and are more prone to overheating, especially so when internal deposits are present, or steam flow is restricted in any way.

Flaming through screen tubes can produce local zones of high-temperature oxide scaling in the superheater tube bores; once formed the scaling further reduces the heat transfer through the tube walls, oxidation then increasing even more rapidly. This may be due to dissociation of the highly superheated steam.

It follows therefore that the internal condition of superheater tubes, as seen from inside the headers, is of little guidance when assessing their overall condition and, in cases of doubt, selected elements should be removed and sectioned for examination.

The previous remarks on high-temperature oxide scale formation in the bores apply also to the outside of the tubes and, although fortunately a rare condition at a boiler survey, failure of severely overheated superheater tubes has in several cases resulted in the destruction of all the boiler, superheater and economiser tubes through the reaction which ensues when iron burns in highly superheated steam. Figures 18.38 and 18.39 illustrate an incident of this nature. In this case, overheated tubes reacted with steam until all boiler, superheater and economiser tubes had been destroyed. The vessel had water tube boilers of Continental design and was in port at the time the incident occurred; while the exact sequence of events was not afterwards clearly established, it was obvious that trouble had been experienced in maintaining the correct water level and, for that reason, the oil burners had been extinguished for a time. The boiler was not coupled to the steam range and the superheater was not being circulated. One of the burners had been relighted but had been extinguished after about ten minutes, owing to a blow-back. Shortly afterwards the boiler front became visibly hot, there was no explosion, and the heat became so intense that the engineers were obliged to leave the boiler room. These conditions continued for nearly two hours while efforts were made to control the fire with water hoses.

Several cases of this nature have occurred and it is generally thought that failure of a severely overheated superheater tube, accompanied by the exit of steam superheated to over 649°C is sufficient to start the reaction, which once started is self supporting, the iron burning in the steam and the produced hydrogen burning in air, the combined fire probably lasting until the supply of steam is exhausted.

Having noted any repairs or renewals required to superheater tubes, supports and support tubes, etc., and also any further cleaning necessary, the next stage of the survey is the economiser at the side and above the boiler.

ECONOMISER

On leaving the superheater access space the condition existing in the gas space between the underside of the economiser and the rear of the main bank tubes should be investigated – operating temperatures are lower here, but defects in refractories are not uncommon, through water, from water washing the economiser, being allowed to saturate the brickwork, instead of drying the boiler out, by flashing-up immediately after water washing.

There is, maybe, a tendency at surveys to treat the economiser as an accessory to the boiler and to underestimate the importance of its examination. In some installations an economiser failure necessitates shutting down the boiler concerned but it is general practice nowadays to fit bypass arrangements.

A typical economiser construction is shown in Chapter 11. The

water side inspection normally presents no problems although, in the past when feed regulators came between the economiser and the boiler, fluctuations in pressure were responsible for quite a lot of trouble at the expanded parts of the elements in the headers.

Leakages at the closing arrangements of inspection openings in the headers occasionally give trouble, usually originating through careless rejointing or through defects in the jointing material. Judicious welding up of scored openings, recutting of facings and the employment of the correct jointing materials are the normal remedies.

Operating with low feed and low funnel temperatures often results in sulphurous acid attack on the cast-iron finned surfaces, the upper elements in the lower temperature zones usually being the first to suffer (see Figure 18.40).

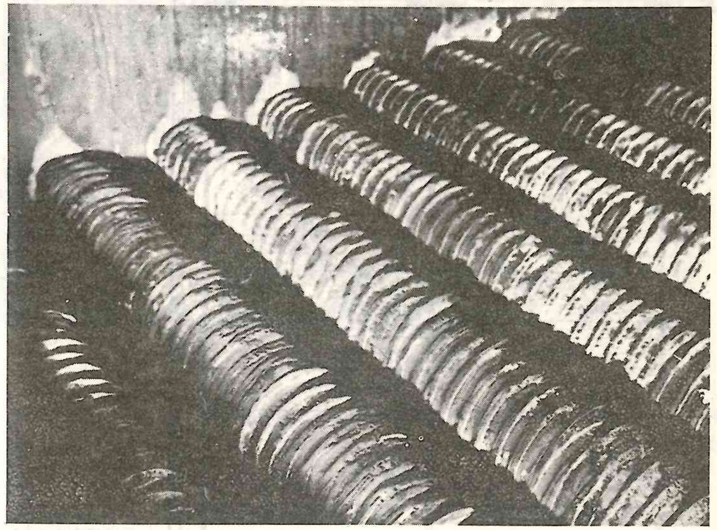


Figure 18.40 Acid corrosion of economiser elements

Providing that the passage for gas is not unduly impaired and the steel tubes beneath the finned section are sound, wastage and deposits between the cast-iron fins are of little concern to the Classification Surveyor. However, to the shipowner these problems mean loss of efficiency and are an indication of incorrect operating conditions.

Apart from the external examination of the finned economiser elements and their internal examination as seen through the header inspection openings, the condition inside the boxes at either end of the economiser should be ascertained (Figure 18.41).

It should be noted that one end of the finned elements is positively located by a collar and locking ring while the other, to take care of differential expansion and maintain gas tightness, is provided with a sliding piston ring joint. While this is good engineering practice, leakages at the sliding joint, due to tube plate distortion and other reasons, have been known to occur, with the result that there have been accumulations of sooty deposits in the end-box containing the bare steel element bends.

Subsequently seepage of water from water washing or maybe steam from soot blowing absorbs the sulphur content of these

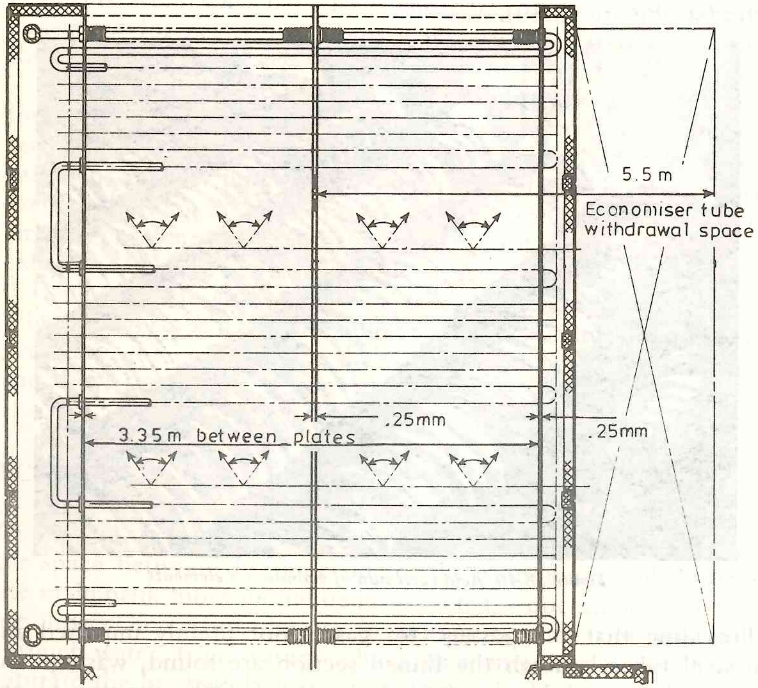


Figure 18.41 General arrangement of economiser showing end boxes

deposits, forming sulphuric acid which vigorously attacks the warm steel of the bends.

The above description illustrates vividly how unsuspected acidic deposits can accumulate and attack, by smooth external wasting, vital parts of the boiler.

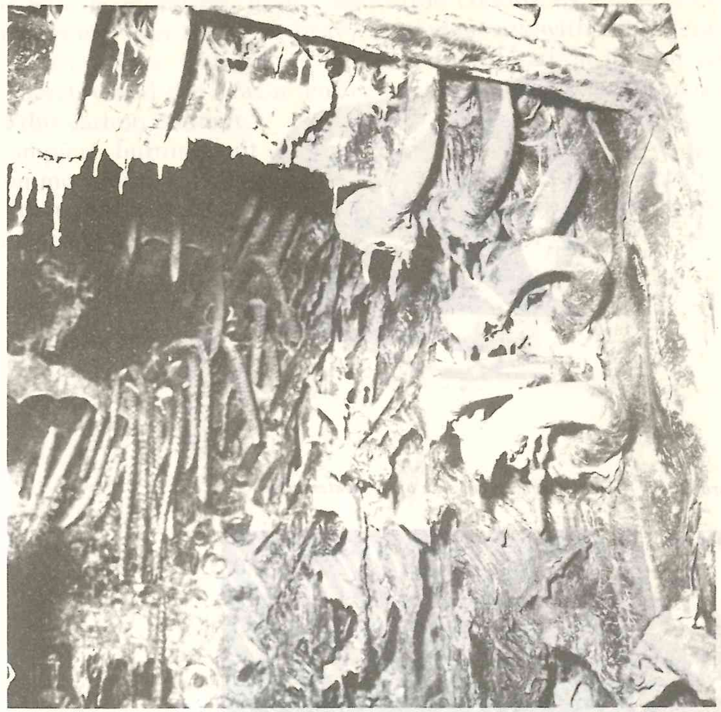


Figure 18.42 Result of a hydrogen fire

Before passing on from the economiser examination, the result of a hydrogen fire, probably originating through accumulations of soot, rich in carbon, is shown in Figure 18.42.

AIR-HEATERS

Gas/air-heaters, when fitted, are usually of the tubular or, alternatively, Ljungstrom rotating plate type. The use of fuels with high sulphur content raises the dew-point of the flue gases, this and operation at low outputs for prolonged periods are often responsible for considerable trouble through acid attack on the gas side of air-heaters. Figure 18.43 illustrates vividly this type of defect.

It is well therefore to pay particular attention to the condition of the tubes, at the cold end, of tubular air-heaters. All the effective parts of the Ljungstrom type of heater are being continually heated and cooled; there is therefore no localised cold end and, on this account, this type is not so prone to severe local acidic attack.

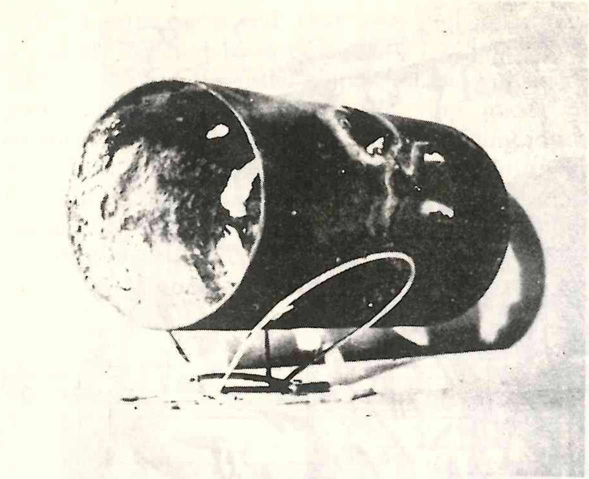


Figure 18.43 Acidic attack on gas side of air heater tubes

Figure 18.44 Result of soot fire in tubular air heater

As with economisers, poor combustion conditions and infrequent soot blowing, can result in heavy soot deposits with the attendant risk of soot fires. The nature and amount of carbon in soot varies considerably and the heat intensity produced in a soot fire increases with this carbon content.

Complete burning out of air-heaters, through soot fires is not uncommon, and it is important therefore at boiler surveys to make sure that soot accumulations are not present. Figure 18.44 shows the result of a soot fire in an air-heater.

19 Tank type boiler surveys defects and repairs

For the purpose of this chapter, a tank boiler is considered as one having a large water content with relationship to its volume and in which the heating surface consists of a cylindrical furnace or firebox located in the lower part of the pressure shell.

Until comparatively recently, the most common tank boiler in service was the Scotch boiler. However, during the last decade, the construction of Scotch boilers has declined and, so far as can be ascertained, there appear to be no manufacturers currently making this type of boiler for marine purposes. In modern steam and motor ships, Scotch boilers have been replaced either by watertube boilers, by horizontal 'packaged' tank boilers or by vertical tank type boilers.

The original vertical boilers were riveted and were either of cross-tube design with a central uptake or of horizontal smoke tube design. Typical of the latter is the well known Cochran boiler. Many of these riveted vertical boilers are still in service and the majority of present day, all welded, vertical boilers with their fireboxes and smoke-tubes are basically developments of the earlier designs. A type of boiler differing from the foregoing, in as much as it is fitted with water

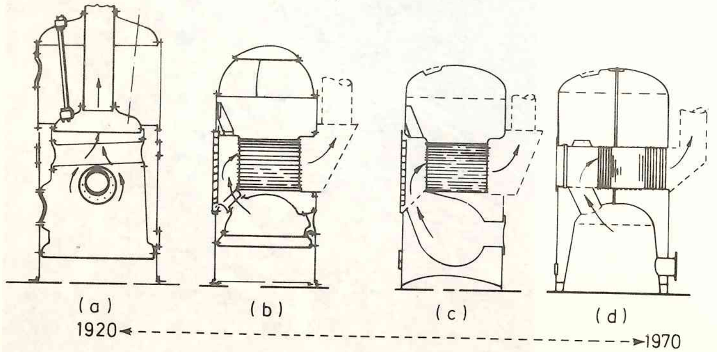


Figure 19.1 Development of vertical boilers
(a) Riveted vertical cross-tube
(b) Riveted Cochran
(c) Welded spheroid Cochran
(d) Welded Aalborg

tubes instead of smoke tubes is, however, gaining in popularity. The original riveted Cochran boiler, a present-day all-welded Cochran 'Spheroid' boiler and an all-welded Aalborg boiler which incorporates water-tubes are shown, for comparison, in Figure 19.1.

The modern horizontal tank boiler can be considered to be a development of the Scotch boiler, in many respects their constructional arrangements and design are similar. There are still a large number of Scotch boilers in service and bearing in mind that the defects likely to be encountered during surveys of horizontal boilers are similar to those found in Scotch boilers the latter has been retained in this chapter as the standard reference. Indeed, many of the defects encountered in Scotch boilers apply equally to vertical boilers.

SURVEYS

Tank boilers require to be surveyed at two-year intervals until they are eight years old, thereafter they become due for survey annually.

In preparing a boiler for survey, there are certain fundamental safeguards which should always be observed. The most important of these are listed below, it having been assumed that the boiler to be surveyed has been taken off range in a proper manner, allowed to cool down slowly and drained.

1. During the cooling down period, when the pressure gauge registers zero, the air cock should be opened to avoid the formation of a vacuum. When an air cock is not fitted, some other suitable connection to atmosphere such as the upper water gauge cock and drain cock, should be used.
2. All mountings should be isolated safely from any live feed or steam ranges so that these boiler mountings can be opened out for inspection and overhauled. Blanks should, if necessary, be fitted to secure safe isolation. Care should be taken to ensure that the ship's side blow-down valve is shut.
3. Where, in a multi-boilered installation, a common waste-steam pipe is connected to the safety valve chests of two or more boilers, a length of this piping adjacent to the valve chest of the boiler to be surveyed should be removed. This prevents steam and hot water entering the off-line boiler in the event of the safety valves of any other boiler lifting. Spade blanks should not be used for blanking off waste-steam pipes in these circumstances as failure to remove these after the survey could result in a serious accident.

4. The top manhole door nuts should be slacked back sufficiently to allow the manhole door joint to be broken, leaving the dogs in place. A sharp tap with the large spanner used for slacking off the nuts will usually start the joint. After this has been done, the nuts and dogs can be safely removed and the door withdrawn.
5. When it has been established that there are no large quantities of hot water lying in the bottom of the boiler the bottom doors can be removed.
6. The boiler should not be entered until it has been well ventilated. No person should enter a boiler without authority. Some responsible person should always be standing by the manhole door when another person is in the boiler.

Before a boiler is surveyed it should be thoroughly cleaned. Failure to do this may result in serious defects being overlooked. It is not unknown for surveyors to decline to carry out surveys when boilers have not been cleaned properly. In well maintained boilers, some wire brushing and a good hose down may be sufficient to prepare the boiler for survey; in other cases, where hard scale has been allowed to form, recourse to chipping hammers and chains passed between the tubes may be necessary to obtain the cleanliness required.

If traces of oil are found in the boiler chemical means may have to be adopted to remove them. The 'fire side' of the boiler should not be overlooked at this stage as it is an integral part of the survey to examine the 'fire sides' of furnaces, fireboxes, combustion chambers, tubes, smoke boxes and uptakes. Smoke-box doors should be opened out and tubes swept clean.

During the course of the survey, the surveyor is required to examine the boiler, superheaters, economisers and air heaters internally and externally together with their safety valves and other mountings. If it is considered necessary by the surveyor, the thickness of the various pressure parts such as shell plating and furnace or combustion chamber plating may require to be ascertained by drill testing or by ultrasonic methods. When the boiler is of a type that cannot be examined internally to the surveyor's satisfaction, because of inaccessibility, a hydraulic test may be called for. A hydraulic pressure test is also required when any repairs affecting pressure parts have been carried out.

When all the recommendations and repairs have been completed, the boiler is closed up, steam raised slowly and afterwards examined under pressure. The safety valves should always be adjusted to the

correct pressure at the first occasion when steam is raised following a survey. It is often a statutory requirement that before the boiler is put back into service, the safety valves are to be adjusted to the approved working pressure (see Chapter 13) and this to be witnessed by the surveyor. At this time, it is prudent to examine the oil fuel burning equipment for leaks, verify the efficient working of remote and automatic controls including low-water alarms and also check the fuel cut-outs. The water gauges should be tested to ensure they are working correctly and the accuracy of the pressure gauge should be confirmed.

In the case of exhaust gas heated boilers and economisers, it is usual to allow the ship's chief engineer to adjust the safety valves at the first opportunity when the ship is at sea. The engineer is then required to confirm, in writing, to the inspecting authority concerned that he has done this.

HORIZONTAL TANK BOILERS – DEFECTS AND REPAIRS

Figure 19.2 represents a horizontal tank type boiler and indicates the various points where defects may be commonly found. These defects will now be considered in order and suitable repairs will be suggested.

Longitudinal stays

These stays are generally found to be trouble free. Formerly they were, without exception, attached to end-plates by means of heavy nuts and washers placed both sides of each end-plate. In recent years, welded attachments have been adopted either with, or without, external washers which are also welded in place. When the welding of longitudinal stays was first introduced some manufacturers included a light sealing weld internally as shown in Figure 19.2a. Cracks subsequently occurred in the sealing welds and in several cases these cracks extended into the bar stay. It is considered that the reason for the formation of the cracks was severe over-stressing of the small seal weld on the inside of the end plate as this 'short circuited' the strength weld on the outside of the end plate. Since such seal welds have been omitted from boiler design, this defect has happily become almost unknown. However, it is possible that there are still some 'seal welded' stays in existence and the importance of being aware of this problem is worth emphasizing.

No attempt should ever be made to repair cracked stays by welding, the correct repair for such a defect is, of course, renewal of

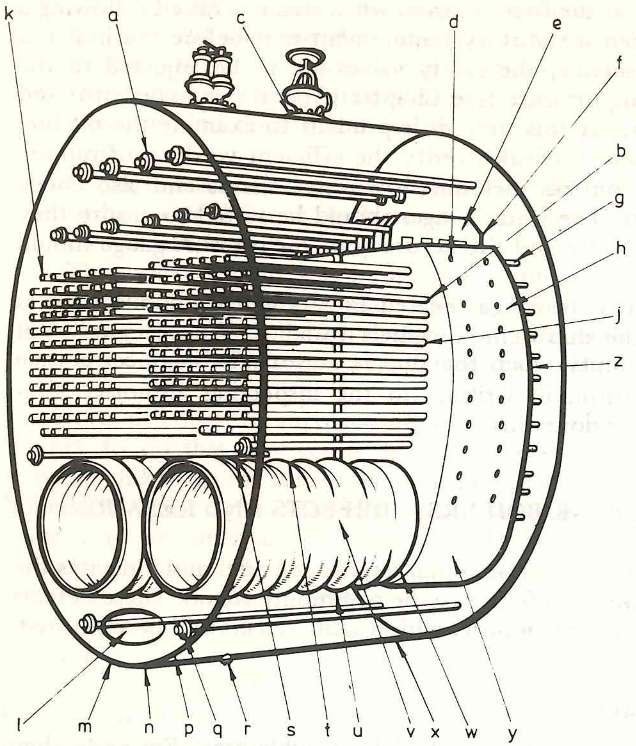


Figure 19.2 Defects and repairs to Scotch boilers
This diagram illustrates the parts of a Scotch boiler where defects are most likely to be found, and which should be carefully examined when the boiler is being cleaned. The appearance of these defects is shown in the enlarged views on the following pages. The causes of the faults and the methods of repair are dealt with in detail in the text relating to these diagrams.

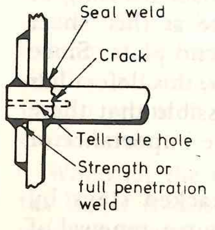


Figure 19.2a Cracks in longitudinal bar stays

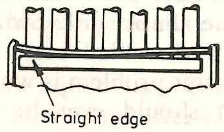


Figure 19.2b Distortion of c.c. tube plate

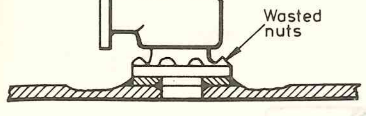


Figure 19.2c External wastage of shell plate

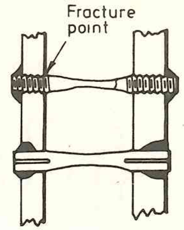


Figure 19.2d Wastage of c.c. stays

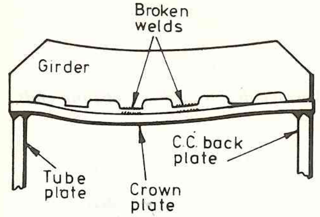


Figure 19.2e Overheated c.c. top plate

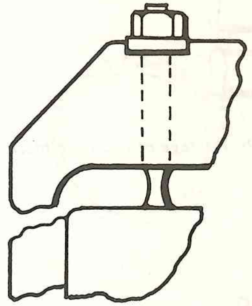


Figure 19.2f Wastage of girder stays, chamber knuckles and girders

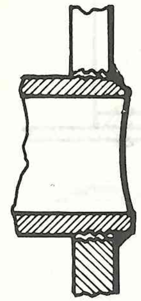


Figure 19.2g Incorrectly welded stay tube

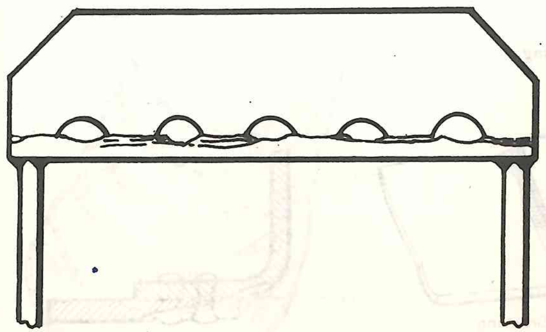


Figure 19.2h Wastage of c.c. wrapper plate

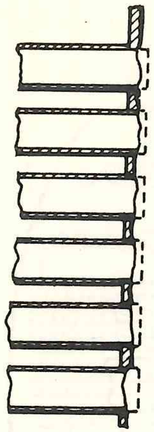


Figure 19.2j Wastage of c.c. tube plate

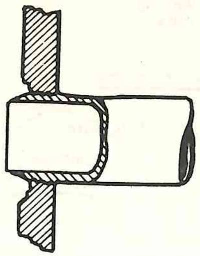


Figure 19.2k Wastage due to leakage at tube ends

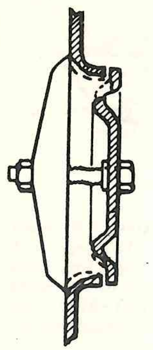


Figure 19.2l Wasted door flanging

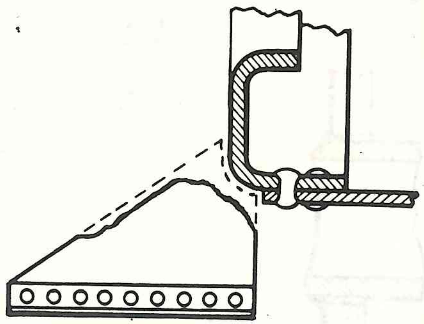


Figure 19.2m Wasted collision chock

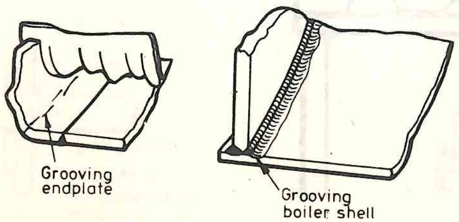


Figure 19.2n Grooving

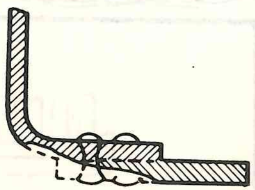


Figure 19.2p Wastage due to leaky rivets

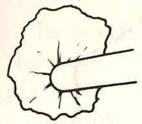


Figure 19.2q Radial grooving around stays

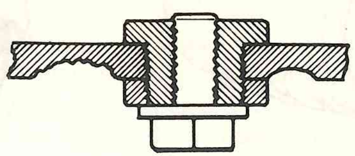


Figure 19.2r Wasting of shell due to leaking drain plug

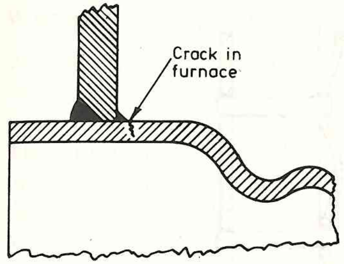


Figure 19.2s Cracks in furnace at connection to end plate

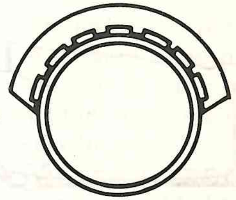


Figure 19.2t Welded on furnace stiffener

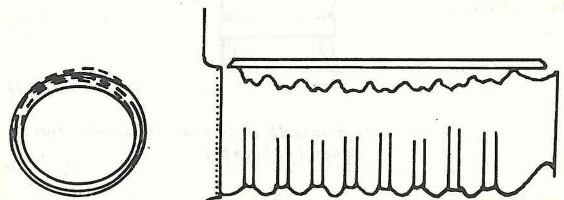


Figure 19.2u Checking furnace for distortion

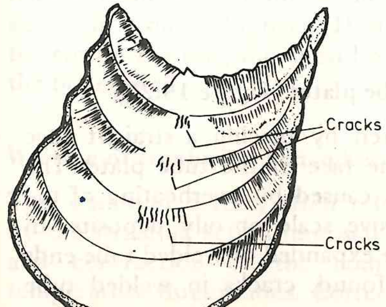


Figure 19.2v Thermal cracks on peaks of corrugations

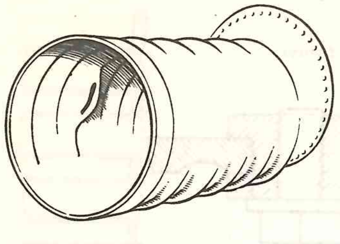


Figure 19.2w Local bulge in furnace

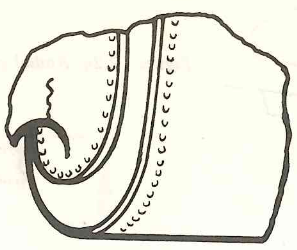


Figure 19.2x Grooving in furnace neck

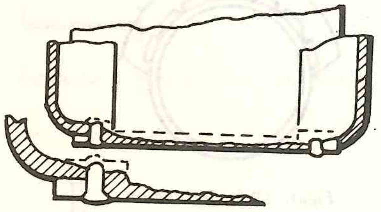


Figure 19.2y Wastage of combustion chamber bottom wrapper plate due to seam leakages

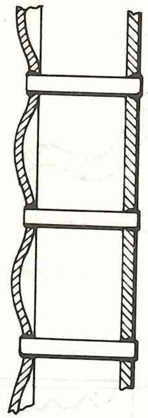


Figure 19.2z Overheated combustion chamber backplate

the stay. All-welded stays should be provided with tell-tale holes in stay ends. These holes should be deep enough to penetrate beyond the line of the inside surface of the end plate and beyond any welded connection of the stay thereto.

Distortion of combustion chamber tube plates (Figure 19.2b)

This defect, if slight, can be detected by placing a straight edge across the tube ends and sighting the face of the tube plate. The pushing of the tube plate inwards is caused by overheating of the tubes, usually attributable to excessive scale or oily deposits. In extreme cases, signs of leakage of the expanded or welded tube ends will be evident and when this is found, cracks in welded tube connections may have occurred.

In severe cases special examination of the welded connection of the tube plate to the wrapper plate is warranted. Where the tube plates are flanged, 'grooving' should be suspected and a check for this carried out.

Slight distortion of a combustion chamber tube plate, where no weld failures have occurred, may not require immediate repair, it being sufficient to make good any expanded tube leakage. More serious distortion can only be repaired by renewing the affected section of the tube plate.

Wastage of shell plating due to defective joint (Figure 19.2c)

Wastage of shell plating around defective mountings – particularly feed-check and blow-down valves – where a damp atmosphere has persisted for some time under lagging or casings is quite common. This may be caused by a leaking joint, the nuts securing the mounting to the shell may also be affected which could result in a dangerous situation arising. In cases where the shell is wasted to such an extent that repairs are deemed necessary, a welded insert of material equivalent to the original shell plating, should be fitted. (See general methods of fitting shell inserts at end of this chapter). The building up, by electric welding, of wasted areas of boiler shell plating should not be permitted.

Wastage at mountings

It is also desirable to consider the advisability of examining the necks and joints of mountings such as check valves, scum valves, etc, especially when these are covered with lagging. In a recent case the necks and joints of the valves were covered with asbestos lagging and portable plates, and it was only after some persuasion that these were removed whereupon the scum-valve chest was found to be badly salted up around the neck. During the chipping operations necessary to remove the salt, the chest broke away from the neck holding it to the boiler shell.

Wastage of combustion chamber or furnace stays (Figure 19.2d)

This common defect, often referred to as 'necking', is accelerated by the straining action imposed on the stays by continual expansion and contraction of the combustion chamber, or furnace, by temperature fluctuations. Correct water treatment and avoidance of sudden temperature changes plays an important part in arresting such wastage. When dealing with wasted stays it should be remembered that their strength varies as the square of their diameter. Repair, of course, should always be by renewal.

These short stays may often be found fractured close to the face of the combustion chamber, or furnace plate. This defect is not easy to detect particularly in small boilers. Ultrasonic means will locate any stays which have failed. Broken stays may also be found by double hammer testing. (This is done by holding a heavy hammer against one end of the stay while the other end of the stay is struck with a hand hammer – the hollow sound emitted by a broken stay is easy to detect by an experienced ear). Most welded bar stays now have tell-tale holes drilled in their ends as described earlier.

Overheated chamber top (Figure 19.2e)

The first part of a boiler to suffer from water shortage is the combustion chamber crown. An accumulation of mud, scale or other insulating material such as oil can also be the cause of overheating.

When distortion of a combustion chamber top occurs, special attention should be given to the welded connection between the crown plate and the adjoining tube plate and backplate before considering the extent of repairs required. The welds connecting the girder stays to the crown plate should also be examined for cracks at such times.

Wastage of girder stays, chamber knuckles and girders (Figure 19.2f)

This type of deterioration may still be found in older types of boiler, the remedy when serious wastage is present is to renew the stays and also the girders where necessary and to build up the chamber landings by electric welding and properly bed in the new girders.

Stay tube attachments (Figure 19.2g)

It sometimes happens that screwed stay tubes, on account of continued leakage, are sealed by welding. This procedure is to be deplored. Where this condition persists the tubes should be renewed and in making the repair it may be possible to incorporate a welded connection prepared in accordance with acceptable standards.

In modern all-welded boilers, stay tube connections are not a common trouble spot.

Wastage of wrapper plates (Figure 19.2h)

This defect is commonly found in neglected boilers and provided the wastage is not extensive is not a serious matter. The cause of the wastage can usually be traced to gross lack of attention to correct water treatment. Careful correction of the water treatment will effectively arrest the progress of the wastage. In extreme cases a portion of the wrapper plate may have to be cropped and renewed.

Sometimes it is only a matter of wastage around the stays and in this case the usual repair is to remove the latter and build up a compensating pad on the fire side by electric welding, machine the stay hole and weld in a new stay. It is not considered that this is a practical form of repair on smaller boilers of the packaged type.

Wastage of tube plates (Figure 19.2j)

Wastage of the ligaments (i.e. the portion of the plate between the tube holes) may be caused by using wet steam for soot blowing. The tube ends may also be affected. Occasionally the ends of over-long tubes may become overheated and new tubes of correct length will be necessary as a remedy.

Local wastage of the tube plate can be made good by removing adjacent tubes, building up the wasted areas by electric welding, grinding down to original plate thickness, remachining any tube holes affected by the welding and fitting new tubes.

Wastage of front tube plate (Figure 19.2k)

Tube plates which do not form part of a combustion chamber may become locally wasted on account of leaking tubes. Where this has occurred it is prudent to remove the leaking tubes, build up affected tube holes by electric welding rebore the tube holes and fit new tubes. Since the introduction of expanded and seal welded plain tubes, this problem has all but disappeared.

Wasted doors flanges and landings (Figure 19.2l)

This type of defect remains all too common. Manhole and handhole door spigot clearances should receive special attention at each boiler examination. The clearance between the spigot on the door and the flange or landing of the manhole or handhole should not exceed 1.5 mm. (i.e. 3 mm difference between the measurement of the door and aperture major axes). Leakage from manhole doors has been the cause of serious boiler shell wastage on more than one occasion.

Particular attention should always be given to the fit of the doors and to obtaining a good joint. Wastage of doors can be rectified by welding, as can wastage of manhole flanging. Wastage of manhole landing faces as shown in Figure 19.22 can be dealt with by fitting a false sealing ring. A careful check should be made for strained door studs, slack fitting or stripped nuts and distorted manhole door dogs. A badly fitted door can cause a joint to blow out under pressure with resultant serious injury to personnel.

Wasted collision chock (Figure 19.2m)

The constant quenching of ashes in coal burning boilers below the furnace mouth used to cause wastage of the end plate which, on account of its smooth nature could easily be missed. This type of wastage can also occur to a lesser extent in oil fired boilers where damp or humid conditions persist. The wastage can also extend to the collision chock itself.

In modern packaged type boilers the collison chock is replaced by cradles or feet, these should always receive special attention as cracks in the boiler shell in way of these attachments are not unknown.

Grooving of flanged end plates (Figure 19.2n)

Grooving of a fine and sometimes deep nature may be found in flanged end plates, a similar defect may be found in older type boilers in the radius of the inwardly flanged furnace mouth. In modern boilers having end plates, without flanging, grooving has been found in the boiler shell plating adjacent to the welded connection of the end plate to the shell.

Repairs to grooving in end plate flanging can be effected by cutting out the grooving and, after making a suitable preparation, completing by welding. In very serious cases where the grooving is deep or has penetrated the full thickness of the plate it may be necessary to weld from both sides. (*Note:* Grooving in boiler *shell* plating should not be rectified by welding but by part renewal of the shell plating).

Wastage due to leaky rivets (Figure 19.2p)

Wastage may be caused to shell and end plates by leakage through defective rivets in circumferential seams especially if the boiler has been subjected to rapid steam raising without proper circulation.

The repair for serious wastage of this nature is to crop back both the shell and end plates insert new material, butt welded to the original and complete by closing the riveted seam. Such a repair should not be embarked upon unless expert boilermakers and riveters are available.

Radial grooving around stays (Figure 19.2q)

This type of defect is the result of mechanical action caused by varying expansion of the heating surfaces and may develop around lower longitudinal stays (see Figure 19.3). The repair for this is to

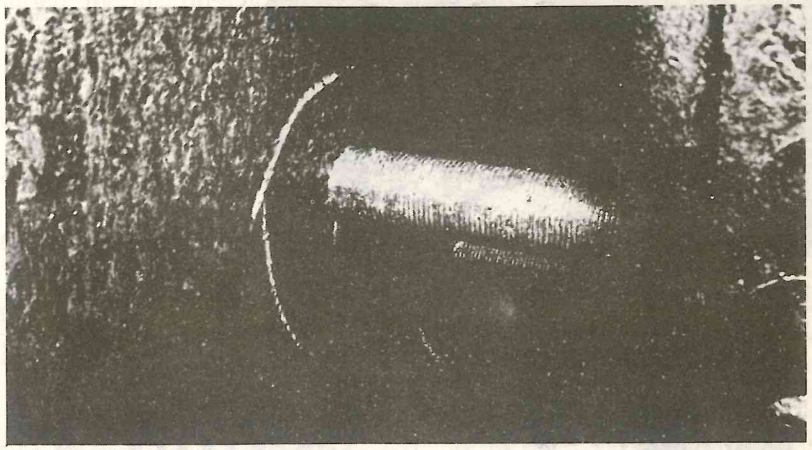


Figure 19.3 Radial grooving of boiler back plate in way of combustion chamber stays

cut back to sound material and weld in an insert piece, the corresponding stay is also renewed.

Wastage to shell due to leaking drain plug (Figure 19.2r)

Drain plugs, if fitted, should always be examined. Badly fitted plugs are dangerous and can cause serious external wastage. Repairs to seriously wasted shell plating are dealt with by fitting welded inserts, (see later).

Cracking of furnace at welded connection to end plate (Figure 19.2s)

A serious furnace failure occurred a few years ago when circumferential corrosion fatigue cracking resulted in the rupture and collapse of the furnace. The cracks had developed from the water side and were adjacent to the seal weld. This defect is reminiscent of that in the earlier section on 'longitudinal stays' and in view of the serious consequences of such a defect particular attention should be paid to this welded connection at each boiler examination (see Figure 19.4).

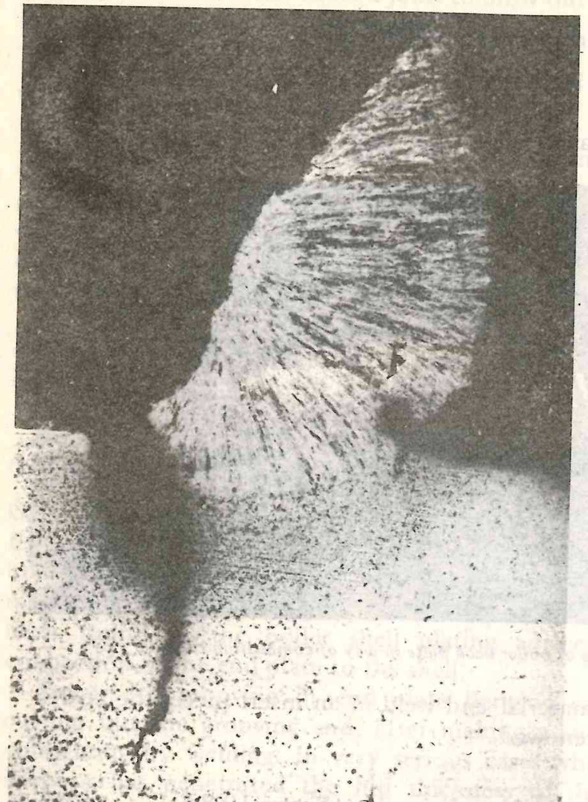


Figure 19.4 A photomacrograph of a section taken through a defective connection of the end plate to a furnace.
An open crack is clearly visible in the furnace plate at the toe of the sealing weld. Lack of penetration at the endplate connection is also evident

Where cracks are found, the repair should consist of partial or complete renewal of the furnace. Merely cutting out the cracks and repairing by welding cannot be recommended.

The attachment of the front end plate to the new furnace, or of any portion should be in the form of a full penetration weld.

Distorted furnaces (Figure 19.2t)

Distorted furnaces are often reinforced by welded stiffeners. When fitting these, care should be taken to see that they extend well beyond the affected area. In general stiffeners, should not be less than 100 mm in depth and 15 mm in thickness. They should be well scolloped to afford adequate cooling. Their welded attachments should be regularly examined.

Uniform furnace distortion (Figure 19.2u)

Overheating and subsequent deformation of furnaces is always caused by the presence of some insulating medium between the furnace and the surrounding water. This medium can be steam, scale, mud or oil, and its effect may be further increased by local overheating due to faulty combustion. It is not proposed, however, to deal with the causes of the defects, but merely to enumerate them.

The usual way of getting some idea as to whether a furnace is passably round is to sight along the corrugations with a torch from

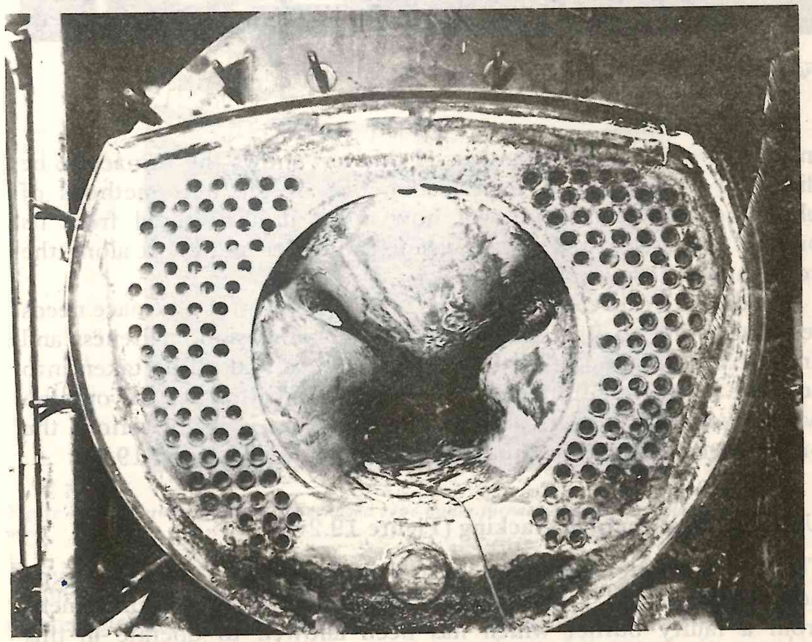


Figure 19.5 Water shortage caused this packaged type boiler furnace to overheat and collapse

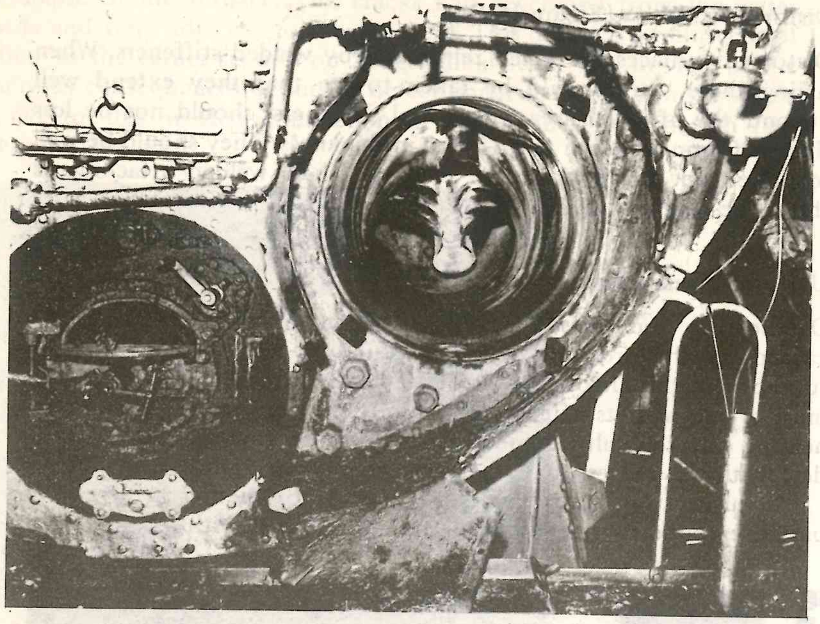


Figure 19.6 Collapse and rupture of Scotch boiler furnace

inside the combustion chamber. If this test shows the furnace to be distorted (a matter of experience), one of the best methods of obtaining an accurate idea of how much it has altered from its original shape is to take a lath inside the boiler and lay it along the corrugations at say, four points.

No definite rule can be stated as to whether or not a furnace needs renewal owing to its distorted shape. Age, corrosion, acuteness and area of deformation, and previous history should all be taken into account. Distorted furnaces may give rise to differences of opinion when examining boilers, but if the distortion is really serious the only remedy is to renew the furnace (see Figures 19.5 and 19.6).

Unidirectional thermal cracking (Figure 19.2v)

Thermal cracking sometimes occurs in furnaces of packaged type boilers (Figure 19.7) This has been attributed to flame impingement from a faulty burner which has been allowed to operate in this condition for some time. The only conceivable repair, when the cracking is serious is furnace renewal.

Local bulge in furnace (Figure 19.2w)

Local bulges in furnaces are caused by overheating and remedied by cutting out the bulged portion and welding in a new piece. Alternatively, it may be possible to heat the bulge and push it back to the original furnace shape. In the latter case, the furnace is cut through in way of the bulge to facilitate the flow of the heated material and the cut is, afterwards, welded.

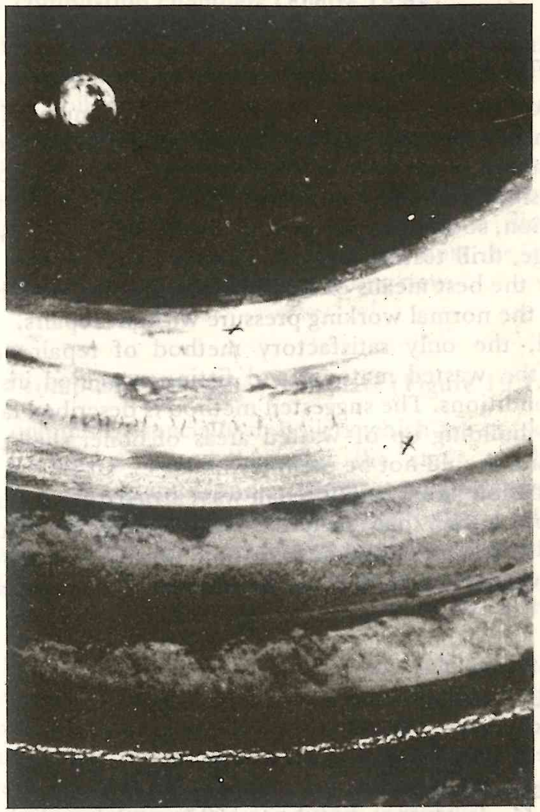


Figure 19.7 Thermal cracking in packaged type boiler furnace as a result of flame impingement

On no account should repairs by fitting doubling plates be contemplated. Locally pitted areas of furnaces can sometimes be repaired by building up the wasted areas by welding and afterwards grinding off to a smooth contour.

Grooving of furnace neck (Figure 19.2x)

In older boilers, grooving may be found to exist in the neck of the furnace. Grooving is a form of corrosion fatigue cracking and is due to the existence of cyclic stresses in a material immersed in a corrosive media.

Repairs consist of cutting out or welding, or, if more serious cutting right through the plate in way of the grooving and closing the resultant gap by welding.

General internal wastage of shell bottom

In neglected boilers, water which has accumulated through condensation is sometimes allowed to remain in the bottom for long periods, with the result that pitting develops. This, in conjunction with the possibility of an accumulation of corrosive deposits through poor circulation, soon turns the pitting into wasted areas. When these areas are large, drill testing and calculations based on the remaining thickness are the best means of deciding whether the shell is still able to withstand the normal working pressure without repairs.

In general, the only satisfactory method of repair consists of cutting out the wasted material and fitting a welded insert under controlled conditions. The suggested method is described later in this chapter. The building up of wasted areas of boiler shell plating by electric welding should not be permitted.

On one occasion an ingenious repair was carried out satisfactorily to a shell bottom which had suffered local wastage over an area of about 450 × 450 mm. A 500 mm dia hole was cut in the boiler shell which effectively removed the wasted material. A compensating tube

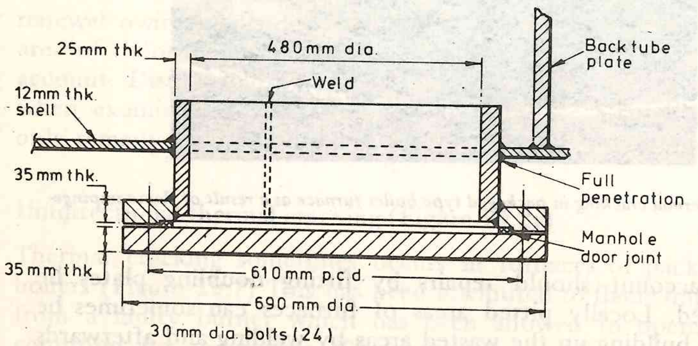


Figure 19.8 Repair to wasted packaged boiler shell where internal access is limited

of Rule dimensions was welded into the aperture and fitted with an access door as shown in Figure 19.8. The access door and fittings were approved by the inspection authority and were manufactured under survey. The door subsequently provided a means of allowing this inaccessible part of the boiler to be cleaned.

Wastage of combustion chambers (Figure 19.2y)

The smooth wastage of the fire side of combustion chamber bottom wrapper plates is a particularly elusive type of defect especially in older riveted boilers. If the plate is judged to be seriously reduced, drill tests or ultrasonic testing will confirm any doubt.

Local wastage can be rectified by building up the affected area by welding but great care should be taken in carrying this out as heavy deposits of welded material may result in distortion of a weakened plate. More extensive wastage must be remedied by cropping back the old material and inserting new.

Overheated combustion chamber backplate (Figure 19.2z)

It is quite common, especially in boilers which are not kept clean, to find the backplate bulged between the stays. A bulged plate accumulates scale and mud, and so promotes further overheating and an extension of the bulge. Provided the bulging of the plating between stays is not very extensive and has not stretched the material in way of the stay holes, so as to cause leakage, the obvious remedy is to keep the water side of the plating as clean as possible, in order to prevent further overheating.

When the chamber plating is bulged to such an extent that it is deemed necessary to effect repairs, it is not advisable to fit additional stays in way of bulges, as they promote the formation of further deposits and make the plates less easy to scale, added to which the extra stays with their nuts form additional local uncooled areas. The only remedy for plating in this condition, is renewal.

The partial renewal of combustion-chamber backs is a very common repair, and a question which sometimes arises is whether the plating should be cut through the lines of stays or between them. A factor in favour of the first method is that the welding is in short lengths between the stay holes and not one long continuous weld, hence the possibility of fractures from contraction stresses is more remote.

VERTICAL TANK BOILERS – DEFECTS AND REPAIRS

In general these vertical boilers are big enough for internal access, although the lower parts around the firebox are often very restricted and resort has to be made to the best possible examination through the small handholes normally provided.

If indifferent feed water has been used, pitting of the firebox and, to a lesser extent, the shell can be expected. In the case of smoke-tube boilers, the tubes as well as the shell and furnace crown, may be affected. In such cases, it is important to ascertain that the stay tubes which tie the flat tube plates together are still in good condition.

The appearance of tubes can be very deceptive even when visual examination supplemented by hammer testing is carefully carried out. A further useful test of thickness is to insert a blunt ended bar into the tube bore and by levering up and down endeavouring to dent the bore.

In the case of riveted boilers longitudinal lap riveted shell seams should always be specially examined at the lap of the plates for fine grooving and the rivets hammer tested.

Fine grooving and cracking at the lap of the plates of the lap riveted seams – probably caused through plating straining, under pressure variations, to become a perfect circle – has, in the case of several land boilers of this type, resulted in serious explosions (see Figure 19.9).

As this fine grooving is difficult to detect, and as a precaution against it being in existence unnoticed, it is recommended that well rounded grooves be cut on the external surface of the lap seam at intervals of about 600 mm, and to a depth of about two-thirds of the plate thickness (see Figure 19.10). This will ensure that if a crack develops and penetrates through the remaining one-third of the plate thickness, warning leakage may develop, or the crack will be revealed when a crack test is applied to the groove.

Whilst concentrating on the internal examination, it is always well to make a special point of looking for distortion of the heating surfaces, especially the flatter parts such as the top flanging of Cochran boiler tube plates which, being horizontal, form a ledge where scale can accumulate. Overheating through water shortage, usually results in serious distortion of the furnace or firebox.

The fireboxes or furnaces of vertical boilers are usually connected to the bottom of the cylindrical shell by what is known as an 'ogee' ring. This joggled ring is connected by riveting or welding, at its top edge to the firebox, and at its bottom edge to the larger diameter

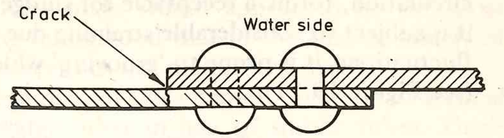


Figure 19.9 Cracking of shell plate in way of top riveted seam

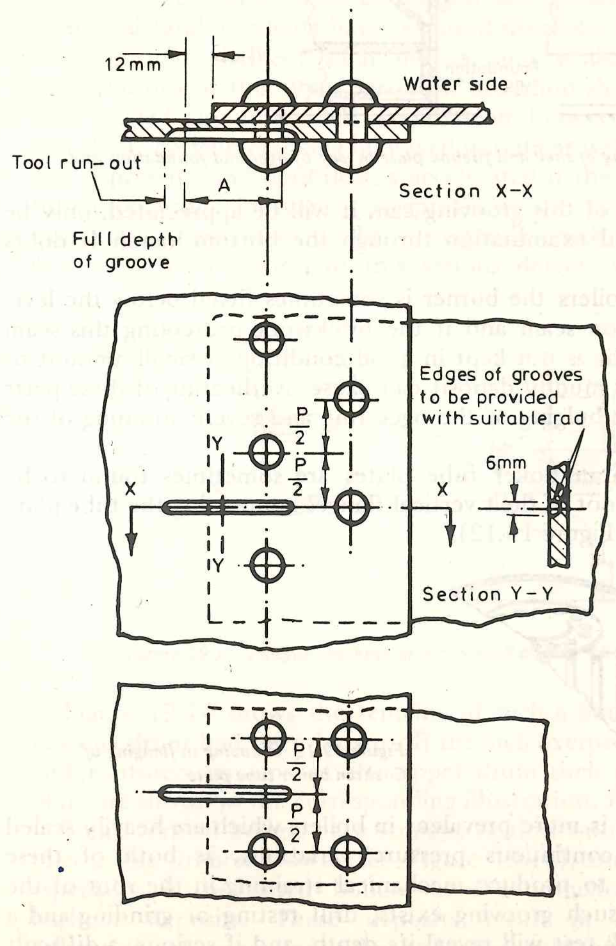


Figure 19.10 Tell-tale grooves for revealing cracking in boiler shell plate

cylindrical shell. In service this ring being in a zone of little if any circulation, forms a receptacle for sludge and corrosive sediments. As it is subject to considerable straining due to pressure and temperature fluctuations, it is prone to 'grooving' which can be of a serious nature (see Figure 19.11).

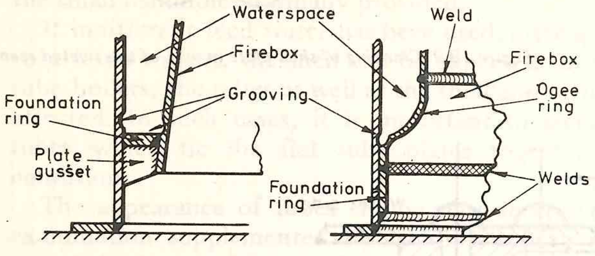


Figure 19.11 Grooving of shell and firebox plate in way of ogee and foundation ring

The presence of this grooving can, it will be appreciated, only be found by careful examination through the bottom handhole doors in the shell.

In oil-fired boilers the burner is sometimes fitted below the level of the foundation seam and if the brickwork protecting this seam and the ogee ring is not kept in good condition, a small amount of internal scale or muddy deposit can cause overheating of these parts with subsequent bulging of the ogee ring and severe straining of the foundation seam.

Riveted Cochran boiler tube plates are sometimes found to be grooved at the root of their vertical flanges connecting the tube plate to the shell (see Figure 19.12).

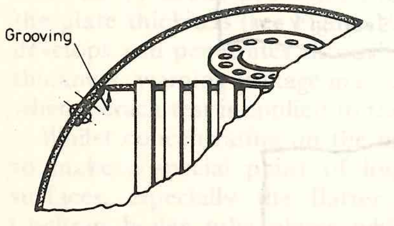


Figure 19.12 Grooving in flanging of Cochran boiler tube plate

This grooving is more prevalent in boilers which are heavily scaled or subject to continuous pressure variations, as both of these conditions tend to produce mechanical straining in the root of the flanging. When such grooving exists, drill testing or grinding and a subsequent crack test will reveal its depth, and if serious, a difficult proposition for repair is created as the grooving is, in effect, a

longidutinal defect in the boiler pressure shell. In the case of riveted boilers renewal of the tube plate would appear to be the most satisfactory repair, it being understood that in the case of boilers of welded construction this defect has not manifested itself.

As mentioned at the beginning of this chapter, one type of vertical auxiliary boiler utilises water tubes in lieu of smoke tubes. These boilers (see Figure 19.1), consist of upper and lower closed cylindrical sections joined to one another by straight water tubes, enclosed in the lower section is the firebox, the gases from which pass around the water tubes en route to the uptake.

Several fatal accidents have occurred involving the detachment of the top half shell of such boilers, and whilst making internal examinations of this type, particular attention should be paid to the right angled circumferential welded seam between upper tube plate and shell. Fatigue cracking may well initiate at weld under-cutting, if any is present, and doubtless is accelerated if the boiler is subjected to fluctuating pressure, overpressure or cold feed. Careful examination and, if in doubt, a magnetic crack test will reveal the presence, or otherwise, of this serious defect (see Figure 19.13).

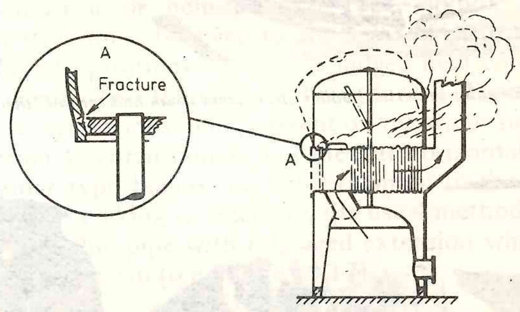


Figure 19.13 Fatigue cracking of boiler shell at tube plate connection

Figure 19.14 shows the remains of such a boiler after the upper (steam) drum had been blown off through overpressure. The twisted and ruptured remains of the upper drum shell plating and crown plate are shown in the corresponding illustration, Figure 19.15.

Some vertical boilers have straight vertical smoke tubes expanded into a flat firebox crown (see Figure 19.16), and this arrangement especially in neglected boilers used intermittently, is liable to harbour deposits. These deposits result in local overheating, relaxation of expanded tube ends and subsequent leakages. Seal welding overcomes leakages, but if further deposits are allowed to

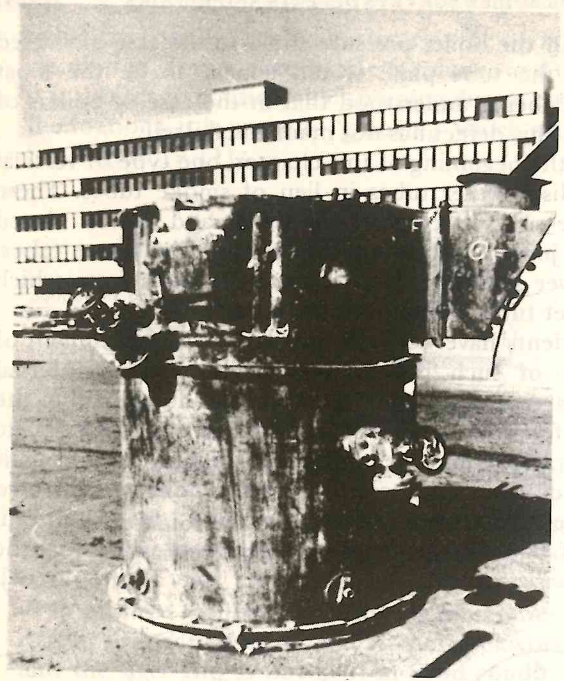


Figure 19.14 Remains of vertical boiler after steam drum had torn off through overpressure

Figure 19.15 Torn and twisted crown plate of steam drum belonging to the boiler shown above

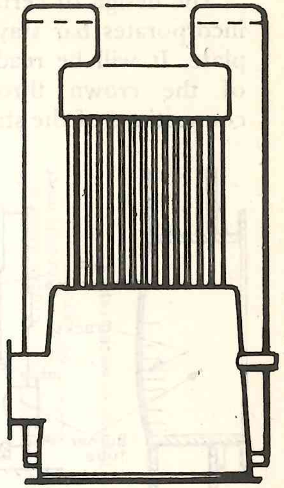


Figure 19.16 Vertical boiler with horizontal flat tube plate

accumulate, distortion and cracking between tube holes often occurs necessitating eventual renewal of the tube plate.

In the cylindrical or hemispherical type firebox or furnace particular attention must be given to any signs of distortion, and to thermal cracking at positions where it is judged heat concentrations are likely to occur when the boiler is being forced (Figure 19.18) or through scale encrustations being present on the water side. The flue pipe outlet from Cochran boilers and the flat horizontal tube plate of some Spanner type boilers are two examples. In the case of the former, when the cracking is extensive, the usual method of repair is to weld in a new flue pipe with a flanged extension which takes in part of the furnace crown (see Figure 19.17).

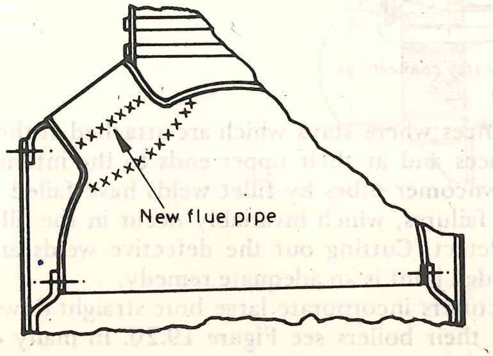


Figure 19.17 Repair for cracked Cochran boiler flue pipe

The design of certain boilers having hemispherical furnace crowns incorporates bar stays between the crown and the flat lower tube plate. It will be readily seen from Figure 19.19 that any distortion of the crown through overheating may result in the welded connections of the stays becoming overstressed.

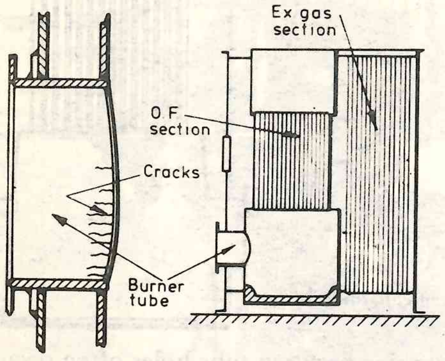


Figure 19.18 Thermal cracks in burner tube

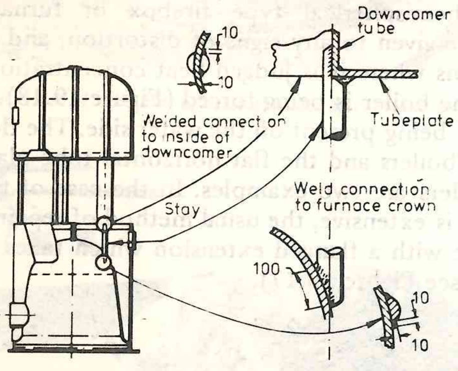


Figure 19.19 Cracking of furnace stay connections

There have been instances where stays which are attached at their lower ends to the furnaces and at their upper ends to the internal surfaces of the large downcomer tubes by fillet welds have failed at these connections. Such failures, which invariably occur in the fillet welds, are difficult to detect. Cutting out the defective welds and restoring an efficient welded joint is an adequate remedy.

A number of manufacturers incorporate large bore straight downcomers in the design of their boilers see Figure 19.20. In many of these boilers the steam drum, water drum and intermediate drum, if

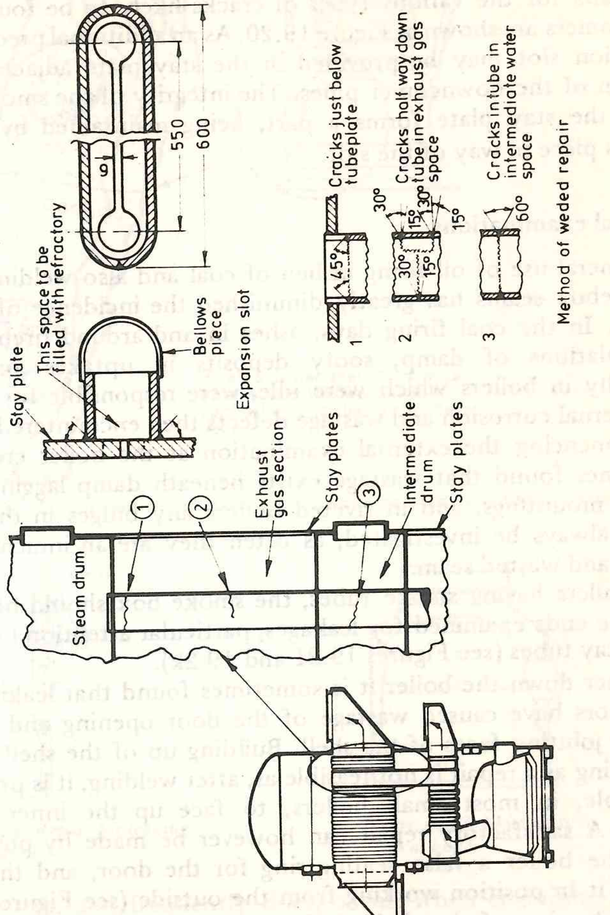


Figure 19.20 Cracks in downcomers

fitted, are attached to each other not only by stay tubes but also by stay plates. These plates are extensions of the boiler shell plate. Differential expansion between the stay plates, the generating tubes and the downcomers, which are subjected to different thermal conditions, has resulted in cracks forming in the downcomers.

Repairs for the various types of cracks likely to be found in the downcomers are shown in Figure 19.20. As an additional precaution an expansion slot may be provided in the stay plate adjacent to the position of the downcomer pipes. The integrity of the smokebox, of which the stay plate forms a part, being maintained by fitting a bellows piece in way of the slot.

External examinations

The general use of oil firing in lieu of coal and also welding of shell and firebox seams has greatly diminished the incidence of external defects. In the coal firing days, ashes in and around fireboxes and accumulations of damp, sooty deposits in uptakes and tubes, especially in boilers which were idle, were responsible for much of the external corrosion and wastage defects then encountered.

Commencing the external examination at the boiler crown it is sometimes found that wastage exists beneath damp lagging around leaking mountings, and in riveted boilers any bulges in the lagging should always be investigated, as often they are an indication of a leaking and wasted seam.

In boilers having smoke tubes, the smoke box should be opened and tube ends examined for leakages, particular attention being paid to the stay tubes (see Figures 19.21 and 19.2k).

Further down the boiler it is sometimes found that leaking hand-hole doors have caused wastage of the door opening and also the internal jointing faces of the shell. Building up of the shell opening by welding as a repair is not feasible as, after welding, it is practically impossible, in most small boilers, to face up the inner jointing surface. A satisfactory repair can however be made by positioning inside the boiler a false seating ring for the door, and then fillet welding it in position working from the outside (see Figure 19.22).

An extension of the shell plating, on some vertical boilers often forms the lower part of the furnace casing, (see Figure 19.23). This skirt should be carefully examined as overheating, due to defective brickwork, may cause buckling and, in consequence, weakening of this structure. Similarly, when this plating is situated below the level of the engine room platform and is subjected to the corrosive effects of occasional bilge water and a generally damp atmosphere, rapid

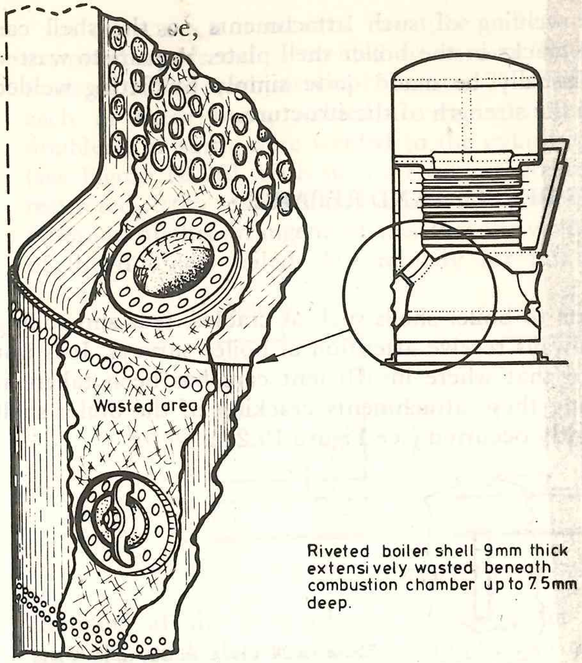


Figure 19.21 Riveted boiler shell extensively wasted beneath combustion chamber due to tube leakage

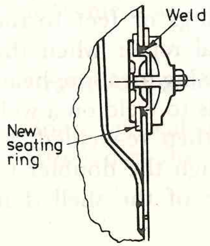


Figure 19.22 Repair for leaking handhole door

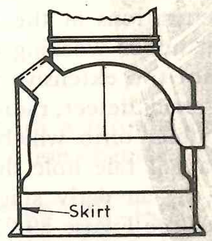


Figure 19.23 Skirt plate in vertical boiler

wastage can, and frequently does, occur. When examining this part of the boiler, it should be remembered that the combined weight of the boiler and its contents, which may be as much as 30 tonnes, is supported by this structure. Cases have been reported where partial collapse of this structure has resulted in some of the weight of the boiler being transferred via the upper shell of the boiler to the rolling stays and their lugs.

Failure of the welding of such attachments to the shell can precipitate serious cracks in the boiler shell plate. Repairs to wasted skirt plating can usually be made quite simply by fitting welded doublers to restore the strength of the structure.

MISCELLANEOUS DEFECTS AND REPAIRS

Shell attachments

Welded attachments to boiler shells such as cradles, feet and rolling stay lugs should always receive attention at boiler surveys. It is not uncommon to find that where insufficient care has been taken in designing and fitting these attachments cracking of the boiler shell plate has subsequently occurred (see Figure 19.24).

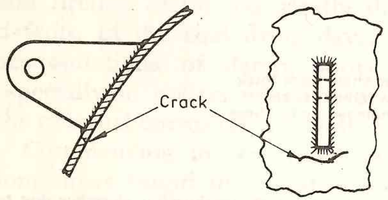


Figure 19.24 Cracks in way of shell lugs

These cracks have sometimes been attributed to the effects of stress concentrations at the connections of the lugs or feet to the boiler when under working conditions. The usual repair when the cracks are not too extensive is to cut out, weld using local pre-heat, grind flush, crack detect, radiograph and afterwards to weld on a well rounded doubler onto which the attachment is then re-welded. In such cases a tell tale hole should be drilled through the doubler to help reveal, at an early stage, any future failure of the shell if it should occur (see Figure 19.25).

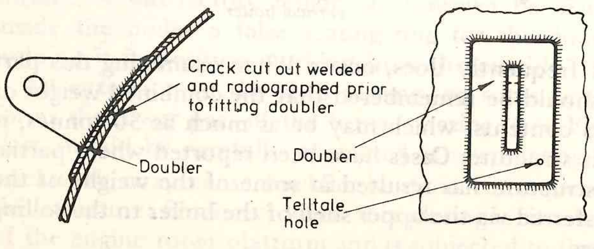


Figure 19.25 Repair for cracks in way of shell attachments

In one case, a horizontal fire tube boiler of packaged type was mounted and securely welded to its own foundations which were made of rolled steel joists of H section. The boiler had four supports, each of these being welded to an individual plate doubler; the doublers, in turn, were welded to the cylindrical shell of the boiler (see Figure 19.26). With such a strong, rigid structure the boiler was restricted from expanding longitudinally when under steam. The outcome of this arrangement was that the welded connection of one of the doublers failed. The remedy for this was to remove both

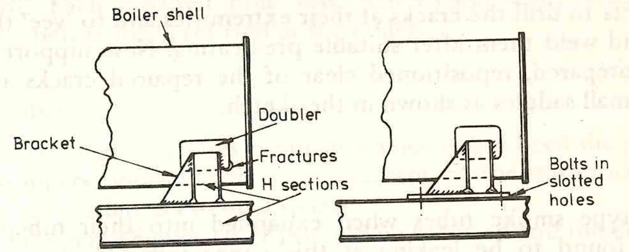


Figure 19.26 Horizontal packaged boiler foundations

doublers at the forward end of the boiler shell, grind the area smooth, crack detect and fit new and larger doublers. This avoided the disadvantage of having to weld over the previous lines of welding. The support feet were then refitted after modifying to allow for movement as shown in Figure 19.26.

Cracks in toroidal headers

Some vertical boilers are designed with a toroidal header which is situated at the bottom of the combustion chamber or furnace. This

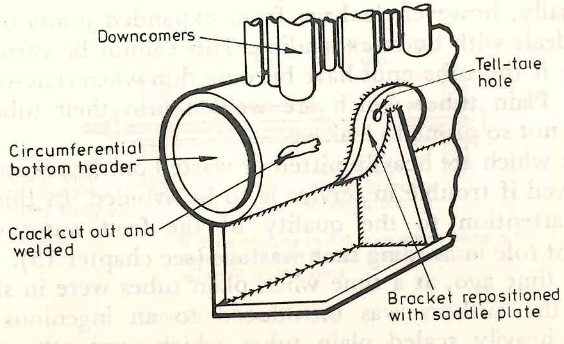


Figure 19.27 Foundation ring attached to toroidal header

header forms the foundation ring and supports the weight of the remainder of the boiler. This header is welded to a T or L section support ring and is further secured by a number of triangular shaped brackets (see Figure 19.27).

Cracks have been found in several of these headers. The cracks have generally been found to have occurred at the toes of the brackets. It is possible that stress concentrations have formed at these points as a result of radial expansion of the header being restricted by the cooler attached support ring.

The repair for this type of defect has been to crop the existing brackets to drill the cracks at their extremities and to 'vee' the cracks out and weld them after suitable pre-heating. New support brackets were prepared, repositioned clear of the repaired cracks and fitted with small saddles as shown in the sketch.

Tubes

Plain type smoke tubes when expanded into their tubeplates are often found to be leaking at this connection. The cause of any leakage can usually be traced to overheating as a result of a low water condition, heavy scale, oily deposits or forcing of the boiler. Very occasionally, where repeated problems have been experienced with leaking tubes, the cause has been established as 'panting' of an inadequately supported tube plate. The remedy for this is to check that the staying arrangements remain efficient and have not been modified by unauthorised persons. Additional staying of the tube plates may be the only remedy in certain cases. As a temporary measure, this can be achieved by fitting substantial screwed rods through a selected number of existing plain tubes and anchoring these firmly to the tube plate by means of tube stoppers of the flanged type.

Normally, however, leakage from expanded joints of plain tubes can be dealt with by re-expanding. This cannot be carried out satisfactorily if the tube ends have become thin when renewal is the only remedy. Plain tubes which are welded into their tube plates are, happily, not so prone to leakage.

Tubes which are heavily pitted or wasted on their water sides must be renewed if trouble in service is to be avoided. In this connection careful attention to the quality of the feed water will play an important role in avoding such wastage (see chapter 15).

Some time ago, at a time when plain tubes were in short supply, one of the authors was introduced to an ingenious method of cleaning heavily scaled plain tubes which were otherwise in good

condition. This consisted of cutting out all the plain tubes by oxy-acetylene torch leaving the expanded ends in their respective tube plates – these were afterwards cut out by hand very carefully, to avoid damaging the holes in the tube plates, and discarded. The tubes were removed from the inside of the boiler, hand scaled and their ends machined true. A small number of replacement tubes were available and these were machine cut into short lengths of about 200 mm. One of these lengths was then oxy-acetylene welded to each of the prepared old tubes using a mandrel to maintain alignment. Each repaired tube was then hydraulically tested in a special rig before being refitted in the boiler.

Tube stoppers

Where isolated tube failures occur in service it has been the practice to fit stoppers, indeed, it is a requirement of the authorities that stoppers are carried as essential spares.

Such stoppers (Figure 19.28) should be removed and the defective tube renewed as soon as possible. One manufacturer provides a stopper with one end of the securing bar in the form of a short length of heavy duty link chain for blanking plain smoke tubes of curved or bent form. Tube stoppers should always be removed at

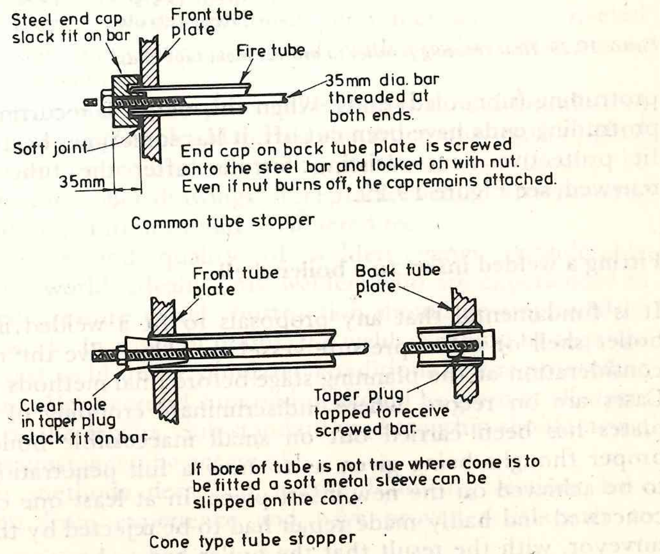


Figure 19.28 Tube stoppers

boiler surveys, whether or not the defective tubes are to be renewed, in order that the rods and threads can be examined. Failure, in service of a smoke tube stopper could result in injury to personnel.

On no account should welded blanks or, worse still, driven in tapered plugs be fitted to plain ordinary smoke tubes. Several cases of such mal-practice have been reported in the past. Isolated defective water tubes of tank type boilers may, of course, be plugged in the usual way by fitting tapered plugs which should be tapped well home.

It sometimes happens that thermal cracks develop in the ends of plain or stay tubes at their combustion chamber or firebox ends. This may be accelerated by the use of over-long tubes, resulting in

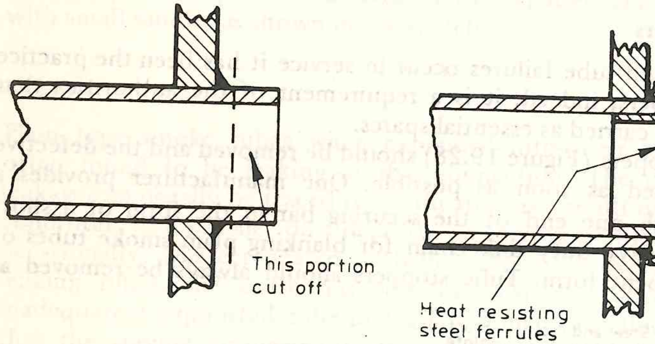


Figure 19.29 Heat resisting ferrules to protect plain tube ends

protruding (uncooled) ends. When this defect is recurring, even after protruding ends have been cut off, it has sometimes been effective to fit protective heat resisting ferrules after the tubes have been renewed, see Figure 19.29.

Fitting a welded insert to a boiler shell

It is fundamental that any proposals to fit a welded insert to any boiler shell or other pressure vessel should receive the most careful consideration at the planning stage before final methods are decided. Cases are on record where indiscriminate cropping of boiler shell plates has been carried out on small inaccessible boilers without proper thought being given as to how a full penetration weld was to be achieved on the new insert piece. In at least one case, a badly conceived and badly made repair had to be rejected by the attending surveyor, with the result that the boiler had to be renewed whereas, proper planning and supervision in the early stages of the repair,

would have saved the boiler and saved the shipowner inconvenience and, not least, expense.

When any particular defect warrants a major repair being effected to a boiler a very careful examination of all other parts is essential in case the original defect has caused secondary damage. In one case a small vertical boiler suffered loss of water and as a result a badly set down furnace crown with set in furnace side walls. In this boiler the furnace plates were considerably heavier than those of the pressure envelope, and the former supported the whole structure of the boiler. Repairs consisting of extensive renewals of the furnace plating were recommended and effected. However, on examination of the boiler under hydraulic test it was noticed that the upper section of the pressure envelope was badly distorted. It can only be assumed that this distortion took place simultaneously with that of the furnace but being hidden by insulation and the metal casing had remained undiscovered until the time of the pressure test. The boiler was, of course, condemned but valuable time had been lost by the shipowner in ordering a replacement.

It is essential, in planning any repair to consider what facilities and materials are available at the port where the repairs are to be effected, the standard of local workmanship must also be taken into account. Riveters who were taken for granted until a few years ago, have disappeared from many large ports. Therefore, certain defects which, at first sight, would obviously lend themselves to riveted methods of repair may have to be dealt with by alternative means using welded connections.

In all cases of boiler repairs, recognised codes should be followed whenever they are applicable. Materials should comply with original specifications or be equivalent to them. These can usually be obtained from the boiler drawings. Acceptable welded attachments, weld form and preparation should be adhered to.

The experience and quality of welders varies considerably throughout the world. Ideally only welders who are experienced in Class I welded pressure vessel construction should be employed on boiler repair work. In cases of doubt, the welders should be required to prepare a test weld under simulated conditions before proceeding with the repair. Very careful supervision should be given at all stages of the work to the repairs. Sub-standard workmanship should never, under any circumstances, be accepted.

The repair methods described in the following sections have been gathered from experience and have proved satisfactory in service.

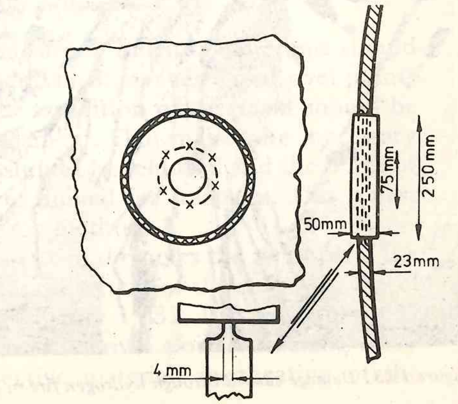
When wasted shell plating is encountered the overall effect of the wastage on the safety of the boiler should be considered. Local pitting, even though quite deep, may not materially affect the strength of the boiler and therefore, apart from ensuring that such pitting remains inactive no further action may be necessary. On the other hand general wastage, deep radial grooving or cracks in shell plating must often be repaired before a boiler can be allowed to steam again.

Nowadays such defects are generally dealt with by cropping out the defective areas and fitting insert plates, all new seams being electrically welded. In carrying out such repairs the following basic principles should be adhered to:

1. Defective areas may be cropped by flame cutting but a suitable final weld preparation of 'double vee', U or J form should be made by careful chipping or grinding.
2. In older boilers, cropping close to a riveted seam should be avoided whenever possible as the flame cutting and subsequent welding procedures will inevitably 'start' an old riveted seam.
3. In all cases the proposed welded seam should be of full penetration type and carried out from both sides.
4. Where welding is to be carried out in both the downhand and overhead positions, the larger 'Vee' or U preparation should be arranged for the downhand position.
5. Where flame cutting or overheating has occurred, hardness plots should be made using a portable testing instrument. The hardness values so obtained enable an approximation of the equivalent tensile strength to be made by referring to published tables. This gives a fair indication as to whether or not the material has been overheated to such an extent that the microstructure of the material has been affected. Under no circumstances may welded repairs be undertaken when the microstructure of the parent material is suspected of having undergone any change from its original form. In any case, magnetic crack detecting methods should be used to ensure that there are no cracks present before welding is commenced.
6. The design of the repair should be such that there are no sharp corners and the new insert plate should be of similar quality and specification to that of the parent metal. The insert piece should be carefully cut (and rolled if necessary) to shape and hand fitted to the cropped aperture.
7. Areas to be welded should be preheated to a minimum of 100°C and maintained at that temperature throughout welding.
8. Care should be taken to eliminate any cold draughts from

impinging upon the area under repair. Insulation mattresses should be made available to protect the welded areas from rapid cooling.

9. The welding should be carried out by a firm approved for Class I Welding under the direct supervision of an experienced foreman and to the satisfaction of the surveyor. Where Class I approval is not available, suitable performance tests should be carried out by the selected operators to the surveyor's satisfaction.
10. Low hydrogen electrodes should be used which deposit metal having tensile properties similar to those of the parent metal. The electrodes should have been satisfactorily stored and baked before use.
11. Welding should be carried out in accordance with approved procedure, to an acceptable technique and sequence.
12. Magnetic crack detection should be carried out at stages during the welding each run of welding being thoroughly cleaned using mechanically rotated descalers, wire brushing or disc grinders as necessary.
13. On completion of the welds, they should be ground flush with the parent metal and crack detected.
14. 100% radiographs are to be obtained of the finished seams to Class I standards and to the surveyor's satisfaction.
15. Stress relieving may require to be carried out if the plate thickness exceeds 20 mm. This should be done by raising the temperature uniformly and slowly over a period of twelve hours to 580–620°C and holding the temperature at that level for a period of not less than one hour after which the repair to be allowed to cool slowly.



gure 19.30 Welded insert repair for ıstage of shell in way of feed check lve joint

16. Stress relieved welds should be thoroughly crack detected by magnetic particle methods. Typical examples of this type of repair are shown in Figures 19.30 and 19.8.

It must be stressed that the foregoing repair methods are applicable only when the material of the boiler plate is carbon or carbon-manganese steel having a tensile strength not exceeding 520 N/mm². Special procedures may be required in all other cases and these are best obtained from the manufacturer of the boiler and applied only after agreement with the inspection authority responsible.

Hydrogen fires

The mechanics of hydrogen fires have been dealt with in some detail in chapter 17. Such accidents are not restricted to water tube boilers and have been known to occur in once through coil type steam generators and also in finned tube economisers. Figure 19.31 shows the results of a fire in such on economiser.

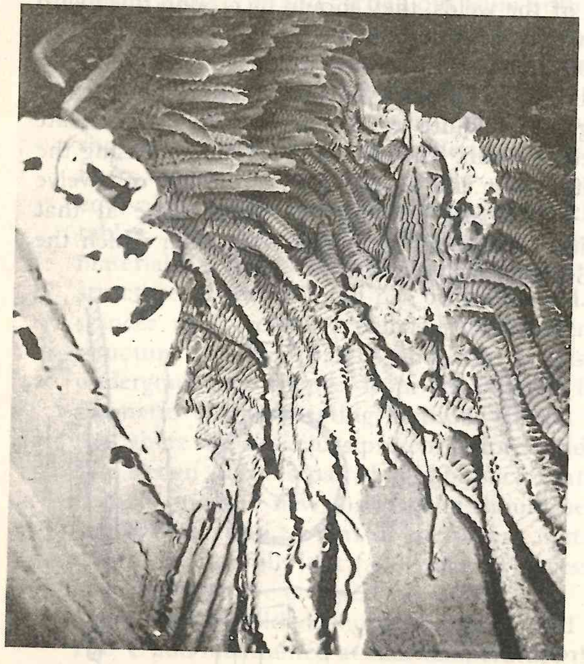


Figure 19.31 Damage caused through hydrogen fire in finned tube type economiser

Caustic embrittlement (intergranular stress corrosion)

This defect has largely disappeared with the decline of riveted boilers. However, in view of the serious consequences of failure to recognise the condition when it exists in a boiler, a few notes are pertinent.

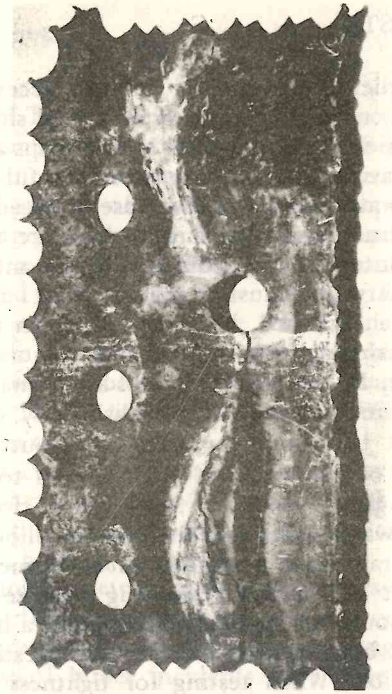


Figure 19.32 Stress corrosion fracture in boiler shell plate

Leakage in way of rivets, especially in longitudinal seams should always be treated with caution and if hammer testing of rivet points results in any being dislodged, the condition of the seam should be investigated for caustic embrittlement. To make the necessary examination the defective rivets should be removed and the bores of the holes polished and carefully examined for fractures. This is best effected by magnetic crack detection methods.

If cracking of the shell is apparent in the holes the removal of the butt straps is essential to determine the extent of the defects. Typical cracks of this nature are shown in Figure 19.32. It is as well to bear in mind that there are other causes of rivet points breaking away from their shanks, such as defective material, overheating of the rivets or excessive riveting pressures and in such cases simple renewal of the rivets in question is all that is necessary.

The cause of stress corrosion (caustic cracking) is explained in chapter 15.

HYDRAULIC TESTS

As mentioned earlier in this chapter, internal access to some of the tank type boilers currently encountered aboard ship is very limited and, in fact, occasionally impossible. It is perhaps as well that, these days, engineers have learned to pay more careful attention to the quality of feed water than was the case a decade or so ago and consequently internal corrosion and wastage are not so prevalent. However, when internal corrosion is obvious and internal access impossible, the surveyor must make the best use of lights and mirrors, if not then satisfied, he should insist on tubes being withdrawn to enable proper access to be gained to questionable internal parts of the boiler. In cases where boilers are so inaccessible that the true internal condition cannot be established by visual means, the only recourse left to a surveyor is to carry out a hydraulic test.

When carrying out such a test it is as well to ensure that the safety valves are gagged and all valves firmly closed. It is always preferable to use warm water and the pressure should be applied by means of a small ram hand pump and *never* by means of the boiler feed pump. About 1.25 to 1.5 × working pressure is the maximum pressure which should be applied when testing a boiler after major shell repairs have been carried out or when testing in lieu of an internal examination. When testing for tightness of expanded or welded tube connections, a pressure test equivalent to working pressure is usually adequate. In general, the pressure should be applied gradually and held at the required level for about 1 hour.

20 Certificates of competency

The Department of Trade (DoT) is primarily concerned with safety and its current examinations covering First and Second Class Certificates of Competency for marine engineer officers require a knowledge of the whole subject of steam and diesel propelling machinery. This book is concerned solely with steam raising equipment. Today it is not unusual for a 21 000 kW tanker to be steamed by one automatically controlled water tube boiler whereas famous passenger liners of the past, such as the White Star Line's 'Olympic', with reciprocating engines on the wing shafts and a turbine on the centre, required twenty-four double-ended and five single-ended Scotch boilers working at 15 bar to produce 22 000 kW from the engines and 12 000 kW from the l.p. turbine.

More efficient machinery and automation, whilst enabling the shipowner to operate the vessel at a lower cost and with a fraction of the personnel, have at the same time increased enormously the scope of knowledge required by such personnel.

In the past large, riveted tank type boilers with cylindrical furnaces, extensive flat surfaces, often poor feed conditions, and of 30 tonnes capacity were a potential source of danger, but in recent years the majority of boiler incidents have been associated with water tube high pressure types. Such incidents have included propulsion failure and at least one stranding of a VLCC, but more serious, because fatalities have occurred, have been a number of furnace explosions. The causes of these incidents are not usually attributed to any fault in the design or construction of the boiler, but rather to faulty operation or to safety equipment which has been rendered inoperative or has not been brought into commission.

Tank type boilers of many designs are still fitted for auxiliary and domestic steam requirements, especially in motor vessels; these are normally of all-welded construction and often fully automatic in operation. Some of these boilers of cylindrical horizontal type are very inaccessible internally and have cylindrical furnaces with small water cover.

The dangers from overheating with these small tank type boilers is high when compared to water tube boilers and they can, when neglected, be 'killers' – an overheated and ruptured furnace will disgorge the contents of the boiler in seconds with fatal results whereas the rate of escape of contents of an overheated water tube boiler is usually restricted to the bore of a burst tube. Every attention should, therefore, be focussed on these tank boilers and the DoT ensure that every certificated engineer officer is aware of this fact.

The UK authorities have recently announced a new structure for marine engineer officers employed in the UK Merchant Navy. This is scheduled to come into force in September 1981; a brief outline of the new regulations in so far as Certificates of Competency is concerned is given below.

Provision has been made for four classes of Certificates of Competency, namely Classes 1, 2, 3 and 4. The first two replace the existing First and Second Class Engineer Certificates of Competency and the syllabuses for these are broadly similar to those for First and Second class examinations. Class 3 and 4 certificates are new innovations and ultimately, with certain endorsements, will enable the holders to serve as senior engineer officers on ships of restricted categories. The Class 3 Certificate of Competency will apply to motorships only. Full details of the regulations are available in booklet form from HMSO *Certificates of Competency in the Merchant Navy – Marine Engineer Officer requirement.*

The syllabuses for the examinations for all the above classes of certificates are given in detail in a publication obtainable from HMSO, *Examinations for Certificates of Competency in the Merchant Navy – Marine Engineer Officer syllabuses* and *specimen papers.*

The Class 4 examination will consist of a ½-hour verbal examination only but the candidate would be well advised to pay particular attention to the following points so far as the operation of steam boilers is concerned.

1. Checking of water level in auxiliary boilers and action necessary if water level is abnormal.
2. Recognition of boiler water contamination.
3. Operation of auxiliary boilers including combustion system.

Although, as stated above, the Class 3 certificate will only be applicable to motor ships, the syllabus for the corresponding examination covers some aspects of auxiliary boiler operation. The candidate should therefore be prepared to answer questions on the following subjects:

1. Constructional details of auxiliary boilers.
2. Management and operation of auxiliary boilers.
3. Firing arrangements and equipment.
4. Water sampling, treatment, causes of contamination.
5. Operation and construction of water level gauges, pressure gauges and formation of scale in boilers, safety valves and other mountings.

With a view to giving intending candidates some idea of the type of questions they are likely to be confronted with at these written examinations of competency, typical examples are given.

CLASS 1 (ENGINEERING KNOWLEDGE – STEAM)

1. Sketch a forced circulation boiler showing the direction of flow of water, steam and combustion gases. Discuss the relative merits of forced and natural circulation boilers.

2. Sketch and describe a 'full lift' safety valve incorporating booster reseating. Explain the purpose of this design and how steam tightness is achieved. Describe the operation of the booster reseating arrangements. Explain how the valve is reset after overhaul.

3. With reference to closed feed systems comment on the following statements:
   (a) The higher the feed temperature entering the boiler the greater the plant efficiency.
   (b) Raw feed can be used in high pressure boilers.
   (c) Main feed pumps are self-regulating.
   (d) Demineralisation plants are essential.
   (e) Cylindrical condensers are superior to rectangular ones.

4. Describe with line diagrams two arrangements in which one small and one large boiler jointly meet all steam demands. Discuss with particular reference to abnormal conditions four advantages this arrangement has over installations comprised of two large boilers. Give two disadvantages of the 'one and a half' boiler concept.

5. Sketch and describe a three element feed water control giving reasons for its location. Explain how unity relationship is maintained between the identified variables. Explain why three element control is superior to two element control.

6. Draw a line diagram of a combustion control system labelling the principal items. Explain how the system functions and in particular how the feed water supply, fuel supply and air/fuel rates are regulated to match the steam pressure and flow variation.

7. Describe with sketches a reheat boiler incorporating a steam cooler, an economiser and air heater. Explain the purpose of the reheat cycle and state what are its advantages and disadvantages compared to simple cycles. Explain the problems peculiar to reheat boilers.

8. Describe an automatic sootblowing system giving with reasons the sequence of operation. Explain why boiler tubes and superheater elements should be kept clean externally. State with reasons the sequence of operation. Explain why boiler tubes and superheater elements should be kept clean externally. State with reasons what precautions are taken during soot blowing operations. Explain how badly maintained soot blowers can cause boiler defects and loss of efficiency.

9. Describe the forms in which magnetite (Fe_3O_4) is found on the water side of a main boiler. State what are the beneficial and detrimental effects of magnetite in a boiler. Distinguish between the following forms of corrosion:

(a) electrolytic action.
(b) chemical action

State where each type is most likely to be found and how combated.

10. Explain the cause of boiler panting and state how it is eliminated. Describe how a combustion control system deals with this condition. Suggest the possible consequences if panting is not quickly stopped.

11. With reference to main boilers explain why:

(a) roof firing is preferable to front firing,
(b) attemperators are preferable to uptake dampers,
(c) rotary air heaters are preferable to tubular heaters,
(d) the passage of all steam through the superheater is preferable to taking dry saturated steam for auxiliary purposes from the steam drum.

12. The first stage in a remote control sequence for the lighting up of a burner is to check that all interlocks are 'healthy'.
Detail five permissive interlocks and three shut-down interlocks which may be fitted in a system where the burners are steam assisted. Give a reason for these interlocks.

13. Describe how the following conditions of the water in a main boiler are controlled:

(a) alkalinity,
(b) phosphate reserve,
(c) oxygen content.

Explain why it is necessary to maintain the above conditions within close limits.

14. Suggest with reasons, to what extent:

(a) the temperature of the steam at superheater outlet is a reliable guide to optimum conditions on the steam and gas sides of a main boiler,
(b) the boiler water analysis is representative of the water in the boiler under the various conditions of operation.
(c) the condenser vacuum is a reliable indication of conditions in the condenser.

15. Sketch and describe an all-welded boiler drum with various flange and facing details included. Describe how the important welds are carried out and what are the special requirements for pressure-vessel welding. How would you locate the important welded joints during a routine inspection?

16. How would you prepare one of a battery of boilers for survey? What safety precautions do you recommend? What examinations would you carry out and what possible defects would you look for? Refer to mountings and possible defects. What repairs would you normally expect to carry out?

17. Describe how you would prepare a boiler for an hydraulic test. When is this test carried out? Describe the inspection that takes place before the test, during the test and after the test.

18. Sketch and describe a water-gauge glass suitable for boiler pressures in the range of 25–40 bar. Describe typical maintenance and how a new glass is fitted. Include overall dimensions and refer to any safety considerations included in the design.

19. Describe with the aid of suitable sketches a full-bore safety valve. If the valve is used as a superheater safety valve compare the effect of placing the pilot on the main steam drum with that when placed on the valve chest at the superheater outlet.

20. Describe the procedure of removing manhole doors and in what order the doors should be removed, particularly in the case of a boiler that is still hot after blowing down.

21. Sketch and describe a feed-water regulator for a water tube boiler. The regulator to be of a type that does not use a float.

22. Sketch and describe a controlled superheater boiler of the type not fitted with damper in the gas path. Show passage of gases and circulation of water, with reference to any precautions necessary when using this boiler. How is the superheat controlled?

23. Describe a superheater as used with a modern watertube boiler. Show clearly the flow of steam and gas with expected temperatures and pressures. Discuss materials, fittings, expansion allowances supports and maintenance.

CLASS 2 ENGINEER (Engineering knowledge – STEAM)

1. With reference to main boilers describe with sketches the following components.
   (a) Air desuperheater.
   (b) Steam air heater.

For each component give two reasons for its incorporation in boiler plant.

2. Sketch a consolidated high lift safety valve indicating the important clearances. Describe valve operation and adjustment. State what components need special attention during inspection and overhaul.

3. Define the significance of the following factors in boiler corrosion and scale formation:
   (a) pH value of the feed water.
   (b) Low oxygen content of the feed water.
   (c) Coagulants in the boiler water.

4. With reference to generating tubes in main boilers:
   (a) Give two reasons why tube expansion into drums and headers has been discarded.
   (b) Describe with sketches a current way of attaching tubes to drums and headers.
   (c) Describe how a faulty tube is traced and isolated.

5. Sketch a full bore safety valve with pilot valve and connections. Describe valve operation and adjustment. State to what defects the valve is prone.

6. Describe how the following conditions of boiler water are checked and controlled.
   (a) Alkalinity.
   (b) Phosphate reserve.
   (c) Oxygen content.

Give a reason why each condition must be kept within close limits.

7. With reference to fires in-gas spaces and air heaters of main boilers describe how they are:
   (a) Caused.
   (b) Dealt with.
   (c) Avoided.

State what inspection is advisable before putting the boiler back into service after a fire.

8. Describe with sketches how a burst tube in the membrane wall of a main boiler furnace is dealt with. Give two advantages of membrane wall construction. Define the importance of correct membrane width and the effect of too broad or narrow a membrane.

9. Sketch and describe a regenerative air heater. Give two advantages and two disadvantages possessed compared to other types.

10. Give a reason why sodium phosphate, sodium hydroxide and hydrazine are each used in boiler water treatment.
Describe any three of the analytical tests normally applied to boiler water.
Explain how the results influence further treatment.
State two precautions to be observed when storing and handling these chemicals.

11. Discuss the following defects in watertube boilers, giving causes, remedies and repairs for each:
   (a) Spalling and cracking of the quarls.
   (b) Local bulging of water-wall tubes.
   (c) Smooth wastage of tubes in way of soot blowers.

Sketch the construction of an air-heater suitable for a water tube boiler, using steam as the heating medium. Show typical temperatures and pressures at various points and the method of drainage of the steam side. Discuss the advantage of the system.

12. Sketch and describe a gas/air-heater of:
   (a) tubular type;
   (b) rotating type.

Explain the maintenance required and state the various pressures and temperatures throughout the circuit. Discuss the various defects to which these are subject.

13. Discuss the effects of a dirty gas side of a water tube boiler tube bank. In particular give a reasoned account of the effects on superheat temperature. Explain the various methods used for cleaning the exterior of the tubes, the precautions to be taken during cleaning, and state the deposits which are difficult to remove.

14. Explain how you would carry out a survey of a water tube boiler. Discuss the defects you may find and the remedies for these defects. Describe how you would prepare one of a group of three boilers for survey.

15. Sketch and describe a section through a fire-brick-furnace wall, showing method of securing the insulation and the type of insulation used.

16. Sketch and describe a section through a water-walled-furnace insulation, showing type of insulation used and the method of securing the insulation.

17. State the various types of insulation material used for a water tube boiler furnace. Explain the use of the various types, method of application and the subsequent drying and firing process. Discuss the various defects to which furnace brickwork is subject, with particular reference to sea-water contamination of fuel and indifferent handling of the boiler.

18. State the necessary precautions to be taken when raising steam from cold in a watertube boiler with reference to
(a) air-heater;
(b) superheater,
(c) dense smoke;
(d) lighting burners.

19. Describe internal cleaning processes for bent tubes in a water tube boiler. Explain how the tubes are checked for being clear of obstructions, and how the tubes are inspected internally.

20. Describe the manufacture of a welded boiler drum, giving details of the plate-edge preparation, welding procedure and heat-treatment processes. Briefly describe the tests the drum and the materials are subjected to.

CLASS 1 ENGINEER (Engineering Knowledge – MOTOR)
(*Usually one steam-type question in each Motor paper*)

1. Recommend the corrective and precautionary measures to be taken before an overfilled boiler is coupled to and shares the load of another boiler already operating under full steaming conditions.
2. Give an account of an examination of the combustion side of an auxiliary boiler. State what defects are likely to be found and the corrective measures taken.
3. Describe how the following conditions are prevented in auxiliary boilers:
(a) Feed contamination by oil from heating coil drums.
(b) Internal corrosion.
(c) Furnace blowback.
(d) Uptake fire.
4. Sketch an auxiliary boiler suitable for using with oil firing and exhaust heating. Show clearly the mechanism for changing over the two methods of heating. Discuss the reasons for flue-gas explosions and how these occurrences may be prevented.
5. Sketch and describe a boiler front of an oil-fired boiler. Give a diagrammatic sketch of the fuel-oil system used with the boiler front described. Describe the burner in detail and explain how combustion occurs.
6. What are the probable causes of collapse of combustion-chamber crowns in cylindrical boilers at sea under full steaming conditions? What defects would be looked for when the boiler is opened up for inspection?

7. What governs the size of safety valves? What is meant by accumulation of pressure? How is it contracted? What is a satisfactory accumulation? What is the normal lift of the valve?
8. Describe the nature and purpose of the tests carried out on the feed and boiler water of an auxiliary boiler.
State what type of boiler is considered and the source of 'make up' feed.
Suggest causes for the fluctuations in the test results obtained.
Explain the effects of inadequate water treatment on the boiler.
9. What are the causes of burners being extinguished in oil-fired boilers? What may be the effects of this occurrence?
10. You have joined a vessel as chief engineer. Describe what inspection you would carry out on the auxiliary waste-heat and oil-fired boiler. Mention faults you may expect to find and the possible cause of each defects.

CLASS 2 ENGINEER (Engineering Knowledge – MOTOR)

1. With reference to auxiliary boiler water impurity describe the effects of the following salts:
(a) Calcium carbonate.
(b) Sodium chloride.
(c) Magnesium chloride.
(d) Calcium sulphate.
Explain how the quantity of each is determined and controlled.
2. With reference to auxiliary boilers state what remedial action is needed in each of the following instances and why it must not be delayed:
(a) oil showing in water level gauge glass.
(b) suspected false indication of water level
3. State what safety devices are commonly fitted to auxiliary boilers designed for unattended operation.
Explain the method and frequency of testing these devices.
State what maintenance each device requires.
4. Describe how you would carry out an inspection of a boiler and discuss typical repairs that may be necessary. If possible, your comments should be related to your own experience.
5. Sketch and describe in detail a boiler gauge glass. What defects may occur in service, and how would these be dealt with?
6. Describe the duties of the engineer, in correct order, when bringing a boiler up to on-load steaming after the boiler has been opened up for survey and cleaning.
7. List the mountings usually fitted to a marine boiler. State the

purpose of each item and the materials normally used in their construction.

8. Where would you expect to find grooving, wastage, star cracking and pitting on a cylindrical boiler? What type of repair would you recommend for these defects?

9. Sketch and describe a fully automatic, oil fired, packaged steam boiler. State what attention is needed to ensure satisfactory operation.

The foregoing examples have been drawn from actual examination papers set in recent years, it is unlikely that they will completely cover all the questions encountered in future examinations. The Department of Trade examiners are well informed of all the developments in the field of boiler manufacture and operations and adjust the scope of the examination papers accordingly.

Candidates for the higher grades of examination would be well advised to be prepared to answer questions set for those of the lower classes.

Appendix

SI UNITS AND CONVERSION FACTORS

The six basic SI units are:

Quantity	*Unit*	*Abbreviation*
Length	metre	m
Mass	kilogramme	kg
Time	second	s
Electric current	ampere	A
Luminous intensity	candela	cd
Temperature	kelvin	K

Units for other quantities are derived by multiplying and/or dividing by one or more of the six basic units. For example:

Quantity	*Unit*	*Abbreviation*	*Derived from*
Force	newton	N	kg m/s^2
Torque (moment of force)	newton metre	N m	N m
Energy (work, heat)	joule	J	N m
Pressure, stress	newton per square metre	N/m^2	N/m^2
Power, heat flow rate	watt	W	N m/s = J/s
Specific energy, calorific value (heat/mass)	joule per kilogramme	J/kg	N m/kg
Heat release (heat/volume × time)	watt per cubic metre	W/m^3	J/m^3 s

The table below lists most of the prefixes employed to express multiples and sub-multiples of the basic SI units.

Prefix and Symbol		*Meaning*	
giga	G	×1 thousand million	(10^9)
mega	M	×1 million	(10^6)
kilo	k	×1000	(10^3)
hecto	h	×100	(10^2)
deca	da	×10	(10^1)
deci	d	1 tenth	(10^{-1})
centi	c	1 hundredth	(10^{-2})
milli	m	1 thousandth	(10^{-3})
micro	μ	1 millionth	(10^{-6})

CONVERSION TO EQUIVALENT VALUES IN SI AND OTHER UNITS

Length

1 in = 25·4 mm
= 2·54 cm
1 ft = 0·3048 m
1 m = 3·281 ft
1 mm = 0·03937 in

Area

1 in^2 = 646·16 mm^2
= 6·4516 cm^2
1 ft^2 = 0·0929030 m^2
= 929·030 cm^2
1 m^2 = 10·76391 ft^2
1 cm^2 = 0·155000 in^2

Volume

1 in^3 = 16·3871 cm^3
1 ft^3 = 0·0283168 m^3
= 28·3168 dm^3
1 U.K.gal = 0·004546 m^3
= 4·54596 litre (l)
1 litre (1901) = 1·000028 dm^3
= 0·220 U.K. gal
1 m^3 = 35·3147 ft^3
= 220 U.K.gal
1 cm^3 = 0·0610237 in^3

Mass

1 lb = 0·45359237 kg
1 ton = 1016·05 kg
= 1·01605 t (tonne)
1 kg = 2·20462 lb
1 t (tonne or metric ton)
= 1000 kg = 1 Mg
= 0·9842035 ton

Force

1 tonf = 9·96402 kN
1 lbf = 4·44822 N
1 kgf or kp (kilopond) = 9·80665N
1N = 0·224809 lbf

Conversions between lbf, kgf, etc., are as for mass units.

Pressure, stress

1 lbf/in^2 = 0·070307 kgf/cm^2
= 6·89476 kN/m^2
= 68·9476 mb (millibar)
1 tonf/in^2 = 1·57488 kgf/mm^2
= 15·443 MN/m^2
1 kgf/cm^2 = 14·223 lbf/in^2
= 98·067 kN/m^2
1 b (bar) = 14·5038 lbf/in^2
= 10^5 N/m^2
= 100 kN/m^2
= daN/cm^2
1 mb = 100 N/m^2
1 kb = 100 MN/m^2

1 hb (hectobar)
= 10^7 N/m^2
= 10 MN/m^2
1 atm (standard atmosphere)
= 14·6959 lbf/in^2
= 1·01325 bar
1 kN/m^2 = 0·145038 lbf/in^2
1 MN/m^2 = 1 N/mm^2
= 0·06475 tonf/in^2
1 GN/m^2 = 1 kN/mm^2

Specific volume

1 ft^3/lb = 0·062428 m^3/kg

Energy, work, heat

1 ft lbf = 0·1383 kgf m
= 1·35582 J
1 kgf m = 7·233 ft lbf
= 9·80665 J
1 Btu = 1·05506 kJ
1 kcal = 3·968 Btu
= 4·1868 kJ
1 kWh = 3412 Btu
= 1·341 hp h
= 859·845 kcal
= 3·6 MJ
1 J = 0·7376 ft lbf
= 0·102 kgf m
= 0·2388 cal
1 MJ = 947·817 Btu
= 0·2778 kWh

Power

1 horsepower = 550 ft lbf/s
= 1·0139 metric hp (CV, PS)
= 76·04 kgf m/s
= 745·7 W
1 Btu/min = 17·58426 W
1 ft lbf/s = 0·1383 kgf m/s
= 1·35582 W
1 W = 0·7376 ft lbf/s
= 0·102 kgf m/s
= 3·4121424 Btu/h

Temperature

$°C = \frac{5}{9}(°F - 32)$
$°F = (\frac{9}{5}°C) + 32$
$K = °C + 273·15$

Calorific Value, mass basis

1 Btu/lb = 2·326 kJ/kg

Calorific value, volume basis

1 Btu/ft^3 = 37·2589 kJ/m^3

Heat release

1 Btu/ft^{3}h = 1·03497 × 10^{-5} W/cm^3
= 10·3497 W/m^3

Pressure Conversions

bar to pounds per square inch

bar	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
	lbf/in^2									
0	—	1·4504	2·9008	4·3511	5·8015	7·2519	8·7023	10·1527	11·6030	13·0534
1	14·5038	15·9542	17·4046	18·8549	20·3053	21·7557	23·2061	24·6565	26·1068	27·5572
2	29·0076	30·4580	31·9084	33·3587	34·8091	36·2595	37·7099	39·1603	40·6106	42·0610
3	43·5114	44·9618	46·4122	47·8625	49·3129	50·7633	52·2137	53·6641	55·1144	56·5648
4	58·0152	59·4656	60·9160	62·3663	63·8167	65·2671	66·7175	68·1679	69·6182	71·0686
5	72·5190	73·9694	75·4198	76·8701	78·3205	79·7709	81·2213	82·6717	84·1220	85·5724
6	87·0228	88·4732	89·9236	91·3739	92·8243	94·2747	95·7251	97·1755	98·6258	100·076
7	101·527	102·977	104·427	105·878	107·328	108·779	110·229	111·679	113·130	114·580
8	116·030	117·481	118·931	120·382	121·832	123·282	124·733	126·183	127·633	129·084
9	130·534	131·985	133·435	134·885	136·336	137·786	139·236	140·687	142·137	143·588
10	145·038	146·488	147·939	149·389	150·840	152·290	153·740	155·191	156·641	158·091
11	159·542	160·993	162·443	163·893	165·343	166·794	168·244	169·694	171·145	172·095
12	174·046	175·496	176·946	178·397	179·847	181·298	182·748	184·198	185·649	187·099
13	188·549	190·000	191·450	192·901	194·351	195·801	197·252	198·702	200·152	201·603
14	203·053	204·504	205·954	207·404	208·855	210·305	211·755	213·206	214·656	216·107
15	217·557	219·007	220·458	221·908	223·359	224·809	226·259	227·710	229·160	230·610
16	232·061	233·511	234·962	236·412	237·862	239·313	240·763	242·213	243·664	245·114
17	246·566	248·015	249·465	250·916	252·366	253·817	255·267	256·717	258·168	259·618
18	261·068	262·519	263·969	265·420	266·870	268·320	269·771	271·221	272·671	274·122
19	275·572	277·023	278·473	279·923	281·374	282·824	284·274	285·725	287·175	288·626
20	290·076	291·526	292·977	294·427	295·878	297·328	298·778	300·229	301·679	303·129
21	304·580	306·030	307·481	308·931	310·381	311·832	313·282	314·732	316·183	317·633
22	319·084	320·534	321·984	323·435	324·885	326·336	327·786	329·236	330·687	332·137
23	333·587	335·038	336·488	337·939	339·389	340·839	342·290	343·740	345·190	346·641
24	348·091	349·542	350·992	352·442	353·893	355·343	356·793	358·244	359·694	361·145
25	362·595	364·045	365·496	366·946	368·397	369·847	371·297	372·748	374·198	375·648
26	377·099	378·549	380·000	381·450	382·900	384·351	385·801	387·251	388·702	390·152
27	391·603	393·053	394·503	395·954	397·404	398·855	400·305	401·755	403·206	404·656
28	406·106	407·557	409·007	410·458	411·908	413·358	414·809	416·259	417·709	419·160
29	420·610	422·061	423·511	424·961	426·412	427·862	429·312	430·763	432·213	433·664
30	435·114	436·564	438·015	439·465	440·916	442·366	443·816	445·267	446·717	448·167
31	449·618	451·068	452·519	453·969	455·419	456·870	458·320	459·770	461·221	462·671
32	464·122	465·572	467·022	468·473	469·923	471·374	472·824	474·274	475·725	477·175
33	478·625	480·076	481·526	482·977	484·427	485·877	487·328	488·778	490·228	491·679
34	493·129	494·580	496·030	497·480	498·931	500·381	501·831	503·282	504·732	506·183
35	507·633	509·083	510·534	511·984	513·435	514·885	516·335	517·786	519·236	520·686
36	522·137	523·587	525·038	526·488	527·938	529·389	530·839	532·289	533·740	535·190
37	536·641	538·091	539·541	540·992	542·442	543·893	545·843	546·793	548·244	549·694
38	551·144	552·595	554·045	555·496	556·946	558·396	559·847	561·297	562·747	564·198
39	565·648	567·099	568·549	569·999	571·450	572·900	574·350	575·801	577·251	578·702
40	580·152	581·602	583·053	584·503	585·954	587·404	588·854	590·305	591·755	593·205
41	594·656	596·106	597·557	599·007	600·457	601·908	603·358	604·808	606·259	607·709
42	609·160	610·610	612·060	613·511	614·961	616·412	617·862	619·312	620·763	622·213
43	623·663	625·114	626·564	628·015	629·465	630·915	632·366	633·816	635·266	636·717
44	638·167	639·618	641·068	642·518	643·969	645·419	646·869	648·320	649·770	651·221
45	652·671	654·121	655·572	657·022	658·473	659·923	661·373	662·824	664·274	665·724
46	667·175	668·625	670·076	671·526	672·976	674·427	675·877	677·327	678·778	680·228
47	681·679	683·129	684·579	686·030	687·480	688·931	690·381	691·831	693·282	694·732
48	696·182	697·633	699·083	700·534	701·984	703·434	704·885	706·335	707·785	709·236
49	710·686	712·137	713·587	715·037	716·488	717·938	719·388	720·839	722·289	723·740

Pressure Conversions
bar to pounds per square inch (cont.)

bar	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
	lbf/in²									
50	725 190	726 640	728 091	729 541	730 992	732 442	733 892	735 343	736 793	738 243
51	739 694	741 144	742 595	744 045	745 495	746 946	748 396	749 846	751 297	752 747
52	754 198	755 648	757 098	758 549	759 999	761 450	762 900	764 350	765 801	767 251
53	768 701	770 152	771 602	773 053	774 503	775 953	777 404	778 854	780 304	781 755
54	783 205	784 656	786 106	787 556	789 007	790 457	791 907	793 358	794 808	796 259
55	797 709	799 159	800 610	802 060	803 511	804 961	806 411	807 862	809 312	810 762
56	812 213	813 663	815 114	816 564	818 014	819 465	820 915	822 365	823 816	825 266
57	826 717	828 167	829 617	831 068	832 518	833 969	835 419	836 869	838 320	839 770
58	841 220	842 671	844 121	845 572	847 022	848 472	849 923	851 373	852 823	854 274
59	855 724	857 175	858 625	860 075	861 526	862 976	864 426	865 877	867 327	868 778
60	870 228	871 678	873 129	874 579	876 030	877 480	878 930	880 381	881 831	883 281
61	884 732	886 182	887 633	889 083	890 533	891 984	893 434	894 884	896 335	897 785
62	899 236	900 686	902 136	903 587	905 037	906 488	907 938	909 388	910 839	912 289
63	913 739	915 190	916 640	918 091	919 541	920 991	922 442	923 892	925 342	926 793
64	928 243	929 694	931 144	932 594	934 045	935 495	936 945	938 396	939 846	941 297
65	942 747	944 197	945 648	947 098	948 549	949 999	951 449	952 900	954 350	955 800
66	957 251	958 701	960 152	961 602	963 052	964 503	965 953	967 403	968 854	970 304
67	971 755	973 205	974 655	976 106	977 556	979 007	980 457	981 907	983 358	984 808
68	986 258	987 709	989 159	990 610	992 060	993 510	994 961	996 411	997 861	999 312
69	1000 76	1002 21	1003 66	1005 11	1006 56	1008 01	1009 46	1010 91	1012 37	1013 82
70	1015 27	1016 72	1018 17	1019 62	1021 07	1022 52	1023 97	1025 42	1026 87	1028 32
71	1029 77	1031 22	1032 67	1034 12	1035 57	1037 02	1038 47	1039 92	1041 37	1042 82
72	1044 27	1045 72	1047 17	1048 62	1050 08	1051 53	1052 98	1054 43	1055 88	1057 33
73	1058 78	1060 23	1061 68	1063 13	1064 58	1066 03	1067 48	1068 93	1070 38	1071 83
74	1073 28	1047 73	1076 18	1077 63	1079 08	1080 53	1081 98	1083 43	1084 88	1086 33
75	1087 79	1089 24	1090 69	1092 14	1093 59	1095 04	1096 49	1097 94	1099 39	1100 84
76	1102 29	1103 74	1105 19	1106 64	1108 09	1109 54	1110 99	1112 44	1113 89	1115 34
77	1116 79	1118 24	1119 69	1121 14	1122 59	1124 04	1125 49	1126 95	1128 40	1129 85
78	1131 30	1132 75	1134 20	1135 65	1137 10	1138 55	1140 00	1141 45	1142 90	1144 35
79	1145 80	1147 25	1148 70	1150 15	1151 60	1153 05	1154 50	1155 95	1157 40	1158 85
80	1160 30	1161 75	1163 20	1164 66	1166 11	1167 56	1169 01	1170 46	1171 91	1173 36
81	1174 81	1176 26	1177 71	1179 16	1180 61	1182 06	1183 51	1184 96	1186 41	1187 86
82	1189 31	1190 76	1192 21	1193 66	1195 11	1196 56	1198 01	1199 46	1200 91	1202 37
83	1203 82	1205 27	1206 72	1208 17	1209 62	1211 07	1212 52	1213 97	1215 42	1216 87
84	1218 32	1219 77	1221 22	1222 67	1224 12	1225 57	1227 02	1228 47	1229 92	1231 37
85	1232 82	1234 77	1235 72	1237 17	1238 62	1240 07	1241 53	1242 98	1244 43	1245 88
86	1247 33	1248 78	1250 23	1251 68	1253 13	1254 58	1256 03	1257 48	1258 93	1260 38
87	1261 83	1263 28	1264 73	1266 18	1267 63	1269 08	1270 53	1271 98	1273 43	1274 88
88	1276 33	1277 78	1279 24	1280 69	1282 14	1283 59	1285 04	1286 49	1287 94	1289 39
89	1290 84	1292 29	1293 74	1295 19	1296 64	1298 09	1299 54	1300 99	1302 44	1303 89
90	1305 34	1306 79	1308 24	1309 69	1311 14	1312 59	1314 04	1315 49	1316 95	1318 40
91	1319 85	1321 30	1322 75	1324 20	1325 65	1327 10	1328 55	1330 00	1331 45	1332 90
92	1334 35	1335 80	1337 25	1338 70	1340 15	1341 60	1343 05	1344 50	1345 95	1347 40
93	1348 85	1350 30	1351 75	1353 20	1354 65	1356 11	1357 56	1359 01	1360 46	1361 91
94	1363 36	1364 81	1366 26	1367 71	1369 16	1370 61	1372 06	1373 51	1374 96	1376 41
95	1377 86	1379 31	1380 76	1382 21	1383 66	1385 11	1386 56	1388 01	1389 46	1390 91
96	1392 36	1393 82	1395 27	1396 72	1398 17	1399 62	1401 07	1402 07	1403 97	1405 42
97	1406 87	1408 32	1409 77	1411 22	1412 67	1414 12	1415 57	1417 02	1418 47	1419 92
98	1421 37	1422 82	1424 27	1425 72	1427 17	1428 62	1430 07	1431 53	1432 98	1434 43
99	1435 88	1437 33	1438 78	1440 23	1441 68	1443 13	1444 58	1446 03	1447 48	1448 93
100	1450 38									

Pressure Conversions
Pounds per Square Inch (lbf/in²) to bar

1 to 40		41 to 80		81 to 200		205 to 500		510 to 900		910 to 1500	
lbf/in²	bar	lbf/in²	bar	lbf/in²	bar	lbf/in²	bar	lbf/in²	bar	lbf/in²	bar
1	·07	41	2·83	81	5·58	205	14·13	510	35·16	910	62·74
2	·14	42	2·90	82	5·65	210	14·48	520	35·85	920	63·43
3	·21	43	2·96	83	5·72	215	14·82	530	36·54	930	64·12
4	·28	44	3·03	84	5·79	220	15·17	540	37·23	940	64·81
5	·34	45	3·10	85	5·86	225	15·51	550	37·92	950	65·50
6	·41	46	3·17	86	5·93	230	15·86	560	38·61	960	66·19
7	·48	47	3·24	87	6·00	235	16·20	570	39·30	970	66·88
8	·55	·48	3·31	88	6·07	240	16·55	580	39·99	980	67·57
9	·62	49	3·38	89	6·14	245	16·89	590	40·68	990	68·26
10	·69	50	3·45	90	6·21	250	17·24	600	41·37	1000	68·95
11	·76	51	3·52	91	6·27	255	17·58	610	42·06	1010	69·64
12	·83	52	3·59	92	6·34	260	17·93	620	42·75	1020	70·33
13	·90	53	3·65	93	6·41	265	18·27	630	43·44	1030	71·02
14	·97	54	3·72	94	6·48	270	18·62	640	44·13	1040	71·71
15	1·03	55	3·79	95	6·55	275	18·96	650	44·82	1050	72·39
16	1·10	56	3·86	96	6·62	280	19·31	660	45·51	1060	73·08
17	1·17	57	3·93	97	6·69	285	19·65	670	46·19	1070	73·77
18	1·24	58	4·00	98	6·76	290	19·99	680	46·88	1080	74·46
19	1·31	59	4·07	99	6·83	295	20·34	690	47·57	1090	75·15
20	1·38	60	4·14	100	6·89	300	20·68	700	48·26	1100	75·84
21	1·45	61	4·21	105	7·24	310	21·37	710	48·95	1120	77·22
22	1·52	62	4·27	110	7·58	320	22·06	720	49·64	1140	78·60
23	1·59	63	4·34	115	7·93	330	22·75	730	50·33	1160	79·98
24	1·65	64	4·41	120	8·27	340	23·44	740	51·02	1180	81·36
25	1·72	65	4·48	125	8·62	350	24·13	750	51·71	1200	82·74
26	1·79	66	4·55	130	8·96	360	24·82	760	52·40	1220	84·12
27	1·86	67	4·62	135	9·31	370	25·51	770	53·09	1240	85·49
28	1·93	68	4·69	140	9·65	380	26·20	780	53·78	1260	86·87
29	2·00	69	4·76	145	10·00	390	26·89	790	54·47	1280	88·25
30	2·07	70	4·83	150	10·34	400	27·58	800	55·16	1300	89·63
31	2·14	71	4·90	155	10·69	410	28·27	810	55·85	1320	91·01
32	2·21	72	4·96	160	11·03	420	28·96	820	56·54	1340	92·39
33	2·28	73	5·03	165	11·38	430	29·65	830	57·23	1360	93·77
34	2·34	74	5·10	170	11·72	440	30·34	840	57·92	1380	95·15
35	2·41	75	5·17	175	12·07	450	31·03	850	58·61	1400	96·53
36	2·48	76	5·24	180	12·41	460	31·72	860	59·29	1420	97·91
37	2·55	77	5·31	185	12·76	470	32·41	870	59·98	1440	99·28
38	2·62	78	5·38	190	13·10	480	33·09	880	60·67	1460	100·66
39	2·69	79	5·45	195	13·44	490	33·78	890	61·36	1480	102·04
40	2·76	80	5·52	200	13·79	500	34·47	900	62·05	1500	103·42

Temperature Conversions

Locate temperature in middle column.
If in degrees Celsius, read Fahrenheit in right hand column.
If in degrees Fahrenheit, read Celsius in left hand column.

−459.4 to 0			1 to 60			61 to 290			300 to 890			900 to 3000		
C	F or C	F	C	F or C	F	C	F or C	F	C	F or C	F	C	F or C	F
−273	−459.4		−17.2	1	33.8	16.1	61	141.8	149	300	572	482	900	1652
−268	−450		−16.7	2	35.6	16.7	62	143.6	154	310	590	488	910	1670
−262	−440		−16.1	3	37.4	17.2	63	145.4	160	320	608	493	920	1688
−257	−430		−15.6	4	39.2	17.8	64	147.2	166	330	626	499	930	1706
−251	−420		−15.0	5	41.0	18.3	65	149.0	171	340	644	504	940	1724
−246	−410		−14.4	6	42.8	18.9	66	150.8	177	350	662	510	950	1742
−240	−400		−13.9	7	44.6	19.4	67	152.6	182	360	680	516	960	1760
−234	−390		−13.3	8	46.4	20.0	68	154.4	188	370	698	521	970	1778
−229	−380		−12.8	9	48.2	20.6	69	156.2	193	380	716	527	980	1796
−223	−370		−12.2	10	50.0	21.1	70	158.0	199	390	734	532	990	1814
−218	−360		−11.7	11	51.8	21.7	71	159.8	204	400	752	538	1000	1832
−212	−350		−11.1	12	53.6	22.2	72	161.6	210	410	770	549	1020	1868
−207	−340		−10.6	13	55.4	22.8	73	163.4	216	420	788	560	1040	1904
−201	−330		−10.0	14	57.2	23.3	74	165.2	221	430	806	571	1060	1940
−196	−320		−9.4	15	59.0	23.9	75	167.0	227	440	824	582	1080	1976
−190	−310		−8.9	16	60.8	24.4	76	168.8	232	450	842	593	1100	2012
−184	−300		−8.3	17	62.6	25.0	77	170.6	238	460	860	604	1120	2048
−179	−290		−7.8	18	64.4	25.6	78	172.4	243	470	878	616	1140	2084
−173	−280		−7.2	19	66.2	26.1	79	174.2	249	480	896	627	1160	2120
−169	−273	−459.4	−6.7	20	68.0	26.7	80	176.0	254	490	914	638	1180	2156
−168	−270	−454	−6.1	21	69.8	27.2	81	177.8	260	500	932	649	1200	2192
−162	−260	−436	−5.6	22	71.6	27.8	82	179.6	266	510	950	660	1220	2228
−157	−250	−418	−5.0	23	73.4	28.3	83	181.4	271	520	968	671	1240	2264
−151	−240	−400	−4.4	24	75.2	28.9	84	183.2	277	530	986	682	1260	2300
−146	−230	−382	−3.9	25	77.0	29.4	85	185.0	282	540	1004	693	1280	2336
−140	−220	−364	−3.3	26	78.8	30.0	86	186.8	288	550	1022	704	1300	2372
−134	−210	−346	−2.8	27	80.6	30.6	87	188.6	293	560	1040	732	1350	2462
−129	−200	−328	−2.2	28	82.4	31.1	88	190.4	299	570	1058	760	1400	2552
−123	−190	−310	−1.7	29	84.2	31.7	89	192.2	304	580	1076	788	1450	2642
−118	−180	−292	−1.1	30	86.0	32.2	90	194.0	310	590	1094	816	1500	2732
−112	−170	−274	−0.6	31	87.8	32.8	91	195.8	316	600	1112	843	1550	2822
−107	−160	−256	0	32	89.6	33.3	92	197.6	321	610	1130	871	1600	2912
−101	−150	−238	0.6	33	91.4	33.9	93	199.4	327	620	1148	899	1650	3002
−96	−140	−220	1.1	34	93.2	34.4	94	201.2	332	630	1166	927	1700	3092
−90	−130	−202	1.7	35	95.0	35.0	95	203.0	338	640	1184	954	1750	3182
−84	−120	−184	2.2	36	96.8	35.6	96	204.8	343	650	1202	982	1800	3272
−79	−110	−166	2.8	37	98.6	36.1	97	206.6	349	660	1220	1010	1850	3362
−73	−100	−148	3.3	38	100.4	36.7	98	208.4	354	670	1238	1038	1900	3452
−68	−90	−130	3.9	39	102.2	37.2	99	210.2	360	680	1256	1066	1950	3542
−62	−80	−112	4.4	40	104.0	37.8	100	212.0	366	690	1274	1093	2000	3632
−57	−70	−94	5.0	41	105.8	43	110	230	371	700	1292	1121	2050	3722
−51	−60	−76	5.6	42	107.6	49	120	248	377	710	1310	1149	2100	3812
−46	−50	−58	6.1	43	109.4	54	130	266	382	720	1328	1177	2150	3902
−40	−40	−40	6.7	44	111.2	60	140	284	388	730	1346	1204	2200	3992
−34	−30	−22	7.2	45	113.0	66	150	302	393	740	1364	1232	2250	4082
−29	−20	−4	7.8	46	114.8	71	160	320	399	750	1382	1260	2300	4172
−23	−10	14	8.3	47	116.6	77	170	338	404	760	1400	1288	2350	4262
−17.8	0	32	8.9	48	118.4	82	180	356	410	770	1418	1316	2400	4352
			9.4	49	120.2	88	190	374	416	780	1436	1343	2450	4442
			10.0	50	122.0	93	200	392	421	790	1454	1371	2500	4532
			10.6	51	123.8	99	210	410	427	800	1472	1399	2550	4622
			11.1	52	125.6	100	212	414	432	810	1490	1427	2600	4712
			11.7	53	127.4	104	220	428	438	820	1508	1454	2650	4802
			12.2	54	129.2	110	230	446	443	830	1526	1482	2700	4892
			12.8	55	131.0	116	240	464	449	840	1544	1510	2750	4982
			13.3	56	132.8	121	250	482	454	850	1562	1538	2800	5072
			13.9	57	134.6	127	260	500	460	860	1580	1566	2850	5162
			14.4	58	136.4	132	270	518	466	870	1598	1593	2900	5252
			15.0	59	138.2	138	280	536	471	880	1616	1621	2950	5342
			15.6	60	140.0	143	290	554	477	890	1634	1649	3000	5432

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