

## CHAPTER 4

### BOILER CONSTRUCTION

**I**T would appear that riveted construction for boilers began in the early nineteenth century, and, according to early works on the subject, wrought-iron riveted boilers constructed from plates only 3 ft. by 1 ft. were in use at that time, working at pressures up to 150 lb./sq. in. A present-day tendency is for electrically-welded seams to take the place of riveting, especially for the internal parts of tank-type boilers, where such parts are in compression.

In this chapter details of the construction of riveted, welded and forged boilers will be given, and also particulars of requirements and tests.

#### RIVETED CONSTRUCTION

The Scotch boiler is undoubtedly the most frequently encountered boiler of the riveted type. In the past they were used in the majority of cargo vessels in conjunction with steam reciprocating machinery for main propulsion purposes, whereas nowadays with the increased popularity of oil engines, their principal role is that of donkey boiler in large tankers. In present-day construction the use of welded seams for combustion chambers and the attachment of furnaces to these chambers has become almost universal, riveting being confined to the shell seams. In order that production of these boilers may proceed smoothly in the shop, it is essential that a definite routine be practised, so that no one part of the whole is held up while production of another is in progress.

The various stages from plate to finished unit will now be detailed and briefly described.

First, the end plates, combustion-chamber tube, back and wrapper plates are marked off and cut to required dimensions. Work is then concentrated simultaneously on the combustion chambers and the boiler end plates.

#### Combustion Chambers

In the case of the chambers, the tube and back plates are flanged in the hydraulic press, the flanging of the sides, bottom and

top being effected prior to finishing with the corners. The plates are then levelled and, in the case of the tube plates, after pilot holes have been drilled for the tubes and centre of furnace, this opening is plunged.\*

The next operation is to prepare all chamber-tube and back-plate edges for welding (see Fig. 11). Then with the wrappers already bent to the requisite shape the chambers are assembled, seams faired, gaps adjusted and all seam welding completed (see Fig. 11).

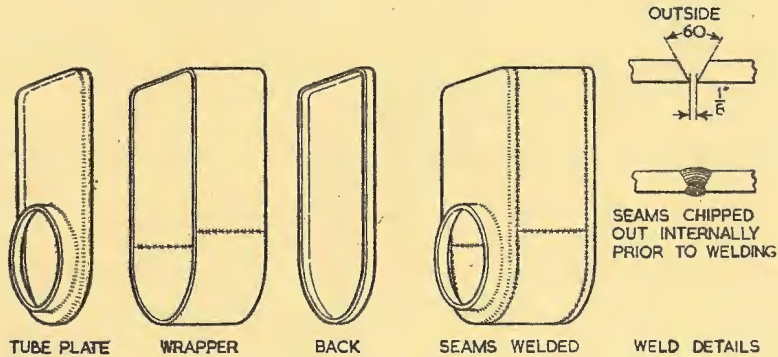


FIG. 11.—WELD DETAILS OF CHAMBER-TUBE AND BACK-PLATE EDGES

This method of production of combustion chambers is virtually, so far as shape is concerned, a repeat of the riveted type, merely substituting welding for riveting of the seams. Some boiler-makers have, however, redesigned their combustion chambers so that the utmost advantage is taken of welded construction (see Fig. 12).

#### Boiler End Plates

The boiler end plates are usually in two parts, the top or steam-space portion being somewhat thicker than the lower portion. It is present-day practice, after the plate edges have been prepared by planing, to butt weld this seam and on completion of welding to flange the complete end. The flanging is effected in the hydraulic flanging press, working around the plate at about 6 ft. per heat, each portion of the flange being completed before proceeding to the next.

\* Term applied to the pressing to shape of the flanged opening.

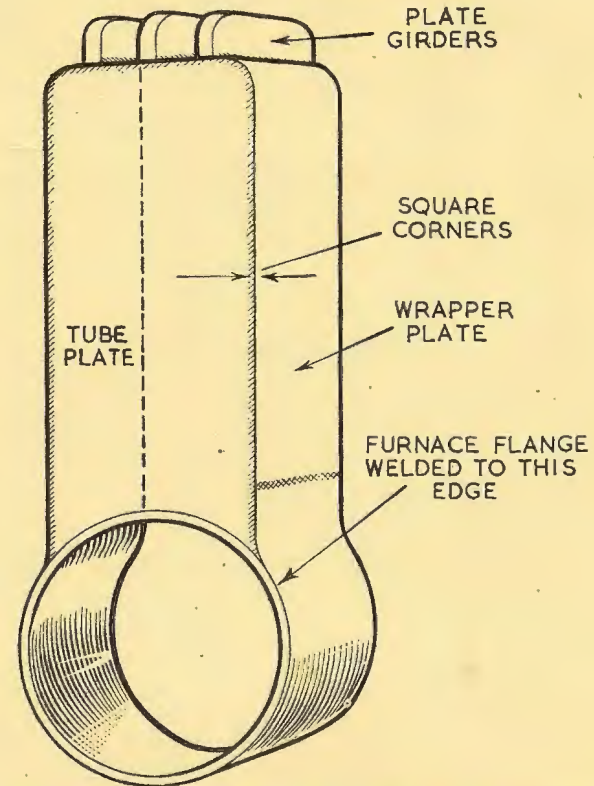


FIG. 12.—ALL-WELDED CHAMBER WITH SQUARE CORNERS AND NO FLANGED PLATES

On completion of the flanging the end plates are annealed and levelled. The flange edges are then dressed, and in the case of the front end plates, locating holes for tubes and furnace openings drilled, after which furnace and manhole openings are plunged. The end plates are then marked off, and then tube holes and combustion-chamber back-stay holes and tacking holes in flanges are drilled in the front and back plates respectively.

#### Shell and Butt Straps

Having concentrated on the production of the combustion chambers and the two end plates, attention is then transferred to the shell. When several similar boilers are being constructed at one time it is advantageous that all the chambers and end plates proceed simultaneously, so that on completion of these

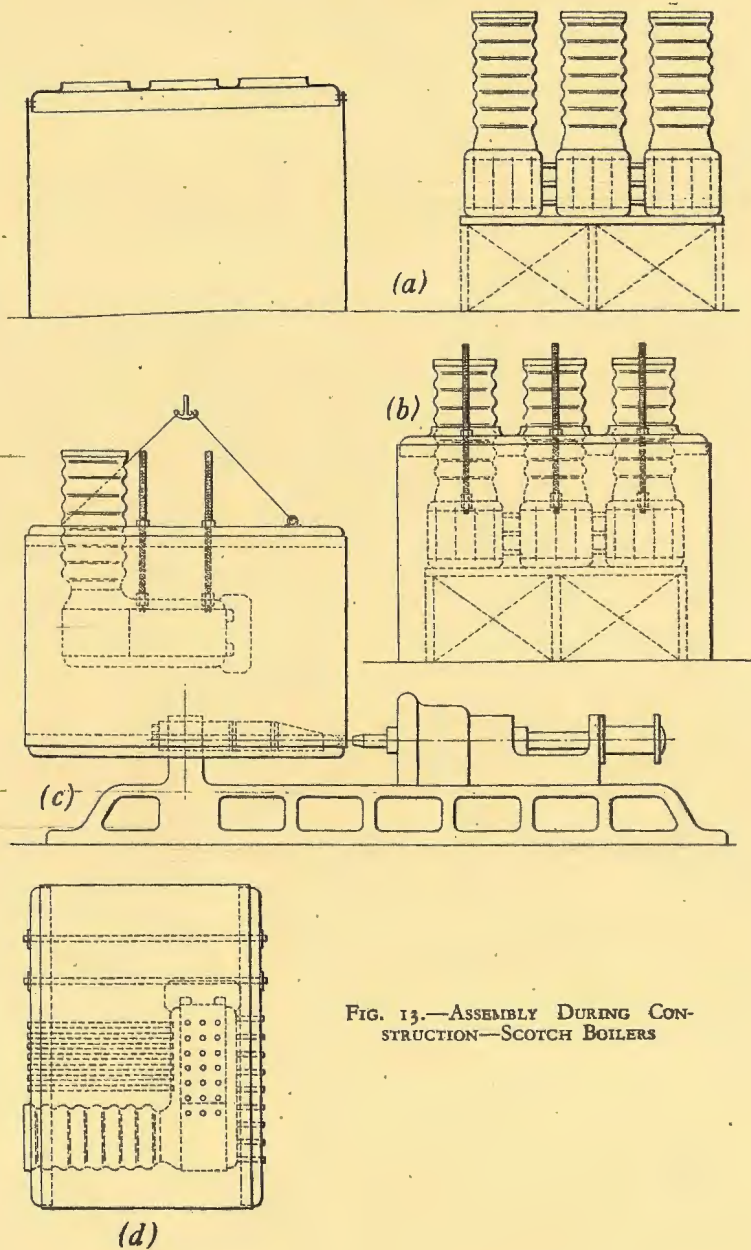


FIG. 13.—ASSEMBLY DURING CONSTRUCTION—SCOTCH BOILERS

components a certain amount of "pairing up" can be resorted to—a difference in circumference of more than  $\frac{1}{4}$  in. between front and back end plates is undesirable.

The shell plates are then marked off to suit the end-plate circumferences, all circumferential-seam rivet-holes are drilled and plate edges planed. Additionally, combustion-chamber side-stay, rolling-stay, lifting-lug and manhole-compensating ring holes are now drilled. At this stage tacking holes only are drilled for the longitudinal butt-strap seams.

The shell plates are now rolled, and as the rolls do not impart correct curvature to the longitudinal edges, these have to be separately faired.

Attention is then directed to the butt straps, and these, after forming to the correct curvature, are, in the case of the outer strap, marked off and drilled ready for riveting, and, in the case of the inner strap, drilled with tacking holes only.

The shell and its butt straps are now assembled with tacking bolts, front and back end plates are fitted also with tacking bolts, and all seams are closed by means of the hydraulic riveting machine. In the case of the back end plate, this is done through a rectangular opening in this plate cut for the purpose and afterwards fitted with a hand-riveted cover plate. When all seams are closed, and all tacking bolts are hardened up, the "drilling through" of all rivet holes for the circumferential and longitudinal seams, and for the manhole ring, is effected.

The boiler shell is now taken apart and any burrs removed from around the drilled holes and plate edges.

With the inner butt straps fitted in place, the longitudinal seams are now faired up and the 9 in. at the ends of each longitudinal seam are butt welded. On completion of this welding the outer butt straps are fitted in place and then the double-butt-strap longitudinal seams, as well as manhole-compensating ring, are hydraulically riveted.

Work is now concentrated on the front end plate. The furnace openings are bored out to take the furnaces, the circumferences of the bored openings being made about  $\frac{3}{8}$  in. larger than the furnace-mouth circumference. The bottom manhole flanging is also faced true at this stage.

#### Assembly

Major assembly now begins. The front end plate is refitted into the shell, and the front circumferential seam is hydraulically

riveted (Fig. 13 (a)). On completion of the riveting, all possible internal caulking is effected.

The combustion chambers have meanwhile been drilled and reamed for plain tubes, after which each chamber top is fitted with its welded-on girder stays. The chambers are then faired-up to their respective furnaces, and the circumferential furnace-to-chamber seams are welded, each assembly being annealed on completion of all welding.

The combustion chambers are next grouped together in their correct positions, relative to one another, and all inter-chamber screwed stays fitted. On completion of this staying the group is placed on a pedestal with the furnaces vertical, and the shell with the front end plate is lowered over the group until the furnaces protrude sufficiently far through the end plate to allow ample room behind the chambers for work to proceed on the back-shell circumferential seam (see Fig. 13 (b)). Temporary screwed stays are fitted between the front end plate and the combustion-chamber tube plates to hold the chamber group, and the back end plate is then fitted and hydraulically riveted, working through the cover-plate hole in the end plate (Fig. 13 (c)). Having completed the back circumferential seam, the cover plate is fitted in position and riveted by hand.

All internal caulking of the shell seams is now effected. The group of combustion chambers is then lowered into its correct position and all furnace-mouth and combustion-chamber shell stay holes are drilled. The furnace-mouth seams are then hydraulically riveted and all combustion-chamber wing stays fitted (Fig. 13 (d)).

The next operation is the drilling of all boiler back-stay holes; these holes are machine drilled, keeping the holes normal to the thinner of the two plates. While the boiler is on the machine, all stay-tube holes are then tapped and the stay tubes fitted.

Any surface depressions of the boiler back are now levelled out, either by strongbacks or by pulling on long bolts passed through the marginal stay holes, after which the combustion-chamber back-stay holes are tapped and all stays fitted.

The plain tubes are now fitted, and these, together with all stay tubes, are expanded and, if required, beaded over at back ends.

All that now remains is external caulking and the fitting of longitudinal stays and manhole doors, after which the completed boiler is prepared for hydraulic test.

### Precautions

In the early days of riveted seams the holes were punched, many different forms of spiral- and slanting-faced punches being used to try to obviate injury to the plate. It was soon found, however, that the punching of holes and also the shearing of plate edges punished the material to such an extent as to make it unreliable for boiler work, and nowadays drilled holes and flame-cut and planed plate edges are universally used.

To reduce to a minimum the possibility of trouble through seam leakage or of caustic embrittlement occurring during the life of a boiler, it is important that: (a) every care be given to the accuracy of fit of butt straps, end plates and furnaces; (b) the faying surfaces mate correctly, and that all holes are drilled and reamed simultaneously through each plate forming the joint; (c) the joint be taken apart for the removal of all burrs around the holes, then re-assembled and tack-bolted prior to riveting.

The efficiency of a hand-riveted or welded seam is to some extent dependent on the human element, and troubles originating from this cause are partly eliminated by the use of hydraulic riveting and machine welding. Hydraulic riveting is effected by applying a steady intense compressive pressure to the hot rivet. This compressive pressure takes place between the dies of the machine, the shape of the dies being varied to suit circumstances. Too high a pressure is dangerous, and may cause cracking between rivet-holes, either at the time of riveting or later in the life of the boiler. Enlarged plate edges are a good indication of excessive pressure having been applied.

The importance of faying surfaces mating correctly and of removing burrs from rivet-holes has already been stressed, but it is equally important to have the plates tightly closed and well bolted together prior to riveting. Otherwise, the plastic rivet material will force its way between the plates.

All rivets should completely fill their holes, and a firm fit around a rivet-head is a fair indication that the rivet in question, when pressed up, filled its hole and overflowed beneath the die, forming the fin.

In present-day construction of Scotch boilers, using electrically-welded combustion chambers, hand riveting is practically dispensed with, and is only used for securing the cover plate over the hole in the back end plate, through which the hydraulic

riveting machine is inserted when working on the back circumferential or closing seam.

The foregoing is a brief description of the technique employed with riveted boiler shells. The adoption of welding for shells naturally lagged behind combustion chambers, as the seams in this case are in tension and special tests and heat treatment are necessary. An example of an all-welded Scotch boiler is shown in Fig. 21 (b) and (c) (pages 52 and 53).

### WELDED CONSTRUCTION

It has already been stated that nowadays the tendency is for electric welding to take the place of riveting in boiler construction. However, when welding is used for a seam of a boiler shell, whether it be for a tank boiler or a water-tube boiler, definite constructional regulations have to be observed. There are many so-called "Codes" or tabulated rules governing the construction of welded boilers, both for marine and non-marine use.

For marine boilers the first principal requirement is that the works making the boilers have to satisfy the inspecting authorities as to their ability to produce consistently good welded work. This is achieved by maintaining the plant in efficient condition, carrying out regular tests of the welding operators, having adequate testing facilities, suitable X-ray apparatus and also a suitable heat-treating furnace.

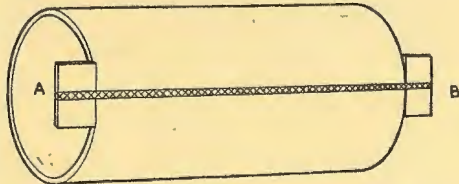


FIG. 14.—FUSION-WELDED SHELL WITH TEST PLATES ATTACHED

A works that has proved its capabilities and is recognized for the construction of welded boilers has to make *each* boiler drum or shell in compliance with certain clearly defined rules; two test plates of material, conforming to the same specification and of the same thickness as the shell being welded, have to be made for each boiler drum or shell. These plates are attached in such

a manner that the edges to be welded are a continuation and duplication of the longitudinal seam (see Fig. 14).

In the case of a machine weld, apart from the first and last few inches, where there may be irregularities due to stopping and starting, the weld from A to B as laid down should be uniform in character, although in the case of hand welding it is unavoidable that the operator may take more care over the test plates than over the actual seam.

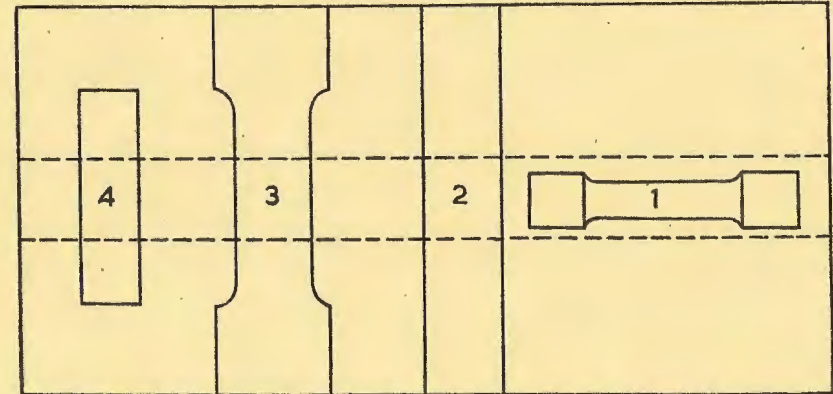


FIG. 15.—TEST PLATE SHOWING TEST SPECIMENS  
1. Tensile all-weld metal      3. Tensile of Joint  
2. Bend                              4. Macro

After the welding of the seam is complete the test plates are detached, straightened if warped and then subjected to the same heat-treatment as given to the boiler drum or shell. The test plates, representing as far as practicable the longitudinal seam, are then cut up into test specimens (Fig. 15), and these have to meet the detailed requirements of the various tests: (1) tensile all-weld metal; (2) bend; (3) tensile of joint; (4) macro.

### Lloyd's Requirements

These requirements vary slightly with different Inspection Authorities. Lloyd's Register of Shipping specifies that:

(1) The ultimate tensile strength of the weld metal has not to be less than the minimum specified for the shell plate, with a minimum elongation on gauge length of 20 per cent and a minimum reduction of area of 35 per cent. This all-weld-metal test-piece is machined longitudinally out of the weld metal deposited in the test-plate seam.

## CHAPTER 5

## TANK BOILERS

THE most common boiler in marine use is of the tank type, namely the Scotch or multi-tubular cylindrical boiler. The fundamental design of this type of boiler has remained unchanged for many years, although higher pressures have necessitated heavier scantlings, and in some details welded construction has taken the place of riveting. Scotch boilers are simple in construction, and are relatively inexpensive. While in service a minimum amount of skill and engineering knowledge is required for their efficient operation, and for this reason this type of boiler was for many years almost universally employed for steam-powered cargo-vessels. The modern trend, however, is for water-tube boilers to be fitted, as for the same power they occupy less space, are lighter in weight and permit of higher pressures and temperatures with correspondingly increased efficiency.

## SCOTCH BOILERS

A typical Scotch boiler of the early part of this century and one of up-to-date construction are illustrated in Figs. 21 (a) to (c).

The working pressure of Scotch boilers has steadily increased from 80 lb./sq. in. in 1880 to the present day when 225-250 lb./sq. in. is in common use. The scantlings for a normal-sized boiler, especially the shell plating, would require to be so heavy for pressures above, say, 300 lb./sq. in. that it would hardly be a commercial proposition.

The most commonly encountered version of the Scotch boiler is undoubtedly the three-furnace, single-ended type, although it is not many years since high-powered turbine and reciprocating-engined passenger-liners were steamed by the six- or eight-furnaced, double-ended type.

The main components of the Scotch boiler are shell, end plates, furnaces, combustion chambers, tubes and stays. It is proposed to summarize briefly the main features of each of these components.

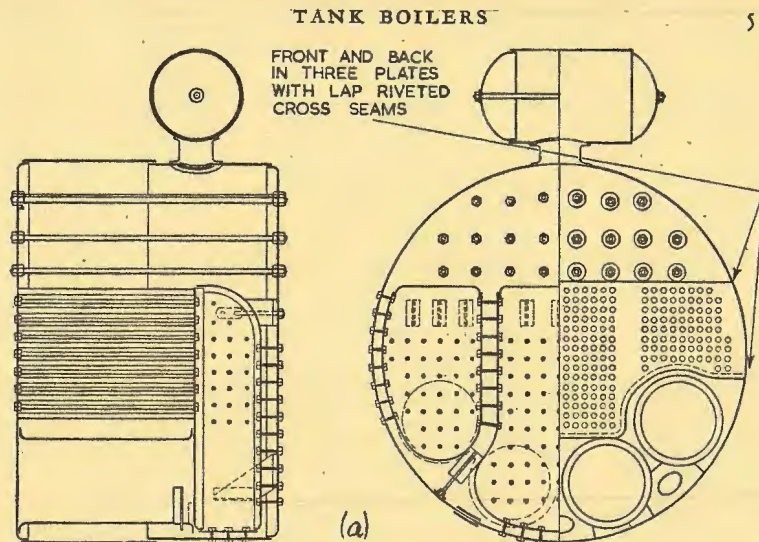


FIG. 21.—SCOTCH BOILERS

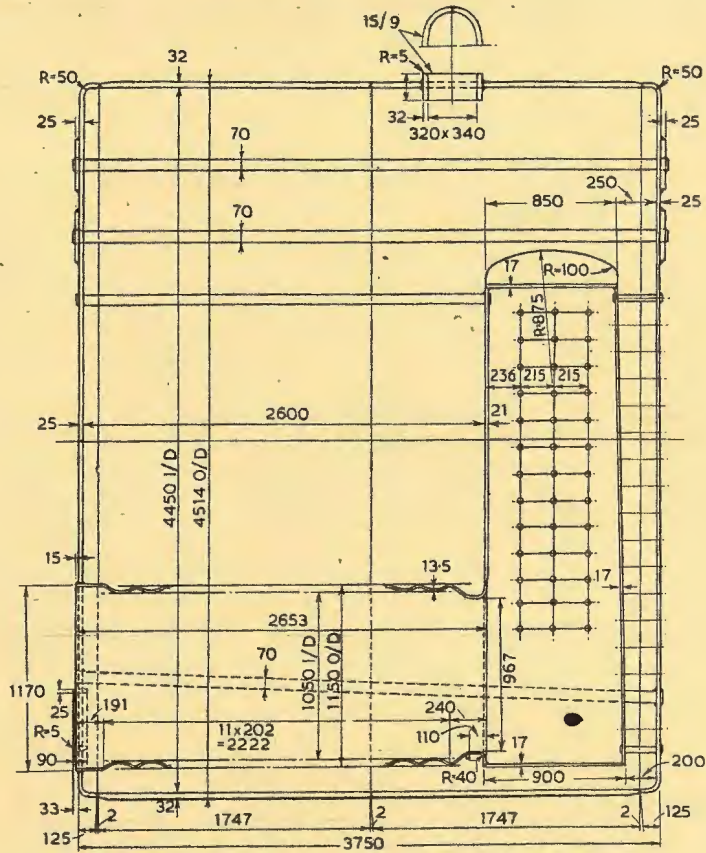
(a) Typical Scotch Boiler of 1900, working pressure 90 lb./sq. in.

## Shell

In the case of the modern three-furnace, single-ended boiler, the shell normally consists of one ring of mild-steel plating in two plates having two treble-riveted double butt-strap joints. The tensile strength of the plating is normally 28-32 tons/sq. in., although in some cases somewhat lighter scantlings are permitted through the utilization of higher tensile steel.

## End Plates

The front and back end plates may be made of individual steel plates, or they may be built up from several plates of varying thicknesses with lap-riveted or welded cross-seams. Both front and back plates are flanged to fit inside the shell, the circumferential seams being double-riveted. It should be observed here that the plate thicknesses required depend on the working pressure, amount of support given by stays and flanging, etc. and so it is quite usual to find end plates built up from two or three different thicknesses of plate, each plate thickness meeting the requirements of its individual loading. End plates are usually riveted into the shell with the flanging outside of the circumferential seam, although in some cases when hydraulic riveting is utilized for the closing seam, the end plate is flanged inwards.



358 COMMON TUBES 63.5mm. OUTS. DIA. 3.65mm. THICK, SWELLED 1.5mm. AT ONE END  
 106 STAY TUBES 63.5mm. OUTS. DIA. 8mm. THICK, SWELLED 6mm. AT ONE END. 9 THREADS PR. INCH CONT. THREADS IN BOTH PLATES

**Welded Shells**

Welded boiler shells are becoming increasingly common ; all the welded parts of such boilers are stress-relieved on completion and the shell longitudinal and circumferential seams are X-rayed. A typical all-welded Scotch boiler is shown in Fig. 21 (b) and (c).

**Combustion Chambers**

As the name implies, these are chambers in which combustion, apart from that which has already occurred in the furnaces, takes

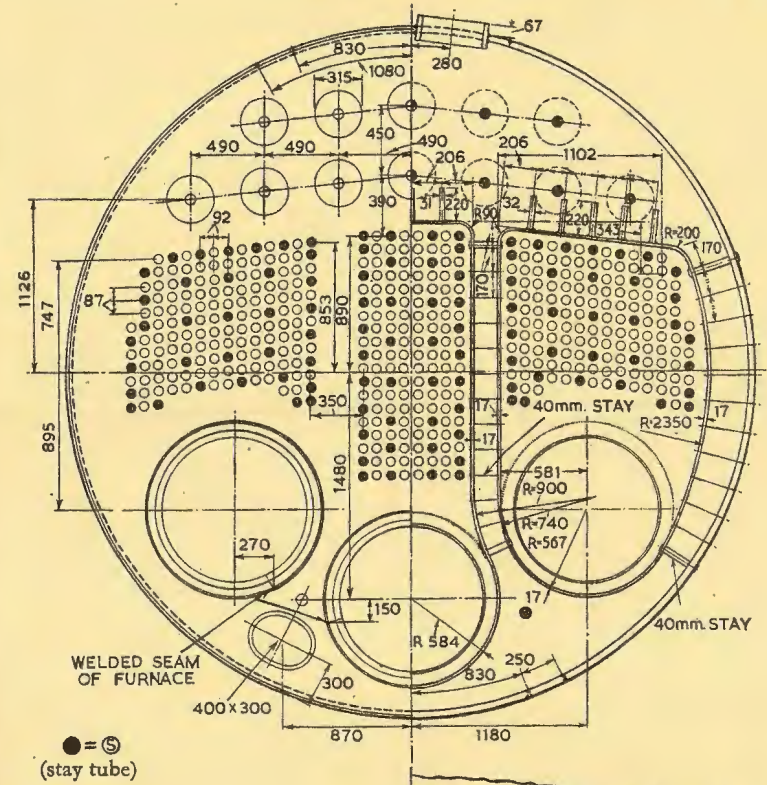
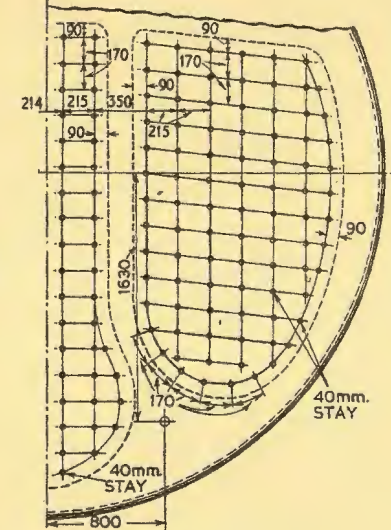


FIG. 21 (Continued).—SCOTCH BOILERS

(b) *opposite page*, plan.  
 (c) *right*, section, of a modern boiler with a working pressure of 160 lb./sq. in.



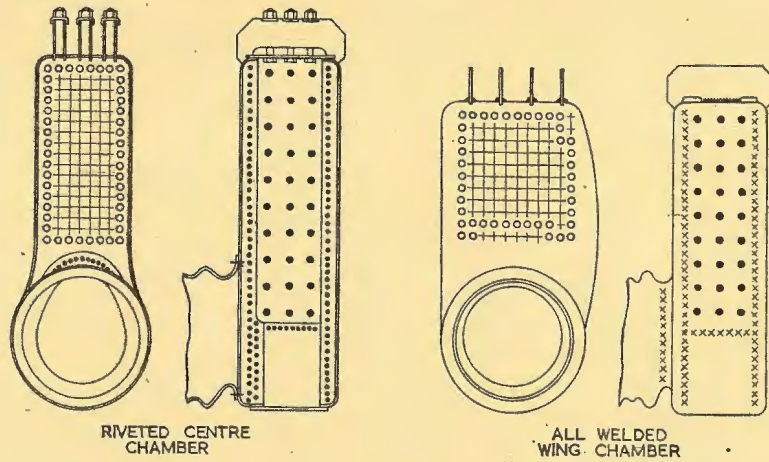


FIG. 22.—CONSTRUCTIONAL DETAILS OF VARIOUS TYPES OF COMBUSTION CHAMBER

place. These chambers, surrounded by the water content of the boiler, are, in addition, heating surfaces, and it is from them that the products of combustion return to the uptakes via the plain and stay tubes. The combustion chamber, being at all times under compression, lends itself admirably to that modern method of fabrication, electric welding. Constructional details of several types are illustrated in Fig. 22.

### Furnaces

Scotch-boiler furnaces are nowadays always made of corrugated steel with welded seams, the corrugation giving, for a given thickness, additional strength and longitudinal flexibility. In the early days of these boilers, they were of plain cylindrical section with lap-riveted or butt-strapped seams.

The number of furnaces in each boiler is usually dependent upon the boiler diameter. For those up to 12 ft. in diameter, two furnaces are usual; from 12 to 16 ft, three are used, while in boilers over 16 ft. in diameter there are usually four furnaces. The usual types of corrugations used for furnaces are shown in Fig. 23.

Modern Scotch-boiler furnaces are always made withdrawable. In the case of furnaces riveted to chambers this is accomplished

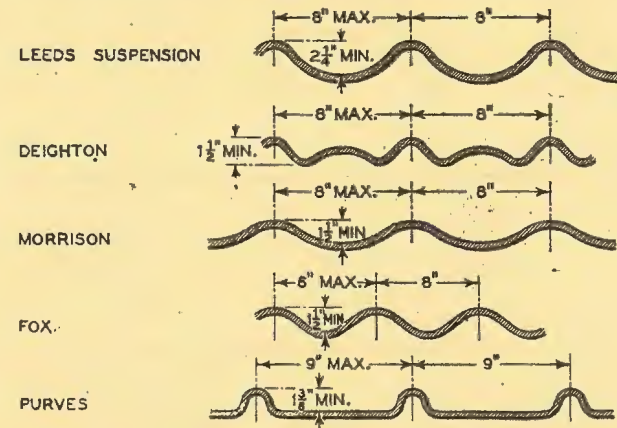


FIG. 23.—VARIOUS TYPES OF FURNACE CORRUGATION

by terminating the inner end of the furnace in a neck and flange (gooseneck), the flange being of such a shape as to be withdrawable through the front end plate opening. In welded construction the furnace is butt-welded direct to the flanged opening in the combustion-chamber front or tube plate. The two methods are illustrated in Fig. 24.

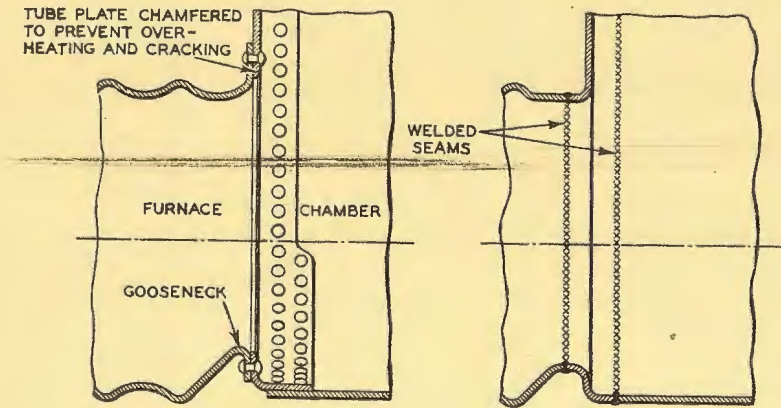


FIG. 24.—METHODS OF MAKING FURNACES WITHDRAWABLE  
(Left) Riveted. (Right) Welded.



### Boiler Tubes

The front tube plate and combustion-chamber tube plate are tied together by means of stay tubes. The stay tubes screwed through both tube plates vary in thickness according to the area of plate which they have to support, and there may be several different thicknesses of tube in one tube-nest, the minimum thickness allowed for such tubes, measured at the base of the threads, being  $\frac{1}{4}$  in. for marginal tubes and  $\frac{3}{16}$  in. for others. The normal pitch for the threads of these tubes is 9 per inch, the smoke-box end of the tubes being enlarged and the thread being continuous, so that when inserted they can be screwed simultaneously through both tube plates. In some cases the ends of the stay tubes are attached to the tube plates by welding, the weld preparation being as shown in Fig. 25. This method ensures pressure-tightness under working conditions, but presents difficulties when renewals are called for. The material used for stay tubes is normally wrought iron or steel. Plain tubes form the major part of the heating surface of the Scotch boiler, and are generally made of either lap-welded wrought iron or steel, seamless steel or electric resistance-welded steel.

The inner tubes in a nest are very inaccessible on the water side, and unless considerable care and attention is paid to their cleanliness, on both this and the fire side, their heating-surface value rapidly decreases.

The normal sizes of plain tubes vary from about  $2\frac{1}{2}$ – $3\frac{1}{2}$  in. outside diameter, with thicknesses of from 11 to 7 L.S.G., i.e.,

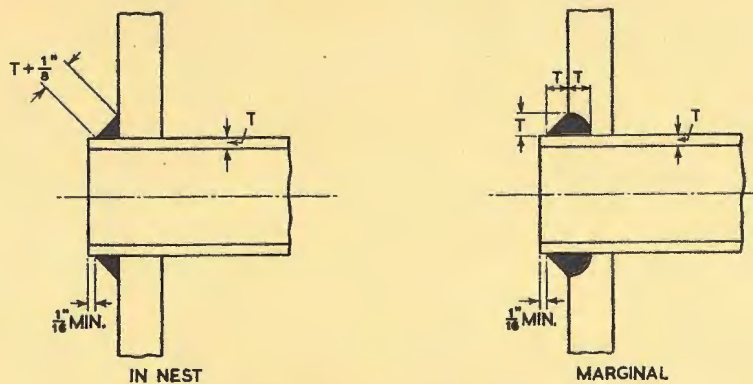


FIG. 25.—WELDED STAY TUBES

0.116–0.176 in., and they are made tight in the tube plates by means of expanding.

### Stays

The majority of the stays used in this type of boiler are of the screwed type; in most single-ended boilers all the stays come in this category. Double-ended boilers, however, are in addition fitted with pin-jointed stays between the combustion chamber girders and the shell to relieve the chamber tube plates of some of the girder loading.

Screwed-type stays are used for staying the chamber tops, sides and backs; also for the longitudinal stays between the boiler end plates, although in this latter case they are not screwed through the plates, but pass through clearance holes with nuts either side of the plate. The materials used are iron or steel for combustion-chamber stays and steel for longitudinal stays (see Chapter 3).

### HOWDEN-JOHNSON AND CAPUS BOILERS

Two other designs of tank-type boiler used for main steam production aboard ship, although not frequently encountered, are the Howden-Johnson and Capus. In both of these the furnaces pass from end plate to end plate and the combustion chamber, common in the case of the Howden-Johnson and divided in the Capus, is at the back, being bounded by circulating tubes and brickwork (see Fig. 26).

These boilers are commonly stated as having “dry back” combustion chambers, and the separation of their combustion chambers from the cylindrical shell greatly simplifies construction and enables this type to be designed for higher pressures than are practicable with Scotch boilers.

The Howden-Johnson and Capus boilers may be said to possess some of the advantages of both water-tube and Scotch types, the water tubes helping to produce very rapid and effective circulation.

In view of the number and small bore of the tubes enclosing the combustion chambers and the fact that they are all of bent form and therefore cannot be sighted, it is very important that every care and attention be given to the boiler feed-water.

Superheaters are fitted to both types, being positioned in the

## CHAPTER 6

## WATER-TUBE BOILERS

**W**ATER-TUBE boilers came into extensive use in the mercantile marine during and immediately following the First World War, at which time many berths were laid down at Hog Island Shipyard, U.S.A., for the purpose of building standard ships, which in the main were equipped with the Babcock & Wilcox sectional-header-type water-tube boilers.

**Advantages of Water-tube Boilers**

The main reasons for the adoption of water-tube boilers in place of the cylindrical multi-tubular or Scotch type are :

(1) *Saving in Weight.* The relative weight of Scotch to water-tube boiler installations for equivalent square feet of heating surface, with water at working level, is approximately 3 : 1.

(2) *The Possibility of using High Pressures and Temperatures.* The introduction of turbine propelling machinery enabled full advantage to be taken of higher pressures and temperatures, thus cutting down machinery size and weight for a given output.

It may be pointed out that to obtain maximum efficiency from the steam machinery being used,  $T_1$ , the steam temperature, should be a maximum and  $T_2$ , the exhaust temperature, a minimum in the equation  $\frac{T_1 - T_2}{T_1}$  where  $T_1$  and  $T_2$  are absolute temperatures. This is Carnot's Cycle for maximum efficiency.

The limit of working pressure for Scotch boilers, for practical reasons, such as shell thickness (see Fig. 37) and lack of flexibility, is limited to 300 lb./sq. in.

(3) *Greater Mechanical Flexibility.* Boiler not so sensitive to fluctuating pressures. The Scotch boiler with its poor circulation, especially when raising steam, is very prone to mechanical straining and subsequent grooving in its many flange attachments. These defects do not exist in the water-tube boiler with its rapid circulation and structural flexibility.

(4) *Rapid Steam Raising.* A normally specified time for raising steam in a water-tube boiler is three or four hours from "flash-

up" to full pressure. The minimum time required will depend upon the initial temperature of the boiler and upon the necessity for avoiding damage which could occur from local overheating. In case of need this time could, with a hot boiler, be twenty minutes whereas with a Scotch-type boiler it is normally considered beneficial to extend this time to the same number of hours.

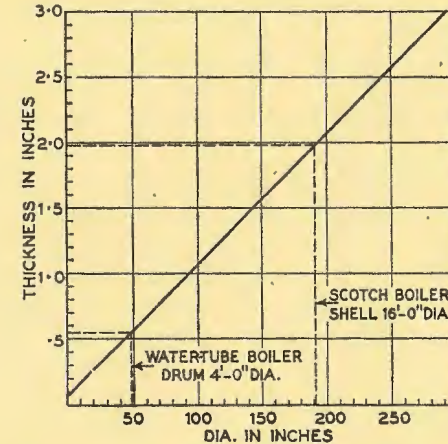


FIG. 37.—INCREASE OF THICKNESS WITH DIAMETER OF WELDED BOILER SHELLS OR DRUMS AT 250 LB./SQ. IN. WORKING PRESSURE

Assuming allowable stress of 12,200 lb./sq. in.

(5) *Saving in Space.* The good circulation and ability to withstand forcing and higher pressures have enabled high outputs to be obtained from water-tube boilers of very small dimensions when compared to the Scotch type.

(6) *Wider Safety Margin in Event of Explosion.* The possibility of a serious explosion is considered to be far more remote with a water-tube boiler than with a Scotch boiler. In the former, tube diameters are wisely limited and drums are protected from direct radiation or flame impingement. Should a tube fail, the contents of the boiler (much smaller than the Scotch type) escape at a rate determined by the tube bore (see Fig. 38), whereas, in the latter, serious rupture of an overheated furnace can almost instantaneously release the 30 ton contents into the stokehold (see Fig. 39).

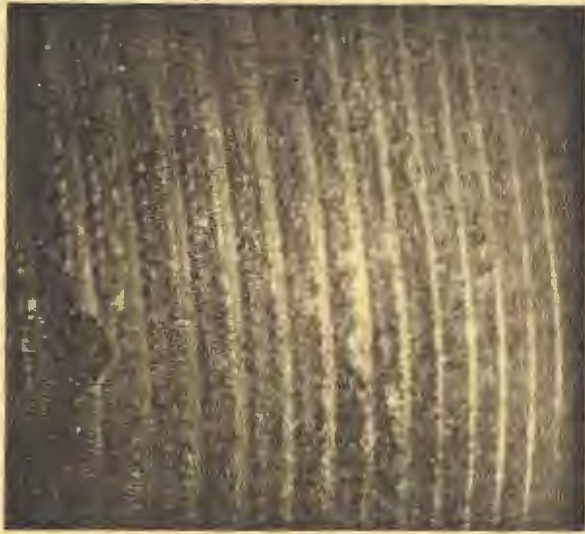


FIG. 38.—FAILURE OF A WATER-TUBE BOILER TUBE

#### Types of Water-tube Boiler

The types of water-tube boiler in everyday use in the mercantile marine are Babcock & Wilcox, Foster-Wheeler, Yarrow and Babcock-Johnson. All these boilers, with the exception of the Babcock-Johnson, are designed for either coal or oil firing. The Babcock-Johnson is for oil burning only.

The circulation in all the aforementioned boilers is natural; this is mentioned in view of the fact that marine forced-circulation boiler installations, although not common, are occasionally encountered. When properly designed, the water speeds with natural circulation are adequate to ensure safety under the normal ratings in use in the mercantile marine. This means that it is essential to have sufficient circulation through every tube in a boiler to ensure that it does not become steam locked, then overheated, with subsequent failure.

#### Direction of Circulation

The direction of flow, or circulation, in the tubes of a vertical-tube-type water-tube boiler is dependent largely on external conditions. If the tubes contained only water at varying temperatures, it is evident that, due to difference in specific weights, the colder tubes would function as downcomers and the hotter

ones as risers. In water-tube boilers, however, the tubes contain a mixture of steam and water, the proportion of which may, due to fluctuations in the furnace, be continually varying, hence it is possible that a particular tube may function as a downcomer one minute and a riser the next.

In a bank of tubes of a vertical-tube type of boiler the relative speed of circulation will obviously be at a maximum in the front and rear rows, as between these rows exists the greater difference



FIG. 39.—FAILURE OF A SCOTCH BOILER FURNACE

(By permission of the Controller, H. M. Stationery Office)

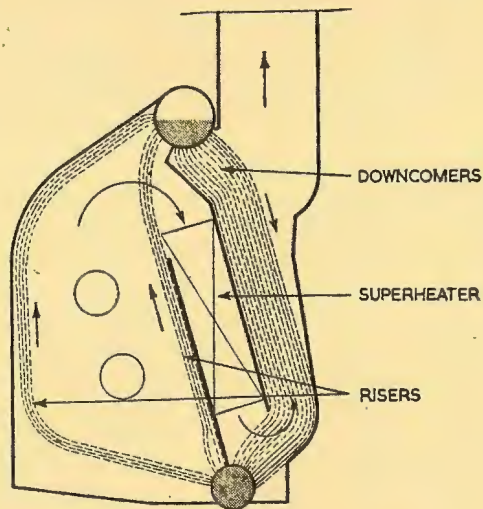


FIG. 40.—WATER-TUBE BOILER WITH SUPERHEATER BETWEEN DOWNCOMERS AND RISERS

in specific weights. The position of the tubes which act both as downcomer and riser will lie within the bank, their positions relative to the front and back of the bank being largely dependent on the intensity of the furnace heat. From this it will be apparent that the proportion of downcomers to risers varies according to the steam output of the boiler.

Efficient circulation is more easily obtained in a low- than in a high-pressure water-tube boiler, as increase in pressure and temperature involves a levelling out in the differences in specific weights of steam and water—the cause of circulation. At the higher pressures, say above 450 lb./sq. in., it is usual therefore to assist the circulation by the fitting of unheated external downcomers.

Stable conditions of circulation are assisted in some types of water-tube boiler by inserting the superheater between the downcomers and risers, this giving a considerable temperature difference between the two nests of tubes and between the specific weights of their contents (see Fig. 40).

#### Circulation in Babcock Boilers

The foregoing remarks regarding circulation apply to the vertical-tube-type boilers; with the inclined-tube, sectional-header Babcock type, the circulation always follows the one path, i.e., downwards from the steam drum into the front headers and

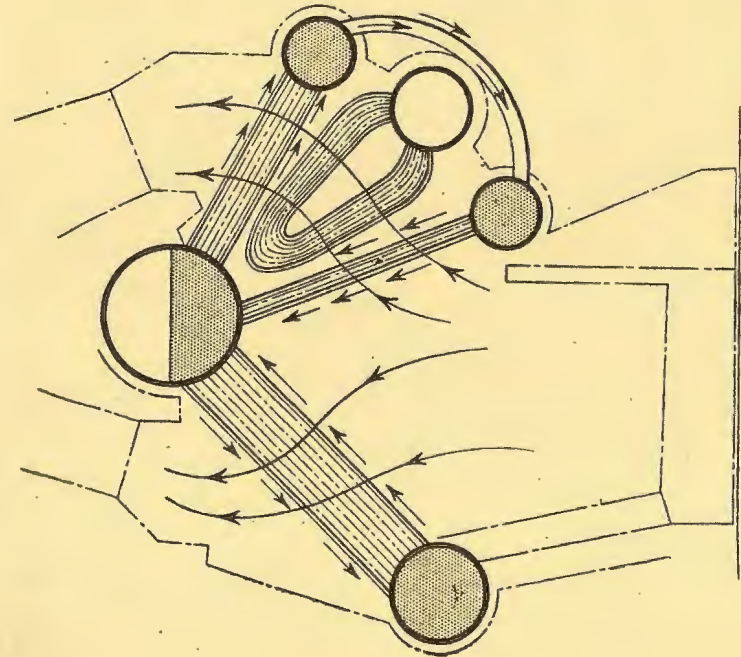
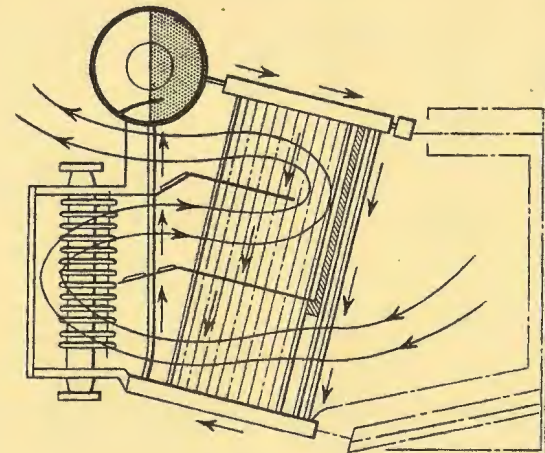


FIG. 41.—CIRCULATION OF (left) YARROW AND (right) BABCOCK & WILCOX HEADER BOILER

up the inclined tubes, the steam and water then rising through the rear headers and passing back to the drum by way of the return tubes.

In order that a water-level free from foam and undue ebullition may be obtained, it would appear that the hottest tubes, in which the major part of the steam is generated, should have their outlets at or above the working water-level in the steam drum and that the downcomers should leave the bottom of the drum. In practice, however, with vertical-tube boilers, this reasoning is not generally fulfilled—it would be impracticable in the case of the Yarrow boiler with its straight tubes, and it has the reverse lay-out. The Babcock & Wilcox boiler, however, as mentioned before, does circulate in this manner (see Fig. 41).

The question of circulation has been discussed at some length, as all water-tube boilers depend upon it for their satisfactory operation.

### BABCOCK & WILCOX BOILERS

Initially famed for sectional header straight-tube boilers, several different types of bent-tube two-drum designs now bear this name.

#### Sectional-header-type Boiler

The long-established header boiler with its straight tubes and a single gas pass is very popular for steam generation on vessels required to operate on services where facilities for correct water treatment, or skilled maintenance, are not normally available; it also has useful applications as an auxiliary boiler on oil-engined tankers and large passenger vessels.

This boiler consists of a steam drum connected at the bottom by nipples to a series of vertical sinuous headers. Into these headers are expanded one end of each of the inclined tubes forming the heating surface, and the other ends of the tubes terminate in a further series of vertical headers, these being re-connected back to the steam drum by the return tubes at their top ends. All the front headers are nipples into a common mud box running across the front of the boiler at the bottom.

This boiler, with its sections of headers and tubes, is commonly known as a sectional-header boiler. The sectional-header boiler, with its straight and readily accessible tubes, forms a convenient stepping-stone for marine engineers between fire-tube boilers and

the less-accessible, often higher-pressured, two- and three-drum-type boilers.

#### Early Babcock Boilers

The early Babcock boilers were fitted with tubes of 4 in. diameter throughout, and the steam drum was positioned in line with the tubes, the headers of cast iron being connected by nipples and connecting pipes to saddles riveted on the underside of the drum (see Fig. 42).

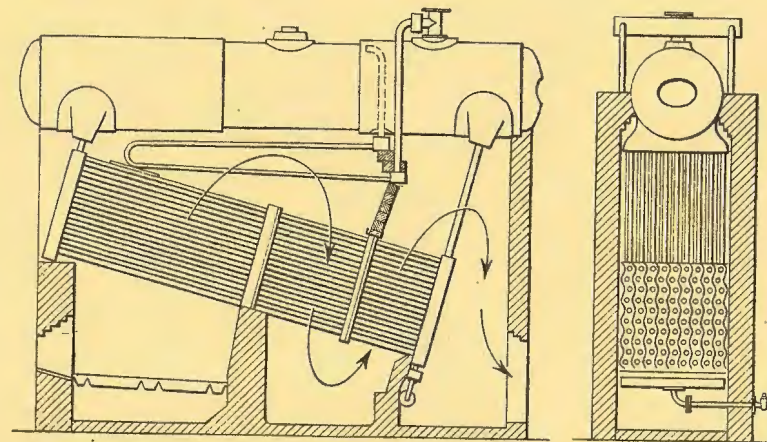


FIG. 42.—EARLY BABCOCK BOILER

#### Basic Modern Design

The major alteration in the lay-out of this type of boiler took place when for marine purposes the drum was re-positioned to lie at right angles to the tubes and all front or down headers were nipples directly into the bottom of the drum. Since that date the basic design has remained unaltered, although with increase in pressures and temperatures, drum and header construction, tube diameters, superheater design and position, etc., have altered considerably.

The Babcock & Wilcox header-type boiler is essentially a robust and accessible unit, and as such was installed aboard many merchant vessels built in the United States during both the First and Second World Wars. Details of these units are illustrated in Fig. 43.

The major differences between these two boilers, as will be

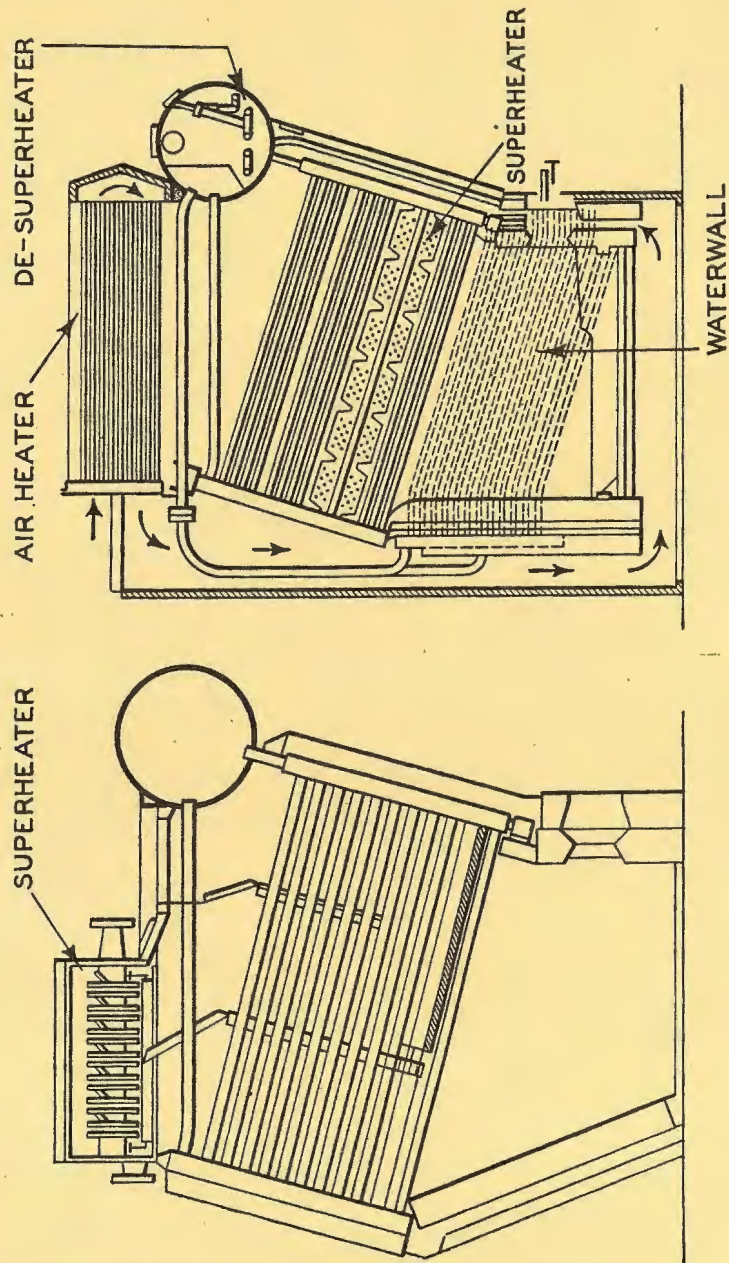


FIG. 43.—BABCOCK HEADER-TYPE BOILERS  
 (a) First World War, working pressure 200 lb./sq. in., temperature 430° F. 4 in. tubes, three-pass.  
 (b) Second World War, working pressure 625 lb./sq. in., temperature 900° F. 1½ in. tubes, single-pass.

noted, are the increase in working pressures, difference in tube diameters, drum construction, superheater design and position, addition of water-walls, air heater, desuperheater, etc.

**Tube Sizes**

Improvement in the quality of feed-water led to the use of smaller tubes, which, space for space, give a greater area of heating surface. The sizes of generating tubes normally used are 4 in., 2 in., 1½ in. and 1 in., and these are arranged in nests of one, four, nine and fourteen respectively per header hand-hole. Apart from the earlier boilers, which had 4 in. tubes throughout, it is now usual to find that the lower group, i.e., the tubes nearest the furnace, are of larger diameter than the others (see Fig. 44).

**Constructional Details**

The usual angle of rise of the tubes between front and back headers is 15°, and the amount of heating surface per section is made greater or less by variation in the number of tubes, height of section or in the length of the tubes.

All the pressure parts of the boiler are made of steel, the headers being solid drawn and forged into a sinuous form, so that the tubes, either in groups or individually in the case of the 4 in.

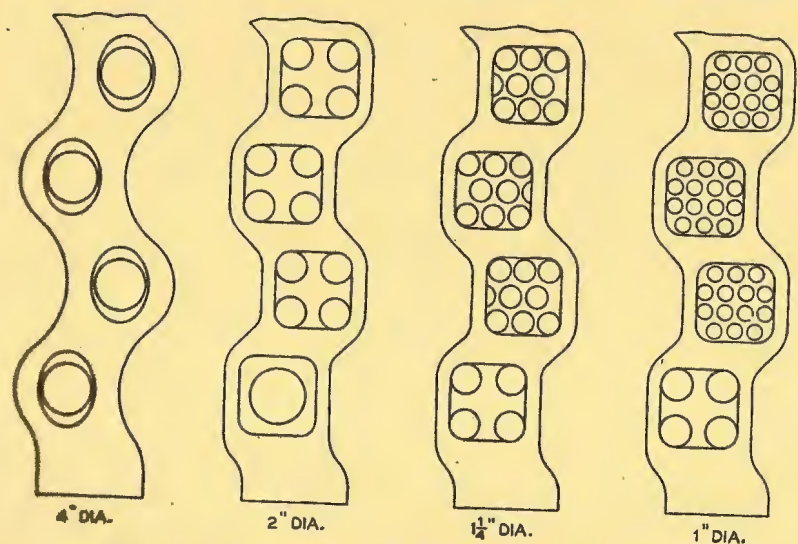


FIG. 44.—TUBE GROUPING IN HEADERS, BABCOCK BOILERS

tubes, are staggered in position relative to one another. The steam drum may be either of riveted, welded or solid forged construction, the majority in recent years being welded. The return tubes, irrespective of the size of the generating tubes, are always of 4 in. diameter, all tubes and nipples in the boiler being expanded and bellmouthed in the normal manner.

### Superheater

The superheater fitted to this type of boiler is of the U-bend type, the ends of the bends being expanded into two separate cylindrical- or rectangular-section steel headers. The U-bends lie across or at right-angles to the generating tubes of the boiler,

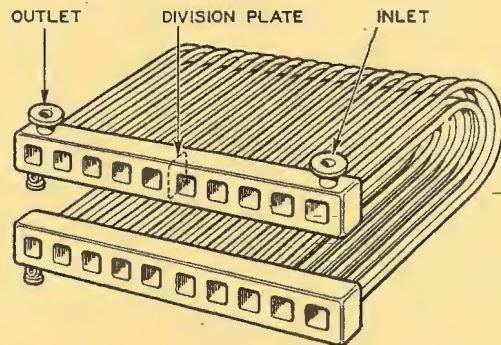


FIG. 45.—SUPERHEATER, BABCOCK BOILERS

and the headers are placed along one side. The superheater headers are fitted with internal welded-in division plates so that the steam makes a number of passes, depending on the number of division plates, before leaving the superheater (see Fig. 45).

In high-pressure units with high superheat temperatures the superheater is moved from its normal position above the first and second passes and placed in what is termed the interdeck position. This interdeck position is between the rows of generating tubes at about one-third of the way up the tube bank, where the desired steam temperature can be obtained with a superheater of moderate size.

### Arrangement of Units

The back headers of these boilers are free to move on the rear structure, whereas the front headers are anchored, thus ensuring

that any variation in tube length when raising steam, during steaming, or when shutting down, is allowed for. It is usual to lead the air supply, hot if from a preheater, through double casings surrounding the sides and bottom of the furnace and then to the front of the boiler, where the burners are situated. In

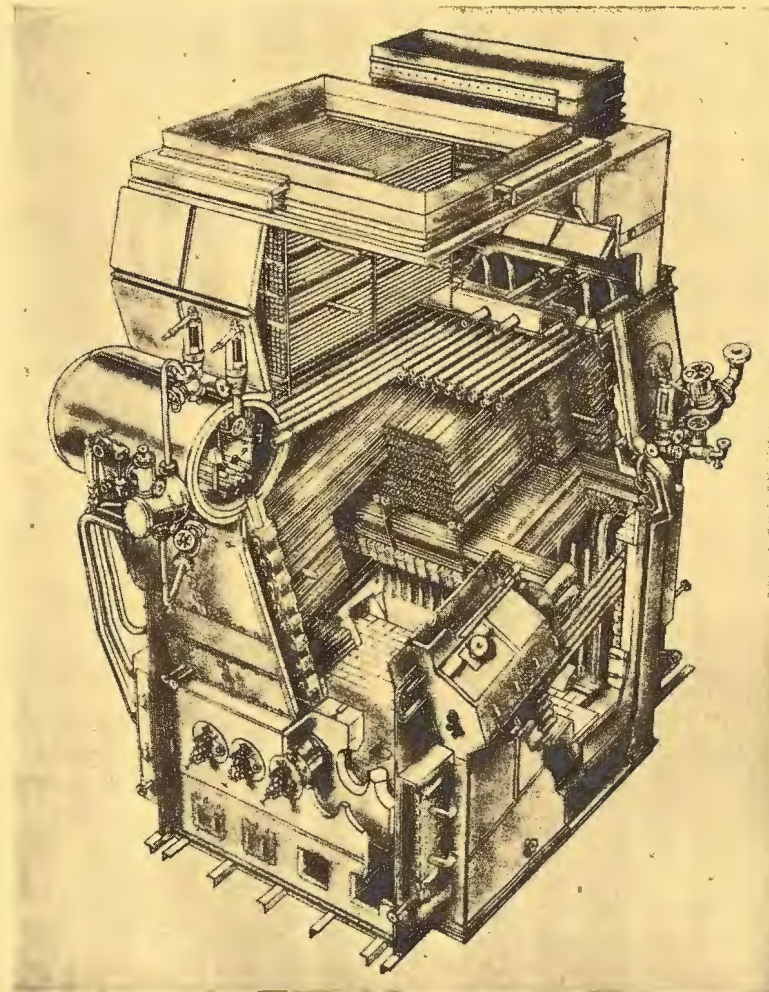


FIG. 46.—CUT-AWAY VIEW OF A BABCOCK MARINE BOILER, SINGLE-PASS HEADER TYPE, SHOWING SUPERHEATER AND AN AIR HEATER, ALSO THE STUDDED TUBES IN THE SIDE AND REAR WATER-COOLED FURNACE WALLS

this manner the refractory-lined furnace is insulated and radiation losses are kept low. The steam drum, as will be noted from Fig. 43 (b), is fitted with a bolted-in longitudinal baffle over the return tubes, so that the mixture of steam and water tends to be separated, the water dropping and the steam rising towards the internal steam collector along the top of the drum. Wash-plates are also fitted in the steam drum to obviate excessive movement of the water level when the vessel encounters heavy weather. In the case of high superheat units it is usual to find a coil-type desuperheater located in the steam drum; this, apart from supplying a quantity of desuperheated steam for use in saturated steam services, is sometimes used in connection with an automatic superheat temperature-control system.

The detailed lay-out of individual units of this type naturally varies according to the purpose for which each is designed, the basic arrangement remaining the same, with variation in position of superheater, the addition of water walls, economizers, air preheaters, etc.

Improved methods of feed-water conditioning led to the use of smaller tubes, and during the last war, single-pass units fitted with  $1\frac{1}{4}$  in. tubes, interdeck superheater, water-walled furnace and air preheater, producing steam at a pressure of 625 lb./sq. in. and 900° F. temperature, were extensively used in both cargo vessels and oil tankers (see Fig. 46).

### BABCOCK BENT-TUBE BOILERS

Control of superheat, particularly when manœuvring, is one of the important factors influencing water-tube boiler design. The bent-tube boilers manufactured by Babcock & Wilcox fall into three categories, each one of which employs a different method of superheat control. The first of these, the "Controlled Superheat Boiler", employs two separate furnaces. Oil burners in one furnace provide the heat for the superheater, which is screened by three rows of boiler tubes, and a separate set of burners in the other furnace heats the saturated steam bank of tubes. The steam temperature is controlled to fine limits by regulation of the firing of the two furnaces, and the full design temperatures can be obtained at low outputs. In addition, these boilers have the advantage that large quantities of saturated steam can be taken direct from the drum, regardless of the superheat output. These boilers with their two furnaces and

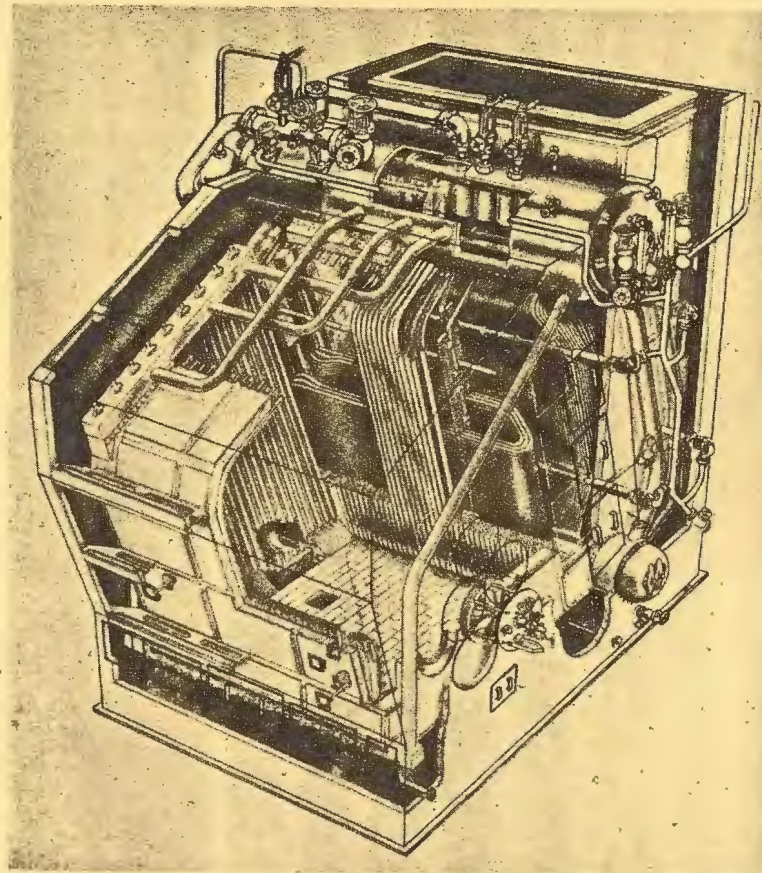


FIG. 47.—A CUT-AWAY VIEW OF A BABCOCK MARINE BOILER, INTEGRAL FURNACE TYPE

three drums are rapidly being superseded by the less complicated Integral Furnace and Selectable Superheat types.

#### Integral Furnace Boiler

This boiler is a two-drum type with the furnace at one side, formed by an extended screen of tubes which are an integral part of the main circulation system (see Fig. 47). Boilers of this type have been built for capacities up to 150,000 lb./hour for pressures up to 1000 lb./sq. in. and for temperatures up to 950° F., the



paths for the feed-water which enters the economizer through the inlet header and flows downward, in counter flow to the gases. From the outlet header the feed-water goes direct to the steam drum.

Earlier units were fitted with return header boxes with expanded joints, but present practice is to use welded return bends and welded connections to stubs on the inlet and outlet headers. The headers are fitted with taper lip handhole plugs for internal inspection of the tubes. This also allows for emergency plugging and isolation of a water path should any element be damaged. It is usual to shutdown a boiler if its economizer is defective, but in an emergency the economizer may be by-passed on the water side by feeding direct to the drum. Under these conditions the output of the boiler should be considerably restricted to avoid over-heating of the empty economizer elements, since gas by-passes and isolating dampers are not fitted. In a multi-boiler installation, where one boiler can be shut down at any time without endangering the safety of the vessel, the additional complications of by-passes on the gas and water sides of an economizer are not warranted.

### YARROW BOILERS

The original Yarrow designs were of simple construction, with one top steam drum and two bottom water drums, connected together by straight tubes. These were expanded and bell-mouthed in the usual manner, and large external downcomers were fitted to each of the water drums. The bottom drums, originally known as water pockets, were D-shaped, i.e., semi-circular with flat tube-plate tops, with the tube plates flanged to take the wrappers or shells. As might be expected, troubles were experienced in the form of grooving of the pocket corners and stretching of the outer rows of tubes, caused through the flat tube-plate tops of the pockets trying to assume, with the wrappers, a circular shape.

In view of the foregoing and also of the increase in working pressure, the cylindrical water drum was adopted. The Admiralty, after many troubles with other types of water-tube boiler such as the Niclausse, Belleville, etc., adopted the Yarrow at the beginning of this century, and have no doubt been largely responsible for its successful development.

### Construction

The superheaters, when fitted, consisted originally of two drums, i.e., inlet and outlet, connected together by U-tubes. An early type of Yarrow boiler is shown in Fig. 59.

Modern Yarrow boilers have a large steam drum connected by straight tubes to three water drums, these drums being designated the four-row, five-row or eleven-row, according to the number of rows of tubes each accommodates. The Yarrow type of superheater consists of a large-diameter drum situated between and parallel to two of the water drums, the elements being U-tubes expanded into this drum and lying between two of the boiler-tube banks. It is not unusual to find external unheated circulating or downcomer pipes connecting the water drums above and below the superheater drum. In some installations header-type superheaters are fitted, in which case the headers are in front and external to the boiler, the elements lying at right angles to the actual boiler tubes. When superheat control is required a double uptake

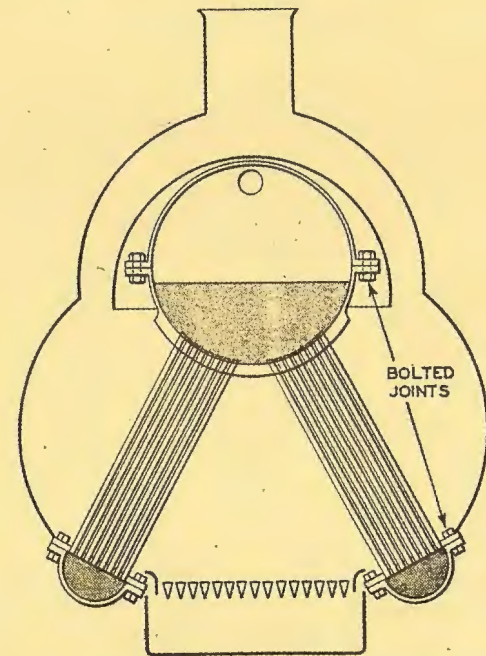


FIG. 59.—EARLY TORPEDO-BOAT-TYPE YARROW BOILER

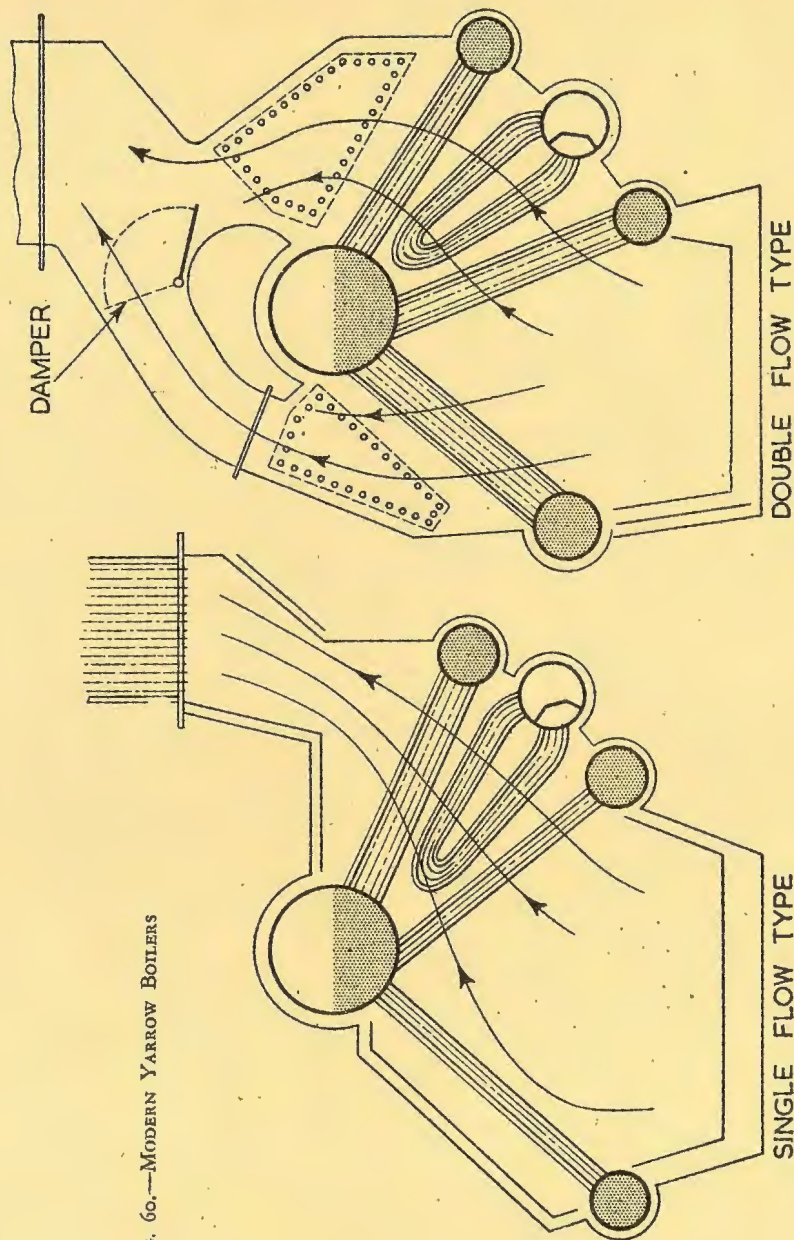


FIG. 60.—MODERN YARROW BOILERS

is fitted, the products of combustion passing up both sides of the boiler, and the side in which the superheater is not fitted is provided with a damper so all, or part, of the gases may be diverted through the superheater. Boilers so fitted are known as the double-flow type, whereas those with a single uptake, in which all the products of combustion always pass through the superheater, are known as the single-flow type (see Fig. 60).

The weight of these boilers is usually taken on feet riveted to the lower water drums, these feet in their turn resting on stools attached to the ship's structure. This leaves the steam drum more or less free to move as required by tube expansion and contraction.

### Performance

The high evaporation rate of the Yarrow type is no doubt one of the predominating factors which have led to its almost exclusive adoption by the British Admiralty since the First World War. It is worthy of record that in 1904 a Committee of Mercantile Marine engineers in conjunction with an officer from the Service, all appointed by the Admiralty for the purpose of deciding whether the Scotch or water-tube boiler should be adopted in the Navy, reported that Babcock & Wilcox and Yarrow boilers were suitable for use in battleships and cruisers.

The Report of this Boiler Committee showed that in their experimental investigations, an efficiency of 82.3 per cent was claimed for the Scotch boiler when burning 20 lb. of coal per square foot of grate; 81 per cent for the Babcock & Wilcox when burning 20 lb. of coal per square foot of grate and 75.7 per cent for the Yarrow when burning 18 lb. of coal per square foot of grate.

### BABCOCK-JOHNSON BOILERS

The Babcock-Johnson boiler consists of a steam drum, immediately above a water drum and connected to it by curved tubes in such a manner that the tubes form a horizontal cylindrical furnace. In the earlier installations the far end of this furnace is completely tube-walled and the front end, apart from burner openings, also tube-walled (see Fig. 61).

Positive circulation at all powers is assured by the fitting of large uncooled downcomers between the drums. The complete

CHAPTER 14

COMMON DEFECTS AND REPAIRS TO SCOTCH BOILERS

AT cleaning times each boiler should be the subject of a thorough examination by a responsible engineer, and this is best accomplished to a definite routine. There are, of course, various opinions concerning the best routine to be adopted, but one suggested routine for a single-ended boiler is as follows :

- (1) furnaces and back ends ;
- (2) bottom of boiler externally, bearers, collision chocks ;
- (3) bottom doors, bottom parts internally, furnaces, etc. ;
- (4) bottom mountings ;
- (5) middle mountings ;
- (6) top internally with tubes, chambers, furnace tops, stays, etc. ;
- (7) top mountings, top door, easing gear, etc.

It would be impossible in these short notes to detail all the defects which might be discovered, and it is therefore proposed to deal with only three main classes of defect, namely :

- (1) wastage ;
- (2) overheating ; and
- (3) the combined effect of corrosion and mechanical action.

WASTAGE

Beginning with the upper parts of the boiler, wastage of the shell round defective mounting joints, as in Fig. 151 (3), of parts exposed to the atmosphere and also of nuts securing the mountings to the shell are common occurrences. Proceeding to the middle parts of the boiler, wastage is often caused by leakage past defective rivets in circumferential, cross and longitudinal seams, Fig. 151 (14), leakage past stay nuts, Fig. 151 (29), and in the case of the front tube plate, leakage past defective tube ends, Fig. 151 (10).

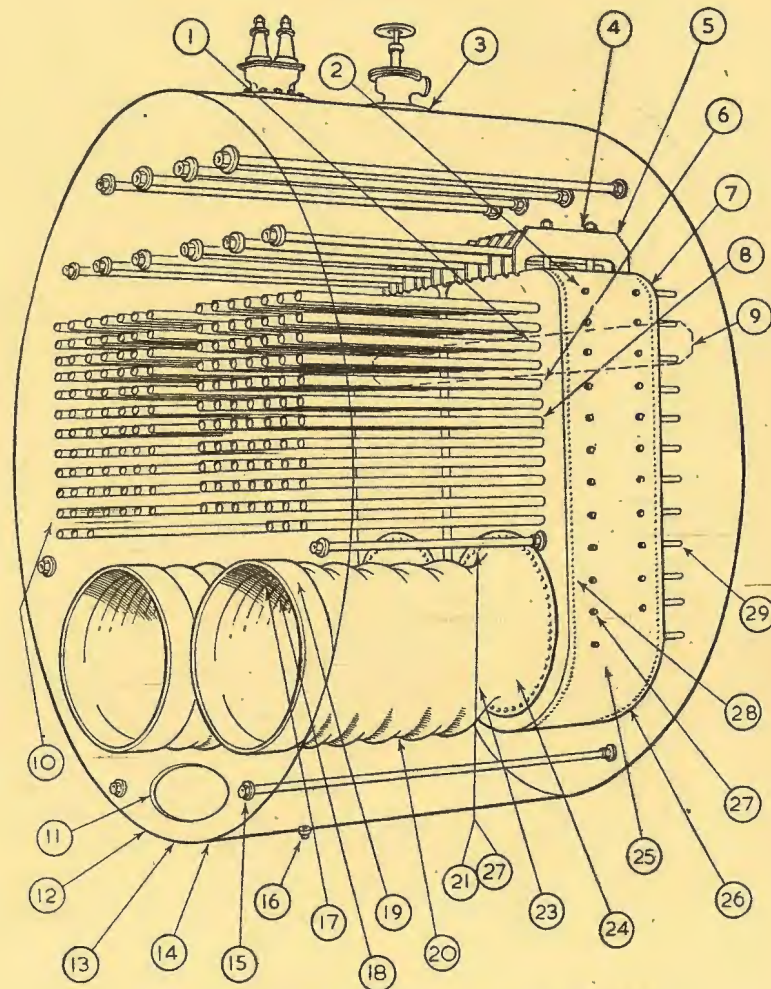
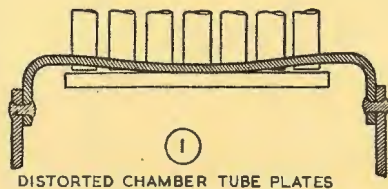
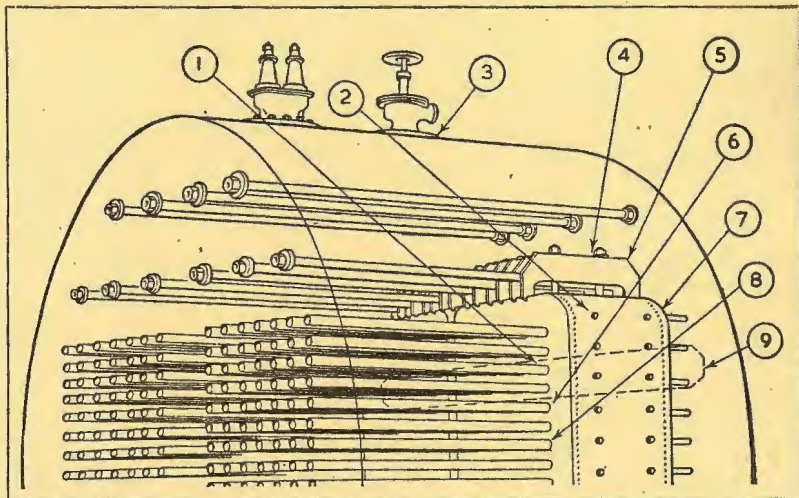


FIG. 151.—DEFECTS AND REPAIRS TO SCOTCH BOILERS

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.

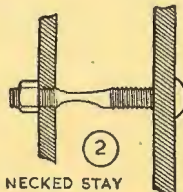
The appearance of these defects is shown in the enlarged views on the following pages.

The causes of the faults and the methods of repair are dealt with in detail in pp. 265 to 273.



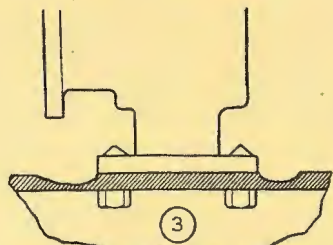
DISTORTED CHAMBER TUBE PLATES

1. The pushing of the tube plate inwards is caused by the tubes having been allowed to become encrusted with scale, with subsequent overheating.



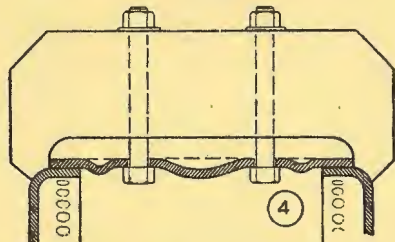
NECKED STAY

2. "Necking", or wastage of a stay tube or stay where it enters the plate, is a very common wastage defect.



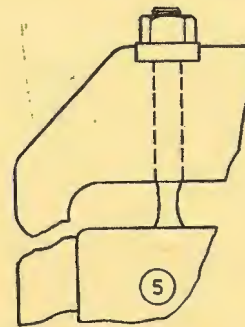
WASTAGE OF SHELL DUE TO DEFECTIVE JOINT

3. In the upper parts of the boiler, wastage should be looked for in parts exposed to the atmosphere, at nuts securing mountings, and, as shown above, around mounting joints.



OVERHEATED CHAMBER TOP

4. Another defect due to overheating is distortion of the chamber crown. Accumulation of mud scale or other insulating medium may cause this.



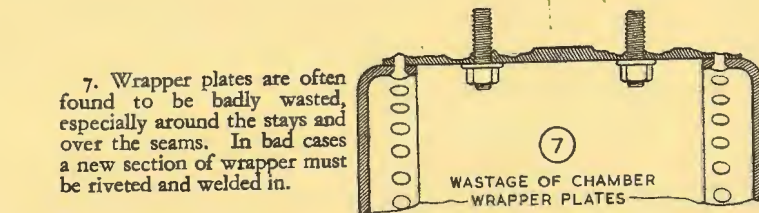
WASTAGE OF GIRDER STAYS CHAMBER KNUCKLES AND GIRDERS

5. The remedy for the type of serious internal wastage shown is to renew the stays and girders where necessary, build up chamber landings and re-bed the girders.



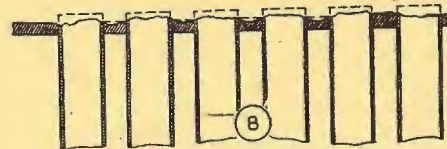
INCORRECTLY WELDED STAY TUBE

6. Wastage may be caused by stay tubes leaking at the threads. Welding around the ends will not provide sufficient anchorage for the tube.



WASTAGE OF CHAMBER WRAPPER PLATES

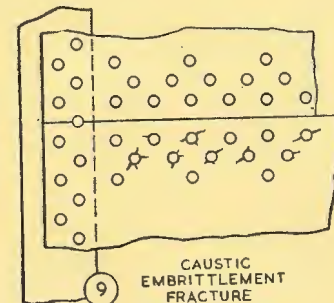
7. Wrapper plates are often found to be badly wasted, especially around the stays and over the seams. In bad cases a new section of wrapper must be riveted and welded in.



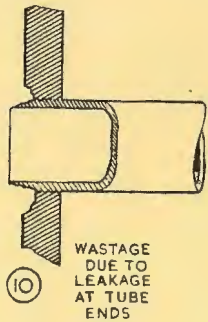
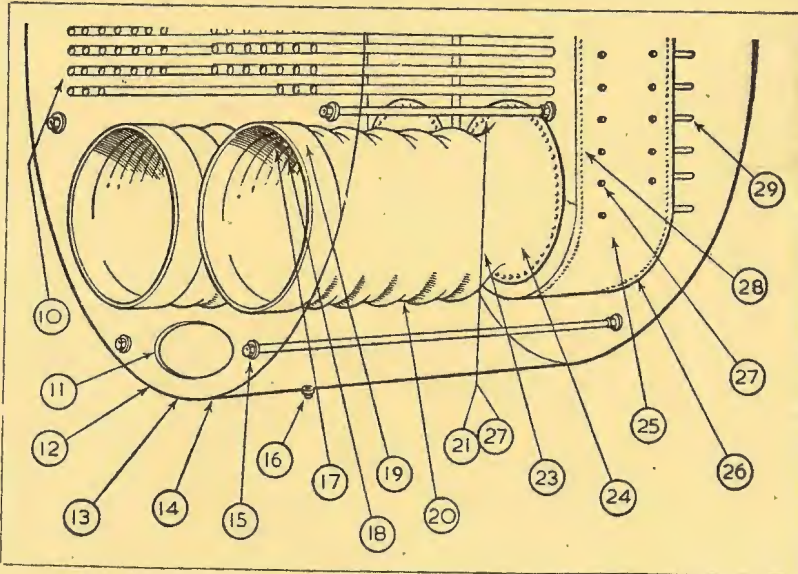
WASTAGE CAUSED BY TUBE BLOWERS

8. The use of wet steam for tube blowing may cause erosion and wastage at the tube plates and tube ends.

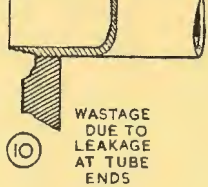
9. Leakage past defective rivets, especially in longitudinal seams, should always be viewed with suspicion. If rivet heads in vicinity are missing or fly off under hammer test, a magnetic crack detector may reveal caustic embrittlement.



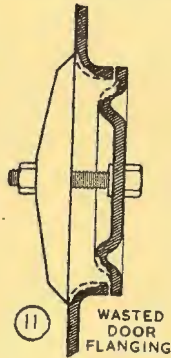
CAUSTIC EMBRITTLEMENT FRACTURE



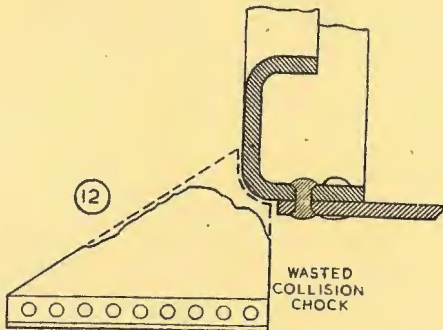
10. The front tube plate should be examined for wastage caused by leakage past defective tube ends.



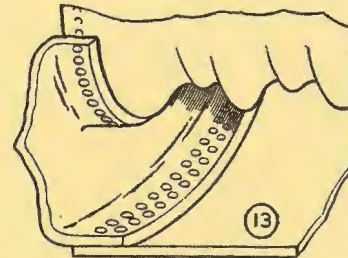
11. Wastage caused through leakage of manhole-door joints is very common. Doors are sometimes built up by electric welding without paying attention to the end plate, resulting in weakening of manhole flanging and eventual distortion.



11 WASTED DOOR FLANGING

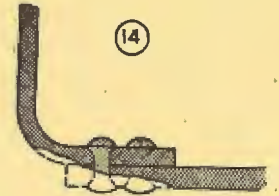


12. Constant quenching of ashes below the furnace mouths causes end-plate wastage, and is also responsible for wastage of the collision chock immediately below.



GROOVING OF FRONT END PLATE

13. Grooving of a fine and sometimes deep nature may be found in front end plates which are flanged inwards to take the furnaces, especially if the radius of the flanging is small.



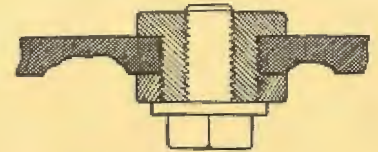
WASTAGE DUE TO LEAKY RIVETS

14. Wastage may be caused by leakage through defective rivets in circumferential seams, especially if the boiler has been subjected to rapid steam raising without any attempt at circulation.



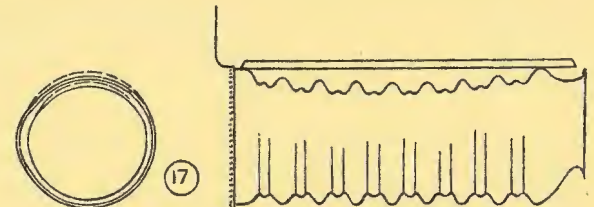
15 RADIAL GROOVING AROUND STAYS

15. Grooving is the result of mechanical action caused by varying expansion of the heating surfaces, and it may develop around lower longitudinal stays.



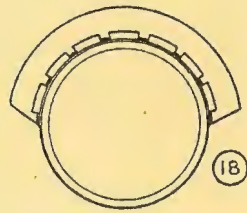
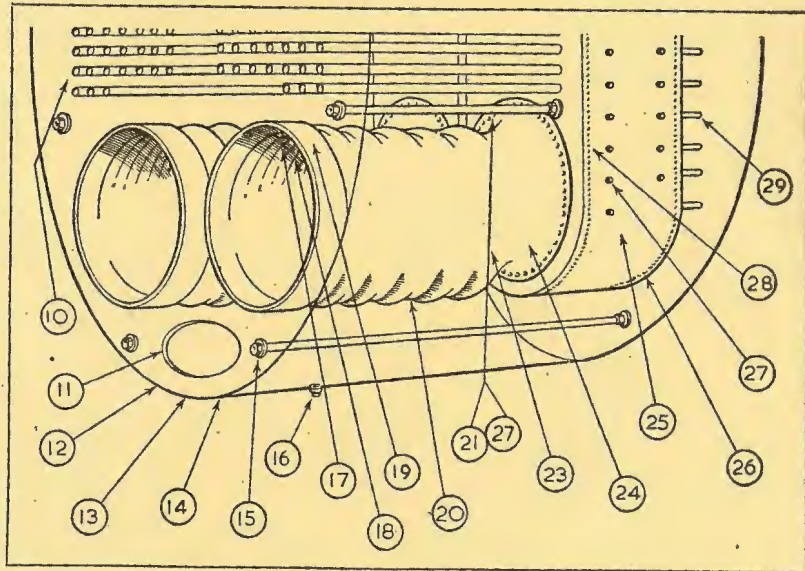
16 WASTING OF SHELL DUE TO LEAKING DRAIN PLUG

16. Drain plugs, if fitted, should always be examined. Badly fitting plugs are dangerous and often cause serious external wastage.



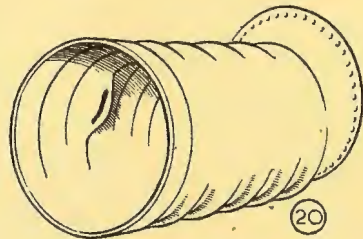
CHECKING FURNACE FOR DISTORTION

17. Overheating may cause deformation of furnaces. The amount of distortion may be checked by taking a lath inside the boiler and laying it along the corrugations at, say, four points. A method of temporary repair for distortion is shown in (18).

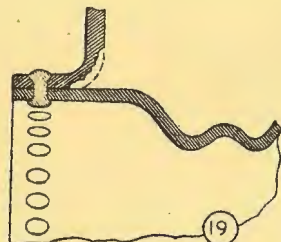


WELDED ON  
FURNACE STIFFENER

18. If a distorted furnace has already been jacked up, welded stiffeners may be fitted as a temporary repair.



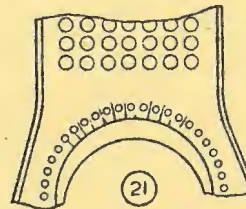
LOCAL BULGE IN FURNACE



WASTAGE OF FRONT END  
PLATE FLANGING TO FURNACES

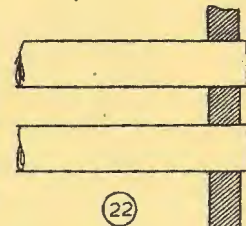
19. Front end plates which are flanged outwards to take the furnaces may be found to be badly wasted over the bend of the flangings, especially at the top.

20. Local bulges in furnaces are remedied either by cutting out the bulged portion and welding in a new piece, or by heating and pushing back into original 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 afterwards welded up.



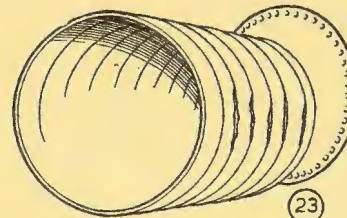
LANDING CRACKS IN FURNACE TO  
CHAMBER ATTACHMENT SEAM

21. If landing cracks in combustion-chamber seams (see 27) extend beyond the line of rivets, or cause leakage, they should be cut out and filled in by electric welding.



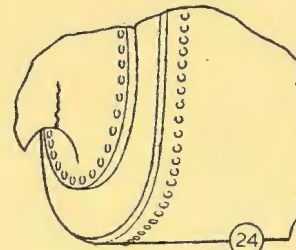
CHAMFERED  
TUBE PLATE

22. To avoid overheating due to an excessive local thickness of material, it is usual to taper off the combustion-chamber tube plate in way of the furnace-attachment seam.



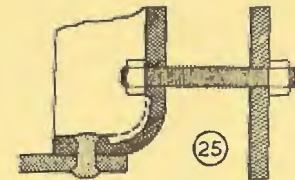
WASTAGE ALONG LINE OF FIREBARS

23. Wastage along the line of and above the firebar level is common. It usually starts with wastage of the peaks of the corrugations and may develop into a belt running along the sides of the furnace. This may cause hinging and the possibility of fracture.



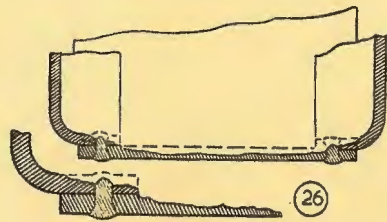
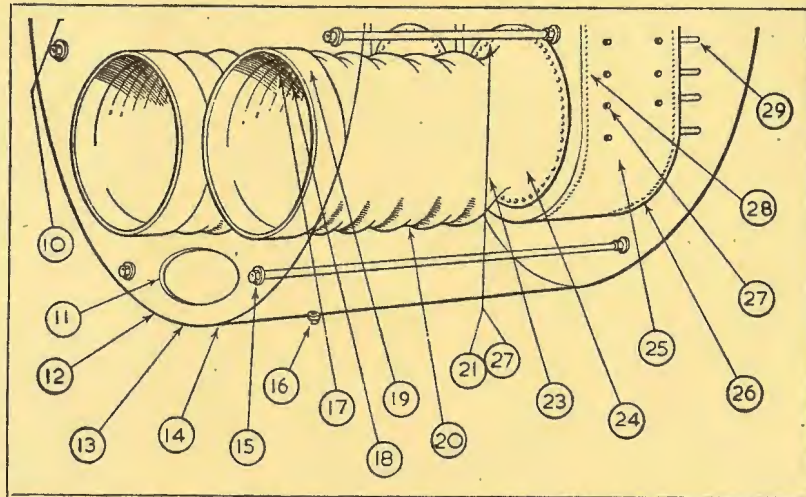
GROOVING IN FURNACE NECK

24. Grooving is a break in the structure of the material due to continual hinging action, and may occur at the bottom of the furnace neck. Repair consists of cutting out and welding, or, if more serious, cutting right through the plate in way of the grooving.



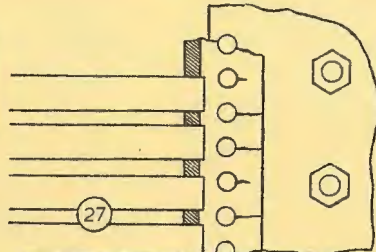
WASTAGE OF CHAMBER BACK  
BENEATH BOTTOM ROW STAYS

25. Wastage of combustion-chamber plating round leaky screwed stays is remedied by removing the stay, building up the plate by electric welding, re-tapping and fitting a new stay.



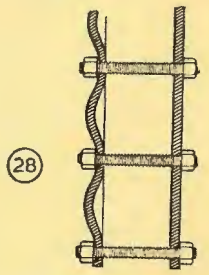
26. WASTAGE OF COMBUSTION CHAMBER BOTTOM WRAPPER DUE TO SEAM LEAKAGES

26. Combustion chambers are very prone to wastage defects through leakages. If a chamber bottom appears thin, a drill test will ascertain whether smooth wastage of bottom wrappers has taken place.



27. LANDING CRACKS IN COMBUSTION CHAMBER

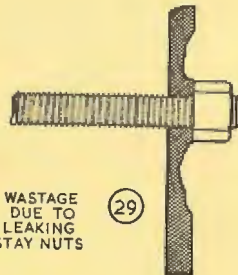
27. Other defects in combustion chambers may be caused by overheating. Landing cracks, running from the plate edge to the rivet holes, may develop on the fire side, but are not serious unless very numerous and causing leakage.



28. OVERHEATED CHAMBER BACK PLATE

28. The water side of the combustion chamber should be kept clean, or overheating may cause bulging of the back plate between stays.

29. Wastage is often caused by leakage past defective rivets in circumferential, cross and longitudinal seams (14) and past defective tube ends (10). Another form of wastage, due to leakage past stay nuts, is shown here.



29. WASTAGE DUE TO LEAKING STAY NUTS

### Leakage Past Defective Rivets

Leakage past defective rivets, especially in longitudinal seams, should always be viewed with suspicion, and if subsequent hammer testing of the rivet points results in these being dislodged, the condition of the whole seam should be investigated in view of the possibility of caustic embrittlement. Rivets should be removed from various points in the seam and the holes carefully examined. If any fractures are apparent in the bores of the holes, a magnetic crack detector applied to the defective plate will reveal their extent, Fig. 151 (9). In the case of a double butt-strap joint this may necessitate the removal of the straps. However, there are other causes of rivet points breaking away from their shanks, such as defective material, overheating, initial faulty workmanship, etc., and it is well to bear this in mind.

### 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, and during the chipping operations necessary to remove the salt the chest broke away from the neck holding it to the boiler shell.

### Circumferential Seam Leakage

The lower parts of the boiler also call for attention. Wastage is very often found where there has been circumferential seam leakage, Fig. 151 (14), especially if the boiler has been subjected to such ill-treatment as rapid steam raising without any attempt at circulation. Here again a recent case showed the shell to be so wasted under the lagging in way of a circumferential seam leakage that a hammer test pierced the shell plate. The repair for this defect consisted of an internal riveted patch welded on to and forming an extension of the end-plate flanging.

### Leakage at Manhole-door Joints

Wastage caused through the leakage of manhole-door joints is very common, and it is worth noting that the doors are some-

times built up by electric welding without paying attention to the end plate, with the result that although the door is made a passable fit, the lower part of the manhole flanging is gradually weakened, and eventually fails to react equally all round to the pull of the door dogs, Fig. 151 (11), thereby producing distortion.

#### Wastage of End Plate and Collision Chocks

The constant quenching of ashes below the furnace mouths causes wastage of the end plate, which, on account of its smooth nature, may easily be missed. It is also responsible for the wastage of the collision chock immediately below, Fig. 151 (12). A point concerning collision chocks is that some makers favour a chock in the form of a small doubler on the boiler shell which bears against one of the boiler stools. If, therefore, an examination fails to reveal the presence of a normal-type chock, one of this variety may be found hidden from view beneath the lagging.

#### Leaking Drain Plugs

When examining the lower part of the boiler internally it is essential to ascertain whether or not a drain plug is fitted, in order that its condition may be noted when the external examination of the shell is being made. Badly fitting drain plugs, apart from being dangerous, often cause serious external wastage, Fig. 151 (16).

#### Wastage of Combustion Chambers

In addition to the external parts of the shell, the fire side of the furnaces and combustion chambers must be considered. The fire side of the furnaces can be more or less ruled out as far as wastage is concerned, unless this takes place as a result of leaky seams. Owing to the number of their seams and the severe racking strains to which they are subjected, combustion chambers are, however, very prone to wastage defects through leakages, shown in Fig. 151 (26). The smooth wastage of combustion-chamber bottom wrappers is a particularly elusive type of defect. The seams are a good guide in this matter, but if the plate is judged to be seriously reduced, drill tests will confirm any doubt. In cases where a chamber bottom appears thin and its seams have been previously welded over, a drill test is essential.

#### Wastage of Stay-tube Threads

Tubes, both stay and plain, of dirty boilers are liable to over-heat and cause excessive expansion, with consequent working of the tubes in their tube plates, the result being a leakage and wasting of the stay-tube threads.

If stay-tubes leak at the threads and cause local wastage, expanding may, if the threads are good, constitute a cure, but on no account should they be welded around the ends, as the shear resistance of this small fillet weld may be the only anchorage of the tube, Fig. 151 (6).

The above remark concerning the welding of stay-tube ends is also applicable to the nutless type of combustion-chamber screwed stay.

#### Wastage of Combustion-chamber Plating

Wastage of combustion-chamber plating around leaky screwed stays, especially beneath those in the back bottom row, is fairly common, Fig. 151 (25), and can nearly always be remedied by removing the stay, building up the plate by electric welding, re-tapping and fitting a new stay.

Before leaving combustion chambers, there is another form of wastage which should be mentioned, the combined effect of erosion and wastage caused by a high-pressure jet of wet steam impinging on some part of the chamber. This defect is often caused by the use of wet steam for tube blowing, in which case the tube plates and tube ends suffer, Fig. 151 (8), or through serious leakage at a defective seam, stay-nut or tube.

#### Internal Wastage

Neglected boilers, and particularly 'tween-deck auxiliary boilers, are liable to suffer from wastage on practically all their internal surfaces, and common defects are serious wastage of the combustion-chamber girders, stays and knuckles of the tube and back plates, Fig. 151 (5). It is quite usual to find the girder toes wasted to such an extent that they are clear of the chamber. The remedy for this is to renew the stays and girders where necessary, build up chamber landings where required and re-bed the girders.

#### Wastage of Wrapper Plates

Wrapper plates are frequently found to be badly wasted, especially around the stays and over the seams, Fig. 151 (7), and



in bad cases the only thing to be done is to cut out the defective portion of wrapper and to rivet and weld in a new section. 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, re-tap and fit new stays. An alternative method of repair is to remove the stays and, working with extra long electrodes through the stay holes in the boiler back plate, to build up the wasted places and refit the stay.

When dealing with wastage over wrapper seams, it should always be borne in mind that the chamber is in compression, and provided that the rivets are not seriously reduced and the seam is tight, wastage of the wrapper outside of the line of rivets is not a very serious matter, Fig. 151 (7).

Wastage of the combustion-chamber tube plates around the stay tubes and the back plates around stays is a frequent occurrence, and here also electric welding can be employed to make good the wastage after the tube or stay has been removed.

#### Wastage of Stay Tubes and Stays

In the lower parts of the boiler, wastage of a stay tube or stay at the point where it enters the plate—usually known as “necking” Fig. 151 (2)—is one of the most common wastage defects. It is accelerated by the straining imposed on the stays by the expansion and contraction of the combustion chamber due to temperature changes.

A point to remember with wasted stays is that their strength varies as the square of the diameter and that it is quite a simple matter to compare the smallest wasted diameter with the diameter at the bottom of the thread.

Stay tubes sometimes blister and pit, the pits being small and deep. Such pits can be quite enough to condemn the stay tubes, although their strength may not appear to be affected. On the other hand, the stay tubes may be so badly wasted that only the removal of a tube can give any guide as to their general condition. This course was recently taken in the case of a 'tween-deck donkey boiler, the stay tubes removed being only one-third of the weight of the new tubes replacing them.

#### Wastage of Furnace

Wastage of furnaces along the line of and above the firebar level is a very common occurrence which is often serious. It

usually starts with a wastage of the peaks of the corrugations, and if not checked or made good by electric welding, this rapidly develops into a belt running along the sides of the furnace, Fig. 151 (23). The result of any such wasting at the sides is a tendency for hinging along the line of weakness and a possibility of subsequent fractures. Drill testing, gauging, careful examination and, if possible, an insight into its previous history must serve to decide whether or not a furnace is still in a safe condition.

#### Wastage at Flanges

Flanges of small radius should always be viewed with suspicion, especially when they are likely to be subjected to varying loads. Front end plates flanged outwards to take the furnaces, Fig. 151 (19), are sometimes found to be badly wasted over the bend of the flangings, especially at the top, such wastage probably being accentuated by the furnaces.

#### Wastage at Boiler 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.

### OVERHEATING

Defects caused through overheating are liable to be developed in the furnaces, combustion chambers and tubes. It is proposed to deal with these three parts individually and to discuss the repairs.

#### Furnaces

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 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, Fig. 151 (17).

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. Local bulges, Fig. 151 (20), can often be rectified by heating and pushing back into original shape. When this is done it is essential to cut the furnace through in way of the bulge in such a manner that the flow of the heated material is facilitated, the cut in the furnace being subsequently welded up.

As an alternative to this procedure, and where experienced welders are available, the bulged portion can be completely cut out and a new piece welded in place.

If a furnace is uniformly down to such an extent as to call for immediate action, provided the material is good and the surfaces not severely corroded, quite a satisfactory repair can be effected by warming up and jacking back the furnace to its original shape, care being taken to examine the furnace carefully for cracks after the jacking operation.

Occasionally one is faced with a distorted furnace, considerably corroded along the line of firebars, which has already been jacked up, and for which no spare is immediately available. As a temporary repair, jacking back to approximately original shape and the fitting of welded stiffeners, Fig. 151 (18), is sometimes resorted to.

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.

### Combustion Chambers

Overheating is responsible for numerous defects in combustion chambers, and it is proposed to start from the upper parts and work downwards.

The first part of a boiler to feel the effects of overheating through lack of water is the chamber crown. An accumulation

of mud scale or other insulating medium on the top of the chamber can also cause similar defects, Fig. 151 (4).

Proceeding lower down the chamber into parts which are subjected to more intense heat, it is quite common, especially in boilers which are not kept clean, to find the back plate bulged between the stays, Fig. 151 (28). 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 inadvisable 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.

The seams of combustion chambers are liable to overheat on their fire sides, because there is a double thickness of metal between the heating surface and the surrounding water. The result is that so-called landing cracks develop, Fig. 151 (27). These cracks may run from the plate edge to the rivet holes, and when dry can be ignored, provided they are not too numerous. If, however, the cracks originating at the plate edge do not terminate at the rivet holes and tend to extend beyond the line of rivets, Fig. 151 (21), or if leakage develops in way of the cracks, they should be cut out and filled in by electric welding, the rivets in the vicinity of the cracks being removed prior to the welding operations and subsequently renewed.

The most usual place for landing cracks to develop is in the upper parts of the seam connecting the combustion chamber to the furnace, which in view of the intense heat at this seam is understandable. It is not advisable to ignore a series of such

fractures in this seam, as the ligaments between the fractures might conceivably be subjected to bending stresses through variations in the length of the furnace, due to temperature changes and straining action. Nowadays, especially in the case of heavy combustion-chamber tube plates, it is usual to taper off the plate in way of the furnace-attachment seam, Fig. 151 (22), this being an obvious way of avoiding overheating due to an excessive local thickness of material.

### Tubes

Tubes which are allowed to become encrusted with scale are liable to overheating defects. In the first place the tubes, especially stay tubes, are subjected to undue expansion, with the result that they tend to push the tube plate inwards, Fig. 151 (1). In a dirty boiler this can be checked by laying a straight edge across the tube plate.

Second, this tendency to excessive expansion causes the tubes to move, and leads to leakage at the end which has the weaker anchorage, the combustion-chamber tube-plate end.

Third, the tube ends in the combustion chamber, especially the lower rows, tend to burn and wear thin.

### COMBINED EFFECT OF CORROSION AND MECHANICAL ACTION

The defects coming under this heading are practically all to be found on the water side in the lower half of the boiler. Poor circulation, rapid steam raising, continued forcing, irregular firing, lack of uniformity of stiffness in design—such faults, often accentuated by the action of indifferent feed-water, are all factors in producing the defects now claiming attention. The areas of the heating surfaces of the furnaces, combustion chambers and tubes vary according to the temperature, and it is these variations which give rise to some of the defects caused by straining or mechanical action.

Variations in the length of the furnaces are to some extent taken up by the corrugations, but the chamber-end flanging attachment is stiffer at the top of the furnace than at the bottom, due to the form of the Gourlay neck, and hinging is liable to take place at the most flexible part, i.e., at the bottom. This results in what is commonly called "grooving", Fig. 151 (24), which is a break in the structure of the material due to continual hinging

action. Grooving develops with age and accelerates as the material gets weaker.

In view of the fact that there are flanged attachments at both ends of the furnace, it is only logical to expect both to be subjected to straining action. In the case of front-end plates which are flanged inwards to take the furnaces, especially if the radius of the flanging is small, grooving of a fine and sometimes deep character is not unusual, Fig. 151 (13). When the front end plate is flanged outwards to take the furnaces, grooving in the front flanging is uncommon and, if present, is usually of a broader nature, Fig. 151 (19).

### Repairs for Grooving

The procedure for dealing with grooving is to pick out what appears to be the most serious part, to drill a  $\frac{1}{4}$  or  $\frac{5}{8}$  in. hole through it and, by examining the bore of the hole, to ascertain its depth. The repair for the grooving when it is not more than, say, 50 per cent of the plate thickness in depth, is to cut it out and weld. If, however, it is of a more serious nature, it is usually best, provided both sides of the plate are accessible for welding operations, to cut right through the plate in way of the grooving.

As has already been said, grooving is the result of mechanical action caused by varying expansion of the heating surfaces. Any variation in length of the furnace and combustion-chamber assembly with the temperature, and also that of the boiler shell due to poor circulation, leads to working of the lower parts of the boiler end-plate flangings and of the end plates where tied by stays. These defects are shown in Fig. 151 (13) and (15). The repair for grooving of the end-plate flanges is the same as for grooving in the furnace-attachment flanges—to cut out and weld.

Where radial grooving around lower longitudinal stays develops, as in Fig. 151 (15), welding does not, as a rule, constitute a permanent repair, and the local stress concentrations at the stay ends should be spread over a larger area by fitting a doubler in way of the stay, suitably riveted to the end plate.

Similar radial grooving sometimes takes place around the stay tubes and combustion-chamber side and backstays, more especially at the combustion-chamber end. The repair in this case is to remove the stay or tube, cut out the grooving, weld up and subsequently refit the stay or tube. Doubling of heating surfaces is not permissible, as this would result in overheating.