Service Performance of Boiler Brickwork—The Causes and Extent of Wastage

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The investigation described in this paper was undertaken by the British Shipbuilding Research Association and the British Ceramic Research Association with the following objects: to determine the extent of deterioration of refractory materials in watertube boilers in the merchant service; to formulate the main causes of wastage; to consider ways of improving the life of furnace brickwork; and to provide a background for any experimental work that may be desirable.

Following an introductory section which gives brief details of furnace linings commonly used, the information gained from the examination of over forty boilers of eight different types is summarized.

It was found that thermal spalling or fracture is undoubtedly the most common and serious type of damage. Cracking of bolted blocks and oxidation of the bolts is probably the second most serious form of failure. Damage directly attributable to slag action is negligible but it is possible that slag penetration of the firebrick may play some part in promoting spalling. More severe damage of all types occurs where the lining is swept by flame.

The aluminous firebricks now generally used have adequate refractoriness but it appears that rammed plastic refractory materials could be substituted with advantage in certain positions, notably in those sections containing the burner openings.

The influence of service conditions on the life of refractories is examined in a further section and it is concluded that the forcing rate (lb. oil/hr./sq. ft. projected radiant heating surface) may be taken as a general indication of the severity of the operating conditions and also the extent of slag deposition.

Information relating to the useful life of sections of the linings of various types of boilers is given and in a concluding section suggestions are put forward for improving the performance of boiler brickwork.

INTRODUCTION

The deterioration of the furnace linings of marine watertube boilers is a problem of serious concern to many shipowners and repairs to the refractories often account for a large proportion of the maintenance costs of boiler installations. Although the trend of recent boiler designs is to reduce the amount of brickwork directly exposed to the furnace, further advances in reducing the size and weight of boilers will probably tend to make the operating conditions of the necessary refractory materials more arduous. Furthermore, the necessity of ensuring a reasonable performance from the brickwork probably remains one of the main factors which place a limitation on the furnace temperature and hence the output for a given size of boiler. The question therefore arises whether any steps can be taken to increase the life of the refractories either by improvements in the operating conditions or by modifications of the materials used, the method of construction and the design of the furnace lining.

It was decided that a joint research into the subject should be instituted by the British Shipbuilding Research Association in conjunction with the British Ceramic Research Association but, before embarking on any laboratory work, the extent of the problem should be investigated by examining typical boilers of different types in various classes of vessels. This paper is devoted primarily to the findings of this survey which included all the different types of watertube boilers more commonly used in the merchant service with the exception of forced circulation boilers. With the co-operation of the owners visits were made to a total of nineteen vessels which included most of the types of ships generally fitted with watertube boilers; for purposes of comparison boilers of older design were included as well as those of the most advanced designs at present in service.

In view of the fact that refractory technology is not a subject that normally comes within the scope of the marine engineer it is perhaps as well at the outset to define briefly the main causes of failure of boiler refractories. This subject was dealt with fully in a paper* presented before this Institute less than two years ago and for further information the reader is referred to this work.

The types of failures most commonly met with in boiler furnaces may be classified as follows: spalling, slag action, failure of the securing devices and permanent volume changes.

The term "*spalling*" is defined by the American Society for Testing Materials as the breaking or crushing of a refractory unit due to thermal, mechanical or structural causes presenting newly exposed surfaces of the residual mass. In this country, the expression "thermal spalling" is generally used to denote cracking caused by fluctuations in temperature. Spalling is dependent on a number of factors in addition to the rapidity and range of temperature fluctuations; these include properties of the refractory material, the degree of contamination by slags

* Clews, F. H. 1951. "Refractory Materials for Marine Boilers", Trans.I.Mar.E., Vol. 63, p. 271.

and fluxes, mechanical damage and lack of provision for expansion. In this paper the term "spalling" is used to indicate loss from the hot surface by fracture and also cracking which causes subdivision of the refractory unit.

Slag attack results from the chemical reaction between the refractory material and the ash from the fuel. The important factors which influence the degree of slag attack are the slag composition and the working temperature. Probably the most important constituents of oil fuel ash in this respect are sodium salts and iron oxide, which both act as severe fluxes. Sodium chloride may also be introduced into the combustion chamber by sea water contained in the fuel. The effect of increase of temperature is to reduce the viscosity of the slag and so render it the more potent.

The action of slag may take the form of erosion of the surface or it may lead indirectly to increased spalling. A reactive fluid slag, such as that from a fuel ash with a high alkaline content, drains away and being continually renewed rapidly erodes away the lining. A viscous slag, on the other hand, may form a thick coating without removing the firebrick surface. When this occurs, however, there is some contamination of the surface with more fusible compounds which tends to increase the degree of vitrification and consequently the liability for spalling to occur. It will be seen that the resistance to slag attack is greatest when the refractory material is dense and of close texture. On the other hand, however, a rather coarse open texture with a fairly high porosity gives maximum spalling resistance; spalling resistance is, therefore, not compatible with slag resistance.

The brickwork in most marine boilers is secured to the casing by bolts or keys of various types. These form a source of weakness, since failure of the securing devices can lead to collapse of the refractory lining.

If the refractory material is not fired originally above the temperature at which shrinkage ceases and the working temperature exceeds this value, further shrinkage will occur in service. This may result in cracks in the working face, or the joints may open and the jointing material be lost. Unfilled joints tend to increase the severity of slag action and also promote spalling.

CONSTRUCTION OF FURNACE LININGS

The various types of marine boilers commonly in use in the merchant service can be divided broadly into two groups, namely the single drum header type or the multi-drum type. Those having two, three or more drums have many variations; the shape of the furnace and the proportion of brickwork exposed directly to the furnace can, therefore, differ widely in different designs. Space does not permit detailed descriptions being given of all the different types of boilers examined but typical boiler designs, which have been chosen to illustrate the various types of lining construction commonly employed, are shown in Figs. 1 to 4.

Walls made up of standard $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$-inch firebricks are often used in all-refractory furnaces or for the exposed walls in boilers which have water walls. Such bricks may be laid in header courses, which construction has been found to give the best service performance, to form 9-inch walls as shown in Figs. 1, 2 and 3. They are sometimes used in stretcher courses forming a lining $4\frac{1}{2}$-inches thick where the walls are not very high. It is usual for walls made up of standard brick to be backed by a layer of insulating material such as diatomite block or asbestos millboard.

It will be noted that, in the 5-drum boiler illustrated in Fig. 3, two alternative methods of construction are shown. In boilers of recent construction of this type it is usual for 9-inch walls made up of standard firebricks to be used for the lower part of the furnace, which is subjected to the most arduous conditions, and bolted tiles for the upper sections. It was formerly the practice to fit two layers of 4-inch bolted blocks in the lower part of the furnace, as shown in Fig. 3, and a considerable number of boilers so fitted are in service.

In boilers where water walls are fitted the details of construction of the lining adopted by various manufacturers differ considerably. In the integral furnace boiler shown in Fig. 2 it will be noted that stud-tube construction is used for the side wall and roof with a plastic chrome ore refractory filling. This material is held in place by studs welded to the tubes and may completely or only partly cover the tubes. A similar type of construction is often used in single-pass header boilers which may be fitted with water walls at the sides and sometimes at the back of the furnace.

In boilers where there is a space between the water wall tubes and the brickwork, it is usual to employ bolted tiles backed by one or more layers of insulating material, as shown in Fig. 4. The thickness of the firebrick does not usually exceed 2 to $2\frac{1}{2}$-inches. The insulating material may consist of insulating blocks of the diatomite type, backed by asbestos millboard, or, where the temperature is lower, calcined magnesia blocks may be used behind the firebrick with an outer layer of magnesia-asbestos composition. In such boilers the furnace lining may be attached to a casing of light plate construction, but it is more common for the refractory and insulating blocks to be bolted to vertical channel bars spaced to suit the size of blocks used, the whole being enclosed in a gas tight casing. Air casings are not usually fitted for conveying the combustion air around the back and side walls; unlike the boilers previously mentioned, air is normally discharged directly into the front casing.

The floors of combustion chambers are almost invariably made up of two or more layers of blocks or standard bricks. Where the design of the boiler incorporates floor tubes, however, details of the construction of the floor may vary considerably. A typical boiler of this type is shown in Fig. 4.

In some boilers bolted blocks are also used for the front walls, the firebrick usually being 3 or 4 inches thick in such positions. This construction involves the use of special shaped blocks to fit around the burner quarls and, where the burners are angled, the construction is made even more complicated. In such applications increasing use is being made of plastic refractory materials since more freedom of shape and variation of lining thickness is possible than with orthodox construction.

The construction of a monolithic plastic refractory lining is illustrated in Fig. 5, which gives details of a front wall for a single pass header boiler. It will be noted that the wall is divided up into relatively small areas by surface cuts made with a trowel to a depth of about 1 inch. These are provided with the object of controlling cracking due to contraction of the hot face and also arresting any other cracks that may be formed.

A number of patent devices are available for securing monolithic walls to the boiler casing or framework. These holders are buried in the plastic material during construction and may provide freedom of lateral movement for the monolith relative to the casing. Other supports may be used, as shown in Fig. 5, to avoid the whole weight of the wall being transferred to the lowest section.

Plastic ramming materials may be either heat setting or air setting, the former being the more commonly used. Air setting is obtained by the addition of sodium silicate which produces a strong bond in the unfired material but reduces the refractoriness. Water only is used in heat setting materials to give a consistency such that it is coherent without either crumbling or slumping; the moisture content should not exceed about 10 per cent.

The two constituents of the mix are the bond clay which provides the necessary workability and the base. The base, which constitutes some 70 per cent of the whole, should be prefired material such as fireclay. Aluminous minerals may be added to increase the refractoriness. Since a monolithic lining is fired hard only on the hot face there will be a plane parallel to this where the material is relatively weak.

The chrome base plastics, previously referred to, which are used with stud-tube wall construction, are usually made up

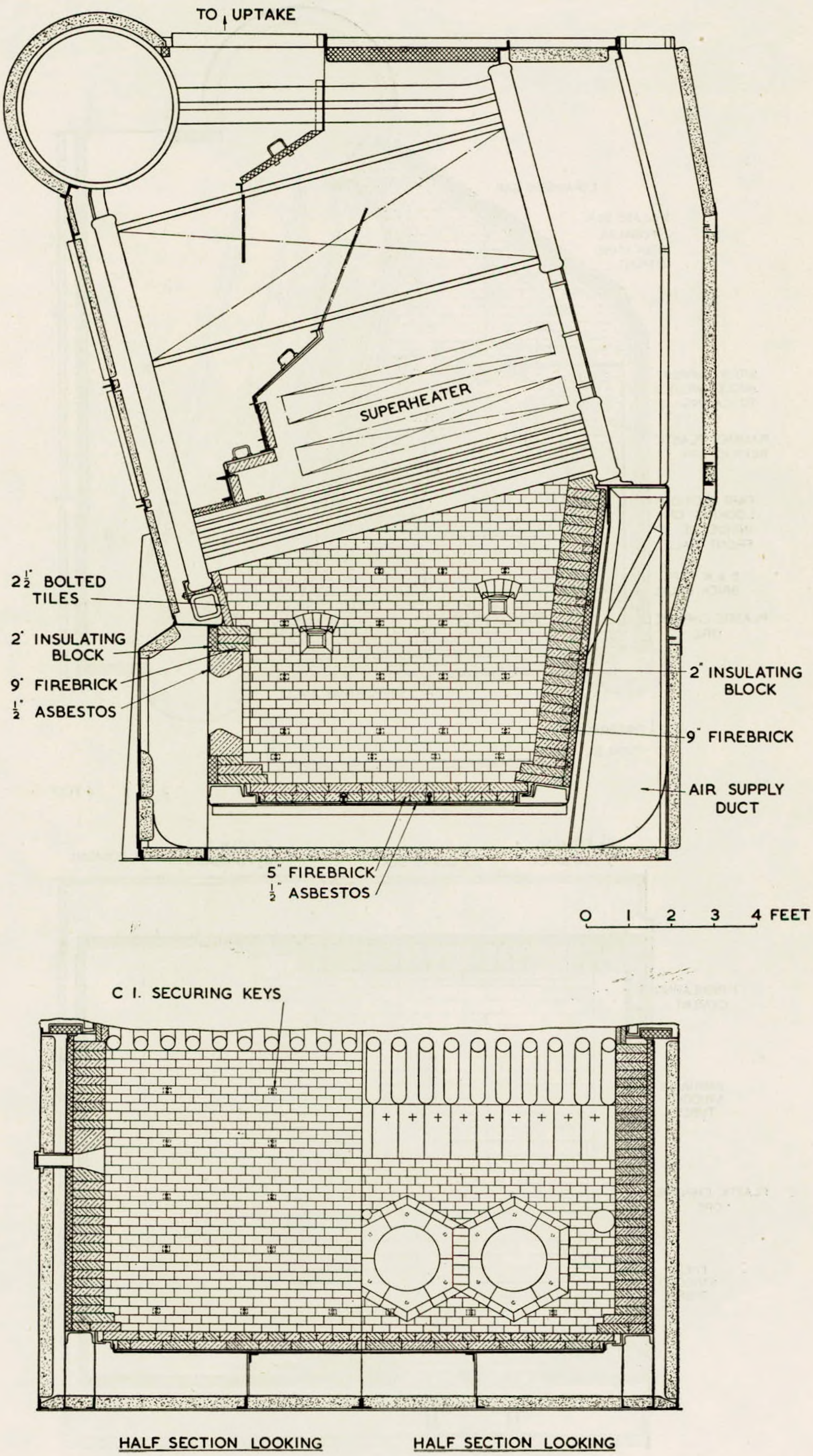


FIG. 1—*Babcock and Wilcox 3-pass header boiler*

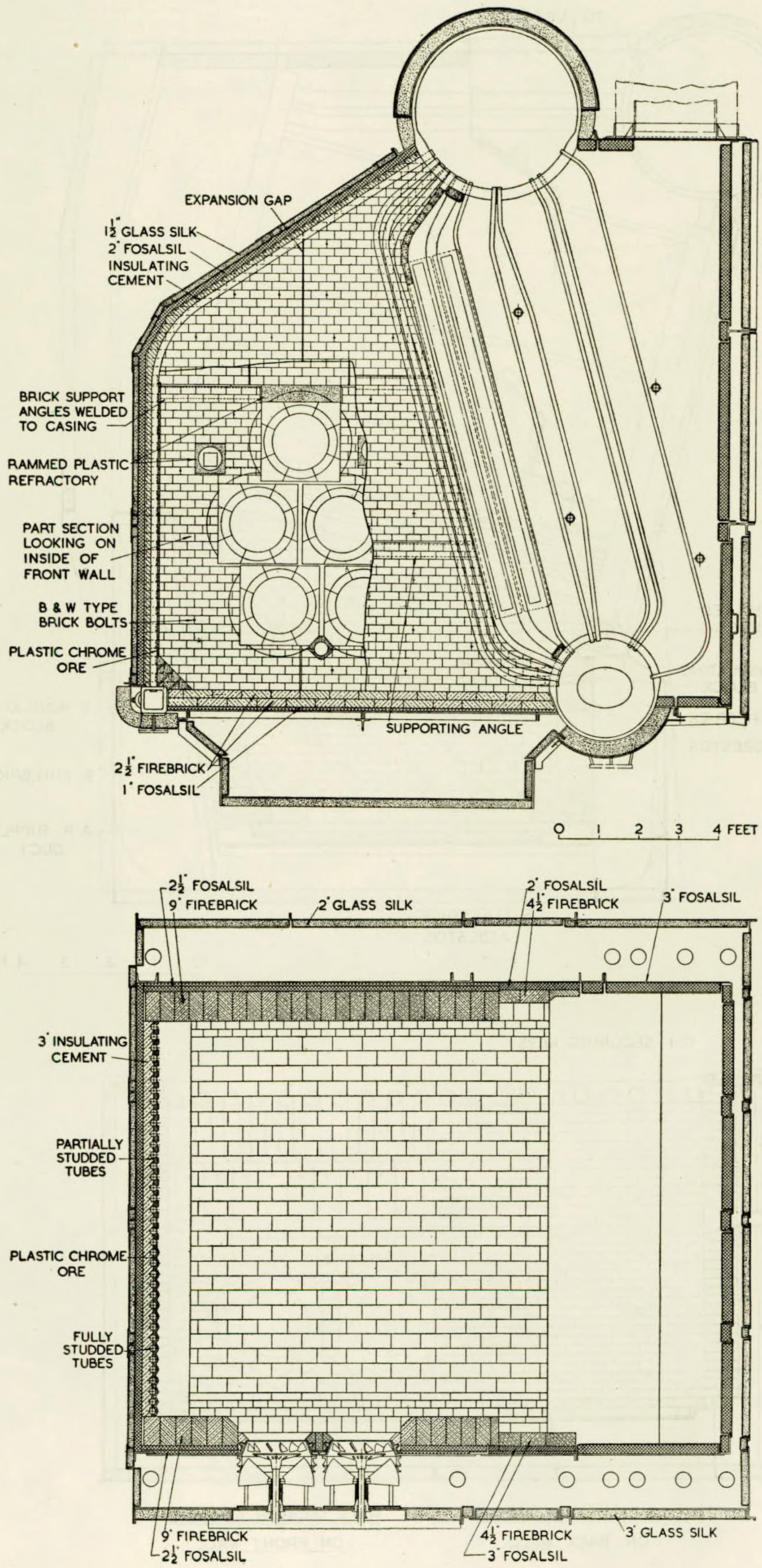


FIG. 2—*Babcock and Wilcox integral furnace boiler*

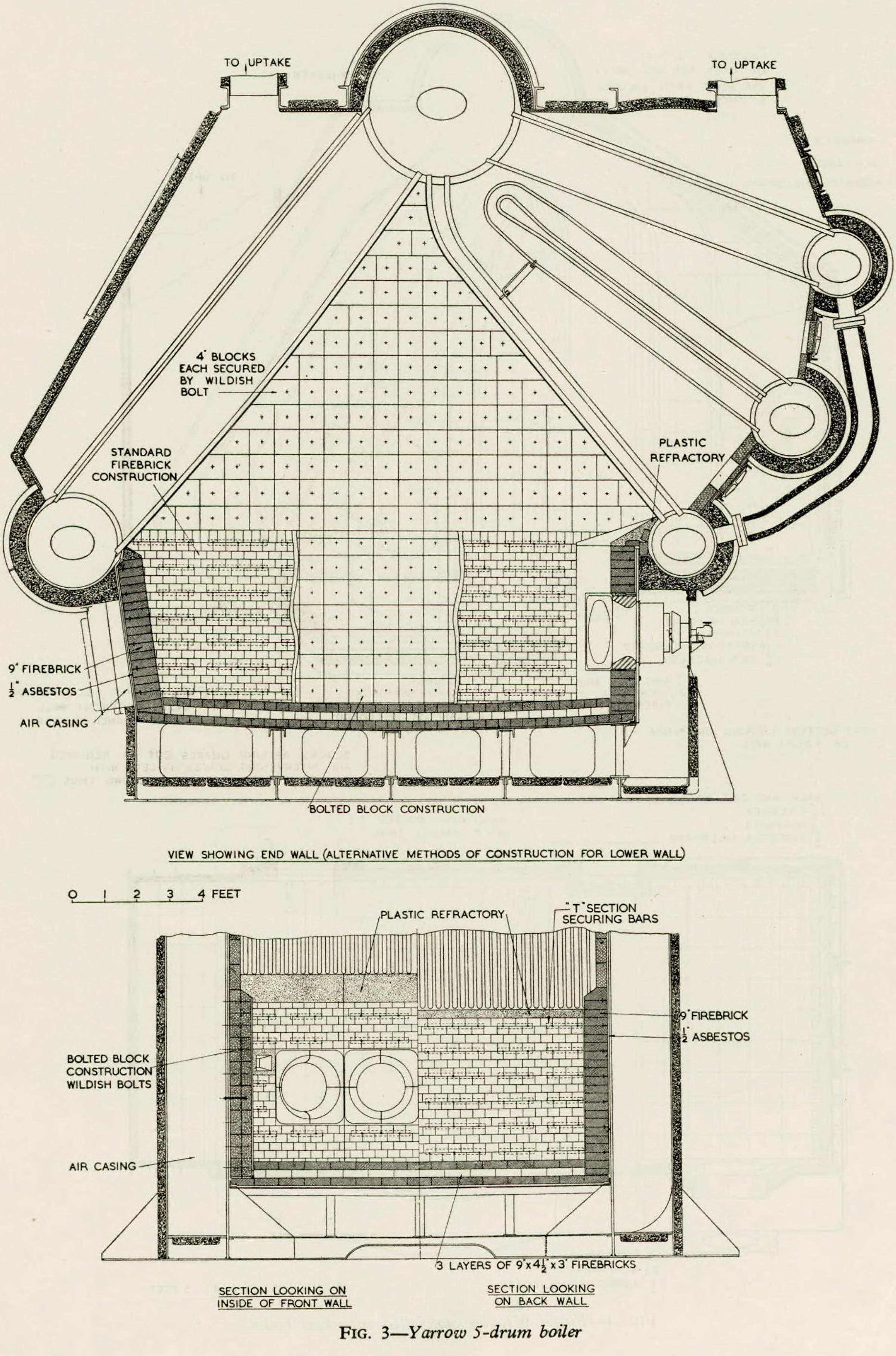


FIG. 3—*Yarrow 5-drum boiler*

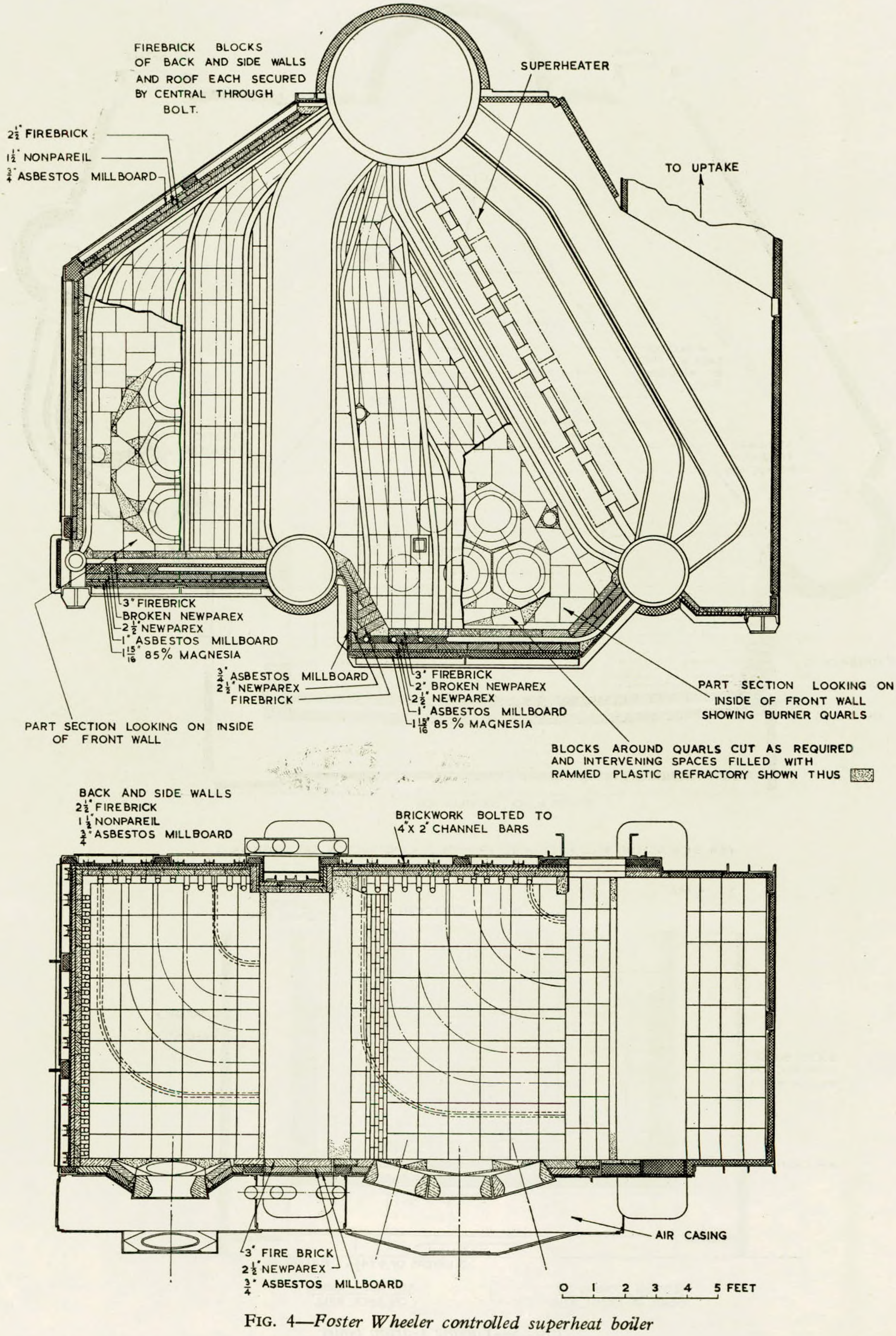


FIG. 4—*Foster Wheeler controlled superheat boiler*

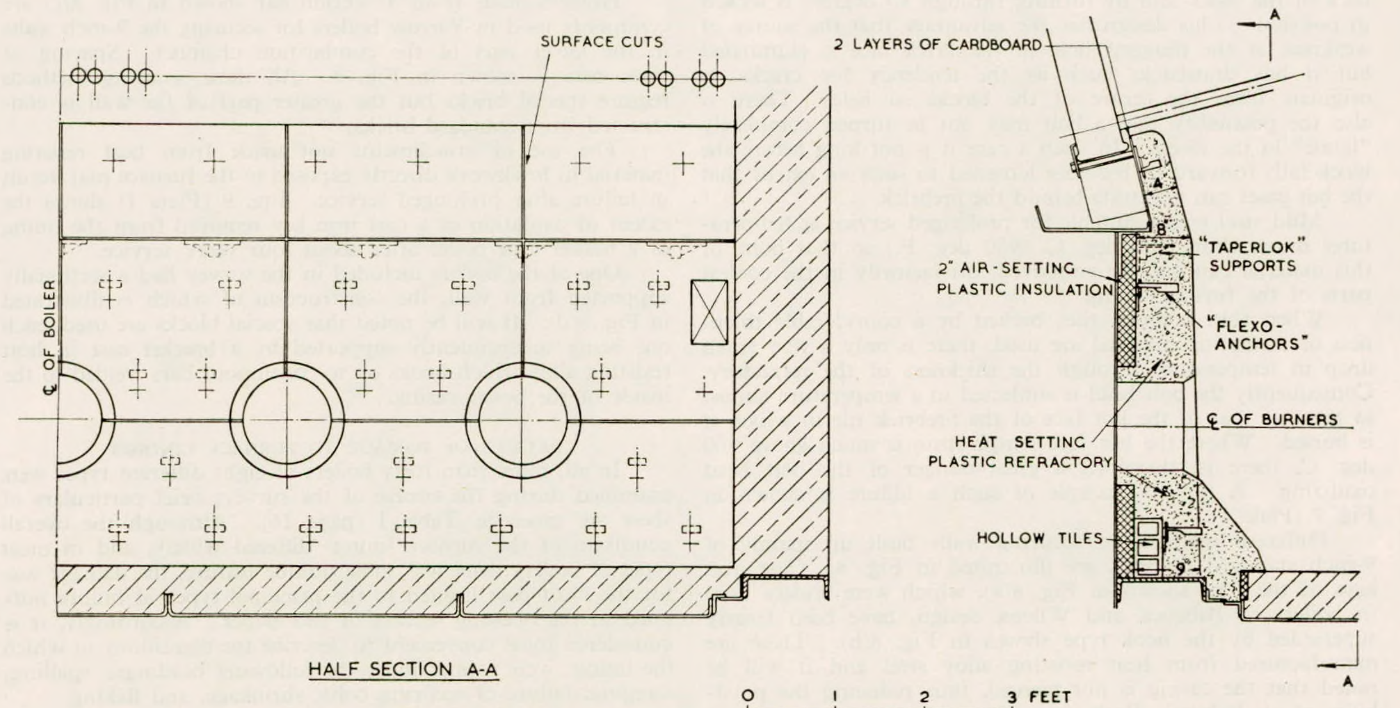


FIG. 5—*Construction of plastic refractory monolithic lining as adopted by the Plibrico Co., Ltd.*

of raw or calcined chrome ore with some bond clay and sodium silicate, the chrome ore usually comprising about 80 per cent of the total. This material is neutral in its chemical reaction to acid or basic slags and is highly refractory.

Burner Brick Tubes

The burner openings in the combustion chamber lining may be formed by specially shaped blocks or quarls or by plastic refractory rammed around a former in place. From four to eight blocks may be used to form the circular throat, each one commonly being secured by a separate bolt. Such bolts usually pass through the quarl block from the front, the head being recessed below the face of the block and the hole filled with refractory cement. Alternatively, Wildish bolts of the type illustrated in the following section may be used. When the burner throat is formed of six blocks of the type illustrated in Fig. 4 it is sometimes the practice to have only one bolted quarl block which locks the other five in place. Other makers dispense with the use of securing bolts altogether, in which case the quarls are held in place by the surrounding brickwork or a retaining ring of the type shown in Fig. 2.

The shape and dimensions of the brick tubes used with burners of different types differ widely. The burner opening may be of plain cylindrical form as shown in Fig. 5, it may be shaped to form a venturi throat as in Fig. 3, or the quarl blocks may only be about 4 inches thick, with the inside edge slightly bevelled.

Methods of Securing Brickwork

In almost all boilers of British manufacture the lining blocks or bricks are secured to the casing by bolts or keys of various designs.

Bolts are of two types: the Wildish, in which the face of the brick is not penetrated, and the through bolt which is inserted from the inner face of the brick, a recessed hold being provided for the head, which, after fitting the bolt, is filled with a plastic refractory material.

In Fig. 6(a) (b) and (c) details are given of various types of through bolts commonly used, the designs shown in (b) and (c) often being adopted for securing relatively thin tiles. Heat resisting alloy steel is now often used for those bolts securing the brickwork in the lower part of the combustion chamber up to the height of the topmost burner; bolts in other sections of the furnace lining are of mild steel. The conical headed bolt shown in Fig. 6(d) is not used to any great extent and only one boiler included in the survey had such bolts fitted. .

Details of the Wildish bolt are shown in Fig. 6(e). The head of this bolt is inserted into a specially shaped recess in the

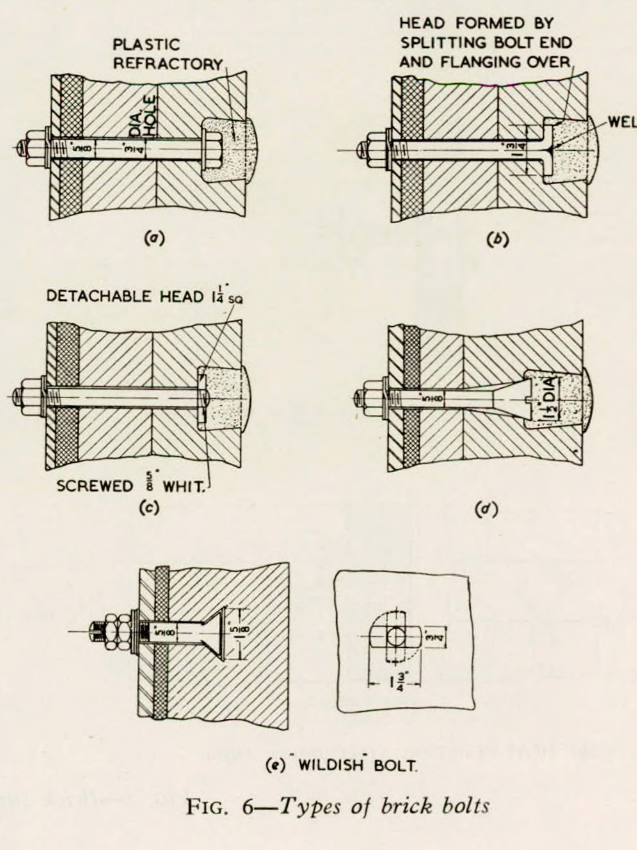


FIG. 6—*Types of brick bolts*

back of the block and by turning through 90 degrees is locked in position. This design has the advantage that the source of weakness at the plugged hole in the brick face is eliminated but it has drawbacks such as the tendency for cracks to originate from the centre of the blocks so held. There is also the possibility that a bolt may not be turned completely "home" in the recess. In such a case it is not long before the block falls forward or becomes loosened to such an extent that the hot gases can penetrate behind the firebrick.

Mild steel is not suitable for prolonged service at temperatures much above 500 deg. C. (930 deg. F.) so that bolts of this material can only be employed satisfactorily in the coolest parts of the furnace lining.

When thin firebrick tiles backed by a considerable thickness of insulating material are used, there is only a very small drop in temperature through the thickness of the refractory. Consequently the bolt head is subjected to a temperature almost as great as that of the hot face of the firebrick tile in which it is buried. Where the hot face temperature is much above 500 deg. C. there is, therefore, a great danger of the bolt head oxidizing. A typical example of such a failure is shown in Fig. 7 (Plate 1).

Different methods of securing walls built up mainly of 9-inch standard firebrick are illustrated in Fig. 8. Cast iron keys of the type shown in Fig. 8(a), which were widely used in boilers of Babcock and Wilcox design, have been largely superseded by the hook type shown in Fig. 8(b). These are manufactured from heat resisting alloy steel and it will be noted that the casing is not pierced, thus reducing the possibility of air leakage. Both types allow for some movement of the lining relative to the casing but type (b) would appear to be more suitable for accommodating expansion of the brickwork.

Holders made from T section bar shown in Fig. 8(c) are commonly used in Yarrow boilers for securing the 9-inch walls in the lower part of the combustion chamber. Spacing of these bars is shown in Fig. 3. All these securing methods require special bricks but the greater part of the wall is constructed from standard bricks.

The use of attachments not made from heat resisting material in brickwork directly exposed to the furnace may result in failure after prolonged service. Fig. 9 (Plate 1) shows the extent of oxidation of a cast iron key removed from the lining of a header type boiler after about four years' service.

One of the boilers included in the survey had a sectionally supported front wall, the construction of which is illustrated in Fig. 8(d). It will be noted that special blocks are used, each one being independently supported by a bracket cast in heat resisting alloy which hooks on to continuous bars welded to the inside of the boiler casing.

DETAILS OF DAMAGE TO FURNACE LININGS

In all, more than forty boilers of eight different types were examined during the course of the survey; brief particulars of these are given in Table I (page 16). Although the overall condition of the furnace linings differed widely, and in most types of boilers there was some unique feature, the damage was for the most part limited to the principal types of failure outlined in the opening section of this paper. Accordingly, it is considered most convenient to describe the conditions in which the linings were found under the following headings: spalling, slagging, failure of securing bolts, shrinkage, and flaking.

Spalling

Thermal spalling is undoubtedly one of the major causes

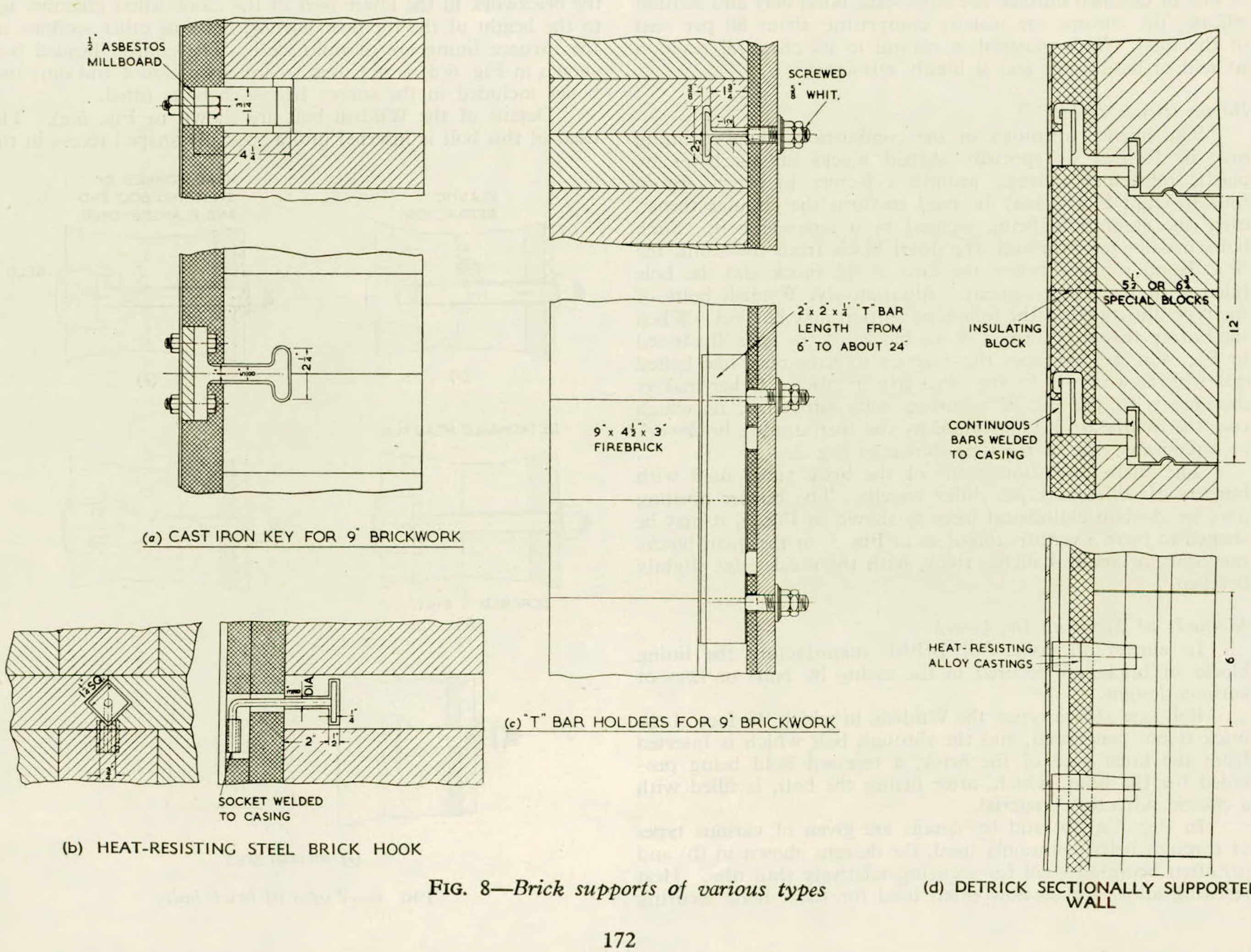


FIG. 8—*Brick supports of various types*

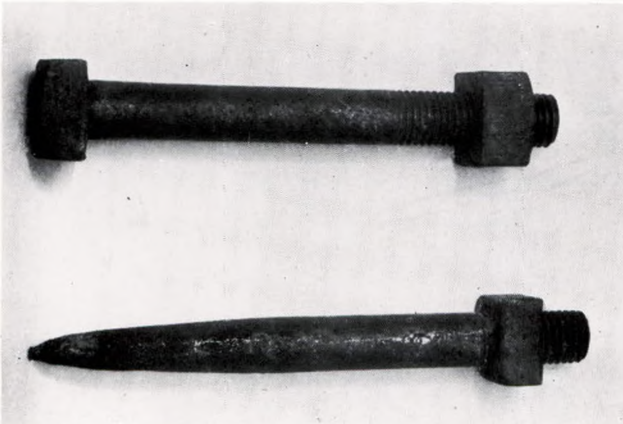


FIG. 7—*Wastage of mild-steel brick bolt*

FIG. 10—*Spalling damage to back wall of header type boiler*

FIG. 9—*Wastage of cast-iron brick key*

FIG. 12—*Spalling damage to bolted blocks: end wall of end-fired Yarrow boiler*

FIG. 11—*Spalling damage to side wall of header type boiler*

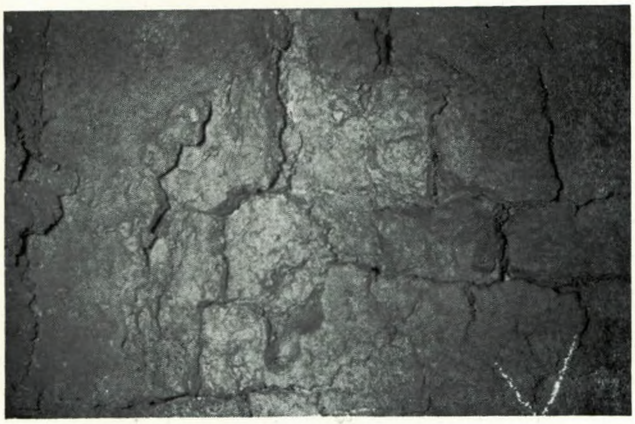


FIG. 13—*Spalling damage to rammed plastic refractory monolithic wall: twin furnace controlled superheat boiler*

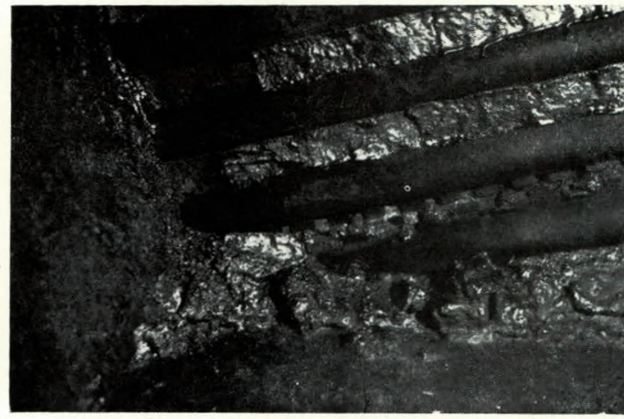


FIG. 14—*Damage to plastic refractory side wall of single-pass header boiler*

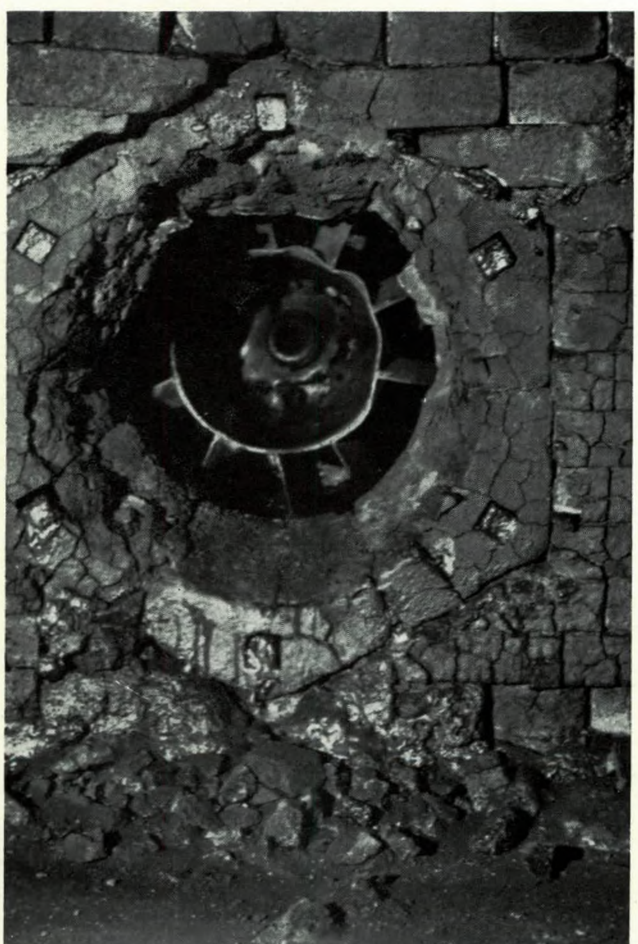


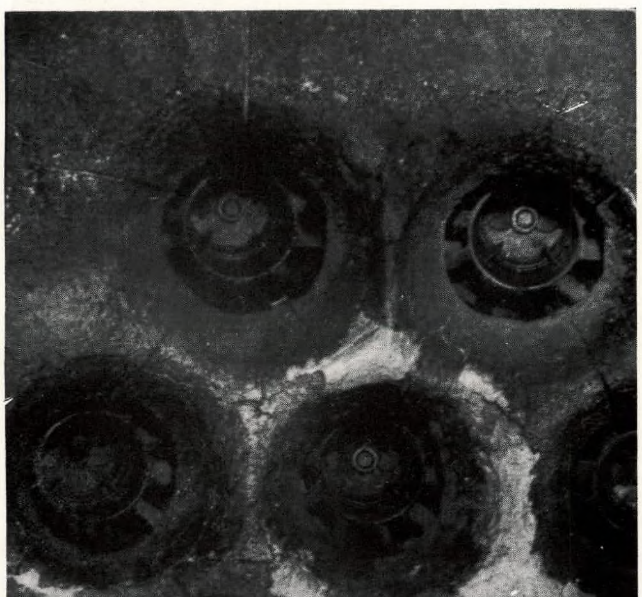
FIG. 15—*Spalling damage to quarl blocks: header type boiler (six months' service)*

FIG. 16—*Cracking of quarl blocks: header type boiler*

FIG. 17 *(left)—Commencement of spalling damage to quarl blocks, D-type boiler (three weeks' service)*

FIG. 19 *(bottom left)—Rammed plastic monolithic front wall: twin furnace controlled superheat boiler (eighteen months' service)*

FIG. 20 *(bottom right)—Burner throat of plastic refractory monolithic construction: header type boiler (twelve months' service)*



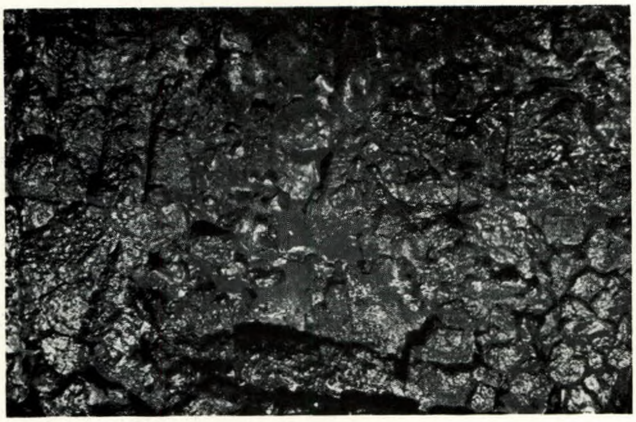


FIG. 21 *(top left)—Spalling and slag erosion damage to plastic refractory monolithic wall: twin furnace controlled superheat boiler*

FIG. 22 *(top right)—Slag erosion at joints of bolted blocks: back wall of Babcock-Johnson boiler*

FIG. 23 *(left)—Slag erosion of bolt hole stopping material: D-type boiler*

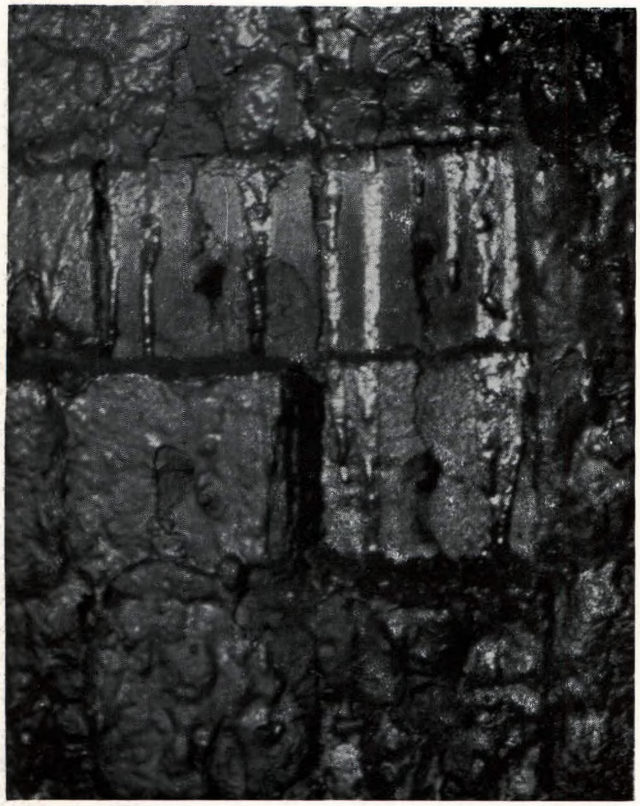
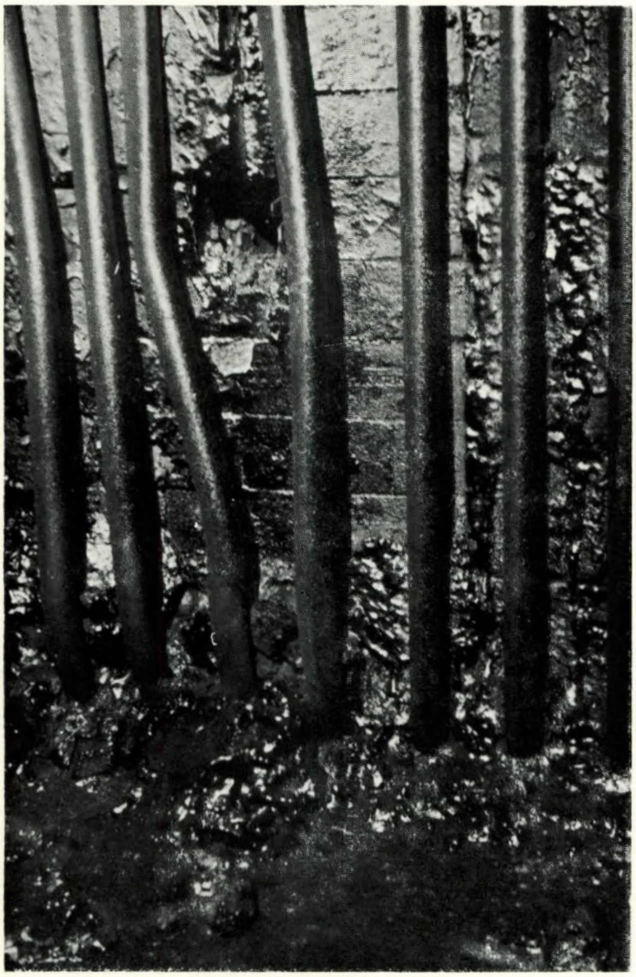


FIG. 24 *(top left)—Damage due to failure of brick bolts: end wall of side-fired Yarrow boiler*

FIG. 25 *(top right)—Cracking of bolted blocks and failure of brick bolts: twin furnace controlled superheat boiler*

FIG. 26 *(left)—Displaced firebrick tiles in back wall of D-type boiler*

Plate 6



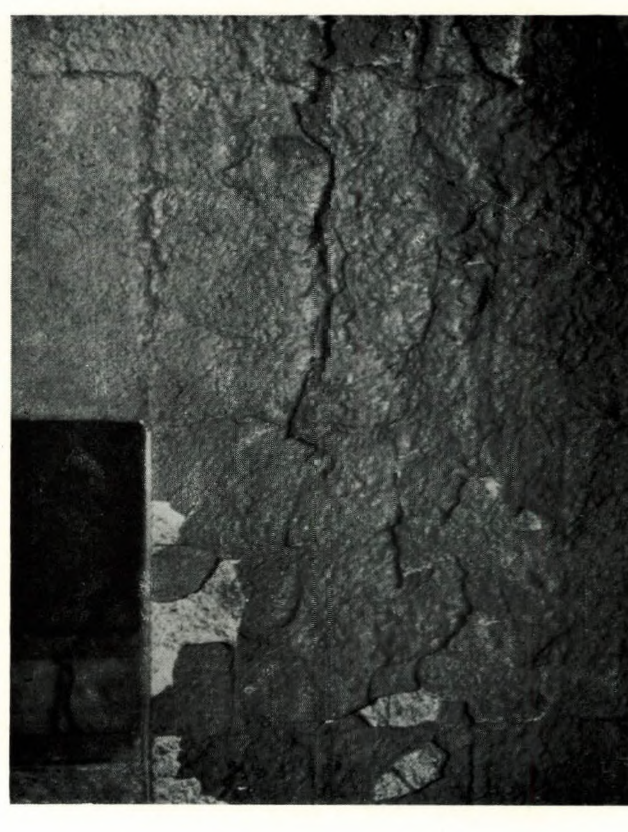


FIG. 27 *(above)—Damage to back wall of superheater-side furnace: twin-furnace controlled superheat boiler*

FIG. 28 *(top right)—Flaking of cement coating from front wall of header type boiler*

FIG. 29 *(bottom right)—Coating of sintered ash: front wall of integral furnace boiler* of failure of combustion-chamber linings in oil fired boilers. Such damage was always found on exposed surfaces that were swept by the flame, even when the lining was comparatively new. The damage frequently found around the burner openings was almost always due to spalling.

The linings of boilers having all-refractory furnaces, such as those shown in Figs. 1 and 3, were found to be particularly susceptible to spalling, the areas most severely affected being the middle third of the end walls and a similar zone across the back wall. No very appreciable mitigation of the damage to end walls was found to result from the practice, sometimes found, of inclining the wing burners towards the centre of the furnace.

In general the spalling damage to back walls of 9-inch header construction brickwork was due to the loss of corners and edges by cracks entering at approximately 45 degrees, giving the walls a "cobblestone" appearance as illustrated in Fig. 10 (Plate 1). This condition is typical of spalling caused by sudden heating and most likely occurs during manœuvring when rapid temperature fluctuations cannot be avoided.

Firebrick refractories are particularly sensitive to rapid temperature changes below 800 deg. C. (1,470 deg. F.) which are most likely to occur in all-refractory furnaces when raising steam or when steaming at reduced power. Unfortunately, it is under just such low temperature conditions that it is most difficult to avoid long flames from the burners and consequent impingement on the lining.

Over the end walls of header boilers there was a much greater tendency for rectangular pieces of brick to be spalled off by cracks entering at 90 degrees. Often the entire ends of bricks, ½ inch or more thick, were detached and the debris at the foot of the walls was largely composed of such pieces. Fig. 11 (Plate 1) illustrates this type of spalling, which is more characteristic of that caused by sudden cooling. In boilers of this type it appears to be the general practice to shut off the wing burners first when manœuvring, the end-wall brickwork therefore being subjected to more frequent temperature fluctuations than if the centre burners were cut out to reduce output. Cooling of these sections may be accelerated by cool air entering the furnace through the registers, which may not be closed simultaneously with the oil supply; even when closed, however, they are not completely air tight.

In those boilers having all-refractory furnaces lined with bolted blocks, the most common cause of failure was by cracking of the blocks parallel to the edges and through the central bolt hole. This type of damage is referred to in greater detail later. For the most part there was little loss of surface from such blocks by spalling although in a few instances one or more of the quarters formed by the cracks had spalled off. An example is illustrated in Fig. 12 (Plate 1) where the face has spalled off to a depth of about 1½ inches leaving the head of the securing bolt exposed.

Spalling damage to the main walls of two-drum and multi-drum boilers, with the exception of those having all-refractory furnaces, was much less severe than that which occurred in three-pass header boilers. This was largely because a considerable proportion of the lining in most boilers of these types was protected by water tubes. It should be noted, however, that little spalling of exposed back walls was seen in furnaces where the distance from the burners to the back wall exceeded about 10 feet. In furnaces of less than 10 feet some spalling of the back wall usually occurred unless closely pitched water-wall tubes were fitted.

Some boilers, particularly those of the twin-furnace controlled superheat type, have low vertical or inclined side walls exposed to the furnace. These were commonly found to suffer extensive damage by spalling caused by direct flame impingement within a few feet of the burner, and in two of the ships visited it was reported that complete penetration of the lining and casing plates had occurred. In this connexion it was noted that in some boilers the clearance between such walls and the centre line of the adjacent burner was less than 2 feet.

In some boilers of this type the original 4½-inch brickwork of the side walls had been replaced by rammed plastic refractory. This was said to give rather better service but it was noted that in three voyages (about six weeks' steaming time) some spalling had occurred and the section affected most severely, where the wastage had extended to a depth of 4 to 5 inches, is illustrated in Fig. 13 (Plate 2).

One or two complete monolithic back walls in header boilers were seen but none had been in service long enough to indicate whether this material showed any advantage over normal brickwork construction in large sections. The condition of walls that had seen about twelve months' service suggested that those of plastic refractory were less liable to spalling than those constructed of firebrick. It was noted, however, that there was a general tendency for fairly wide deep cracks to be formed.

Rammed plastic refractory had also been used to replace the back wall lining of one of the controlled-superheat boilers inspected, where considerable trouble had been experienced with the normal bolted block construction. There was no evidence of spalling after twelve months' service (about six months' steaming time) and the only cracking of any depth had occurred in exposed sections where protection of the tubes was absent.

The plastic chrome refractory used in water walls of stud-tube construction was found to give little trouble on the whole but some replacement had been necessary owing to the difficulty of patching up this material satisfactorily after being in service for any length of time. In one boiler where this material was used the refractory had fallen away in many places; this could be attributed largely to the fact that the rather unorthodox arrangement of the securing lugs practically separated the plastic refractory towards the front of the tubes from that at the back, as shown in Fig. 14 (Plate 2).

Most of the damage to firebrick quarl blocks, which formed the burner openings in about two-thirds of the combustion chambers examined, was due to thermal spalling and varied from a few surface cracks to almost complete disintegration. Fig. 15 (Plate 2) shows a particularly severe example of such damage; this burner throat, in a three-pass header boiler, had only been in service for approximately six months (about 3½ months' steaming time).

Spalling damage to quarl blocks was of three types which were found both singly and in combination. Firstly, the sharp edge between the front face and the curved part was often spalled off. This type of damage varied in extent from one quarl block to the entire circumference but was rather more frequent over the lower half. Fig. 17 (Plate 3) clearly illustrates this type of failure. In this particular boiler several cracks across the corners of the quarl blocks were found and one piece had become dislodged after only three weeks in service. The second effect was general spalling off of the surface of the type shown in Fig. 15 (Plate 2) to a depth of 1 to 1½ inches or more; often half the circumference was damaged in this way. With closely spaced burners the section between adjacent openings was found to be particularly prone to this type of damage. The third type of failure was caused by cracks parallel to the front face extending right through the quarl so as to split it into two parts, as shown in Fig. 16 (Plate 2). Loss of the front part of the block often resulted from this type of cracking. In some cases thermal spalling was augmented by mechanical damage caused by the removal of carbon deposits but it was not always possible to distinguish between damage of this kind and that caused by thermal stresses.

Spalling damage to quarl blocks appears to be caused by direct flame impingement because of an unsymmetrical or too wide a cone of flame or because the burner is located too far back in the throat. In this connexion it is noteworthy that relatively few burners are capable of being adjusted in an axial direction. Flame impingement on the quarl blocks is difficult to avoid completely, however, since for intimate mixing of the air and fuel, to obtain efficient combustion, the flame should fill the burner throat.

Rapid temperature fluctuations in the burner throat are unavoidable during manœuvring so it seems that any improvement in the life of the refractories in the vicinity of the burners can only be effected by improvements in the design of the quarl blocks or the use of materials having a greater resistance to spalling.

In a number of boilers, rammed plastic monoliths had been substituted for orthodox prefired quarl blocks and this type of construction showed promise of a longer life. Some of the improvement is probably due to the somewhat greater spalling resistance of the plastic refractory but a slight modification in the shape of the throat, which was usually noted, would appear to be more significant. This alteration, illustrated in Fig. 18,

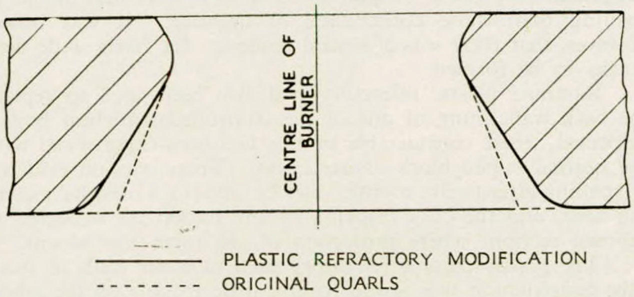


FIG. 18—*Modification to burner throat form for monolithic construction*

consisted of a widening of the angle of the throat and rounding of the inner edge. With this modification the thickness of the section forming the division between adjacent burners is reduced, particularly when the burners are angled towards a focal point. More frequent patching appeared to be necessary at these positions than elsewhere, as will be seen from the view of one of the front walls of a large Foster Wheeler controlled-superheat boiler shown in Fig. 19 (Plate 3). No direct comparison between the performance of the two methods of construction was possible in boilers of this type but the general opinion of the owners was that the monolithic construction gave longer life and reduced the amount of maintenance work necessary.

In another vessel which had four header boilers of the same size, each having six burners in a horizontal row, one front wall had been rebuilt as a monolith. This wall had been in service for one year at the date of inspection. As will be seen from Fig. 20 (Plate 3), damage was relatively slight; there was some disintegration of the surface to a depth of about 1 inch in the lower part of the burner throat in several openings and a few deep cracks had formed in the face of the lining. The condition of this wall should, however, be compared with that shown in Fig. 15 (Plate 2), which was typical of the damage to quarl blocks in another boiler of the same ship after only six months' service.

In linings which embodied re-entrant square corners these positions were found to be particularly liable to spalling damage. Such details of construction are difficult to avoid in some designs, an example being the projecting corner at the inboard side of the saturated furnace back wall in the Foster Wheeler controlled-superheat boiler shown in Fig. 4. This was a common source of trouble. Other examples were seen where projecting corners, which suffered considerable damage through spalling, could have been avoided in the design.

Slagging

In addition to the constituents of fuel-oil ashes that have a deleterious action on refractories, the work of Gray and Killner* has drawn attention to the serious consequences of sea water contamination of the fuel. They concluded that this was the primary cause of slag erosion in naval boilers.

In the boilers examined, however, damage to the refractories that could be directly attributed to slag erosion was negligible. Oil fuel tanks in merchant ships are not often used for ballasting purposes so that the possibility of sodium-chloride contamination is somewhat reduced. Nevertheless, there is little doubt that some sea water is often contained in the fuel but it is evident that this does not lead to serious results in merchant ships, most probably owing to the fact that furnace temperatures, and consequently the reactivity of the slag, are much lower than in naval practice.

It is not suggested that slagging is uncommon in the types of boilers examined. On the contrary, particularly in those having all-refractory furnaces, a coating of slag up to an inch thick was often found towards the bottom of the walls and the layer of glass-like slag over the floors was often several inches thick. In general, the thickness and character of the slag coating varied with the distance from the bottom of the walls. On the upper sections of Yarrow boiler end walls, for example, the coating was thin and glassy but towards the lower part of these sections vertical slag trails became more numerous and there were patches of thicker slag; these can be seen quite clearly in Fig. 24 (Plate 5).

Where there was a comparatively thick layer of slag over the brickwork it was evident that at the operating temperature it was so viscous as to flow down the walls only very slowly. Wherever the slag on the floor was more than a fraction of an inch thick the surface was smooth and level, but no evidence was found to indicate that the slag had ever been fluid enough to flow with the rolling or pitching of the ship. Although the surface layer had obviously been molten it would seem that the temperature gradient through the floor was so steep that the viscosity increased rapidly.

The melting point of a number of samples of slag taken from the floors of several boilers was obtained in the laboratory. In all cases the slag started to soften and flow under its own weight at about 1,100 deg. C. (2,012 deg. F.) but complete melting did not take place until the temperature reached 1,300 to 1,350 deg. C. (2,372 to 2,462 deg. F.).

In one or two instances there was evidence of some erosion by fluid slag where there had been direct flame impingement on the brickwork within three or four feet of the burner. Such an example is shown in Fig. 21 (Plate 4) which illustrates a section of the low side wall in a controlled superheat boiler. There is a possibility that local reducing conditions could exist at points where the lining is swept by the flame and since under reducing conditions, the reactivity of slags containing iron oxide is greatly increased, this may account for such damage.

Even in boilers where the conditions were such that the slag was more fluid, there was little evidence of slag erosion except at the edges of bolted blocks. Slight damage of this nature is illustrated in Fig. 22 (Plate 4) which gives a view of the back wall of a Babcock-Johnson boiler after being in service for about six months (approximately twelve weeks' actual steaming time).

Fig. 23 (Plate 4) is included to show the effect of an unsuitable combination of materials. In this boiler the front wall had been coated with a proprietary sealing compound which had produced a glazed surface. There was, however, a marked tendency for the cement in the bolt holes to be attacked and eroded away, owing to the effect of the fluxing material on an air-setting cement containing sodium silicate. The products of the reaction which ran down from the bolt holes had attacked the firebrick blocks but elsewhere the face of the lining was not damaged, although there was a tendency for the joints to be eroded.

In general, the amount of slag on walls protected by water tubes was relatively slight, as would be expected. Where the spacing of the tubes was such that more than half the wall area was exposed there was often a thicker coating, particularly where the tubes were placed farther away from the lining and where flame impingement had occurred (see Fig. 27 (Plate 6)).

Although, on the whole, the deposition of slag on the linings does not appear to be particularly detrimental to the refractories in a direct way, it may be a contributory factor in

* Gray, C. J., and Killner, W. 1948. "Sea Water Contamination of Boiler Fuel Oil and its Effects". Trans.I.Mar.E., Vol. 60, p. 43.

promoting spalling, which is by far the more serious trouble. This arises from the fact that the surface of the firebrick becomes contaminated with more fusible compounds which increases the degree of vitrification and consequently the susceptibility to spalling. Where there was a thick coating of slag of relatively high viscosity at the working temperature, the depth of penetration of the slag did not appear normally to exceed about ½ inch. On the other hand where the slag had been fluid, as in the cavity shown in Fig. 21 (Plate 4) there was a layer of vitrified refractory 1½ to 2 inches thick below the surface.

It is difficult to say at the moment whether this secondary result of slag deposition is of any great significance but it is a possibility that has to be borne in mind. Further work which is in progress may throw further light on the matter.

Failure of Securing Devices

By far the most common trouble in boilers having linings made up of bolted blocks or tiles, apart from spalling of the quarl blocks, is failure of the securing arrangements, either by burning away of the bolt heads or by displacement or fracture of the tiles caused by vibration.

Owing to the presence of the central bolt hole there is a tendency for cracks to form across such blocks; these were usually found to run parallel with the sides of the tiles and often divided the block into four quarters, as will be seen from Fig. 12 (Plate 1). Very often up to 25 per cent of the tiles in the lower parts of combustion chambers were found to be cracked after little more than a year in service, in both all-refractory furnaces and those which had widely spaced tubes over the walls.

Such cracks allow penetration of the hot gases and so lead to rapid deterioration of the securing bolts; in some of the boilers examined, partial collapse of the lining had resulted before any serious loss of thickness by spalling had occurred. An example is shown in Fig. 24 (Plate 5), which gives a close-up view of part of a lining made up of two layers of 4-inch thick blocks secured by Wildish bolts anchored in the inner blocks. As will be seen from Fig. 24 (Plate 5) a number of blocks from the top two courses of the inner layer had fallen away, leaving about 1 inch of the bolt, tapering to a point, protruding from the remaining blocks. Other blocks could be pulled away leaving similar burned off bolts; such blocks fell into four parts, revealing the remains of the bolt heads.

When through bolts were used to secure the firebrick tiles the bolt hole stopping was usually found to be intact in the upper or cooler sections of the furnace. In a number of instances, however, the cement used to plug the bolt holes in those sections subjected to the most severe working conditions was loose or had fallen out. When the tiles were cracked it was found that burning of the bolt heads was liable to occur even when the stopping material was intact. In the furnace lining shown in Fig. 25 (Plate 5), for example, the bolt hole stopping, although rather loose, had not been lost from most of the tiles but several of the bolt heads were burnt away.

Damage was usually found to be more severe in the superheater-side furnaces of controlled superheat boilers of the type shown in Fig. 4. In the back walls this was usually due to failure of the securing bolts and, as mentioned previously, in one of the boilers inspected the bolted block construction had been replaced by rammed plastic refractory. A section of the back wall of such a boiler is shown in Fig. 27 (Plate 6). Several cracked tiles had fallen forward and rested on the tubes and one of these can be seen in the top left hand corner of the photograph. The adjoining section had been replaced by bricks on an earlier occasion.

Quarl blocks are usually secured by through bolts and in some boilers the plastic refractory in the bolt holes was found to have contracted and to be loose, or even missing altogether. In such cases the bolt heads had burnt away but this was not found to be a cause of failure as the blocks were held in place by the surrounding brickwork.

In the D-type boilers of one ship, overheating of the casing had been experienced and some damage to the lining was suspected. The tubes over the section of the wall affected were so closely pitched as to prevent the lining being seen from inside the combustion chamber but on removal of the casing and magnesia-asbestos insulation it was found that practically all the tiles had been displaced to some extent, as shown in Fig. 26 (Plate 5). Although only one or two boilers were seen where the blocks forming the lining had become displaced by the effect of vibration in this way, it is understood to be not uncommon.

It was also reported in several cases that the firebrick around the bolt holes had fractured, owing to the same cause, allowing the tiles to fall forward, or in the case of roof tiles downward, on to the tubes. Such damage can only result from loosening of the securing bolts due to disintegration or contraction of the insulating material between the firebrick tiles and the casing.

Although not a serious source of trouble, the replacement of isolated tiles behind water tubes involves a considerable amount of work. The use of insulating materials which can be easily compressed should, therefore, be avoided when the bolts pass through the insulation.

No direct evidence of the failure of other securing devices was seen but it was reported that trouble had been experienced with fasteners used for 4½-inch walls of standard firebrick.

Because of the irregular surface and wastage due to spalling of most of the exposed walls of 9-inch header construction that had been in service for a considerable time, it was difficult to detect signs of bulging or movement away from the casing. While instances of complete or partial failure of walls were reported, no details could be obtained and it appears that the securing of such walls is, on the whole, reasonably satisfactory. The success of such devices as the I section keys, hook bolts and T bars illustrated in Fig. 8 depends, of course, on the specially shaped bricks. At the present time these are difficult to obtain and one or two instances were seen where the front walls of header boilers had bowed forward several inches away from the casing owing to the lack of special bricks or poor workmanship rendering the securing devices useless.

Cast-iron I section keys used to secure 9-inch walls in the highest temperature parts of header boilers were found to have suffered damage as shown in Fig. 9 (Plate 1), after being in service for three to four years. It is possible that the heat resisting alloy hook bolts now commonly used in place of cast-iron keys may give better service.

Shrinkage

As mentioned briefly in the introduction, shrinkage of refractory materials is liable to occur in service with consequent cracking or opening of joints. Such contraction was found to be fairly common in floors and walls made up of standard brick. Whether all such damage could be attributed to shrinkage of the firebrick is doubtful; long open cracks were more probably caused by restriction on the contraction of the wall during cooling.

Open cracks were found in the walls of about half the header boilers examined but they did not appear to have any serious consequences. These cracks usually ran zig-zag through the joints extending farthest in a vertical direction and often being continuous from the top to the bottom of the wall. More than two cracks longer than a few feet were rarely found in any one wall, although signs of previous cracks which were filled with slag could often be detected.

Cracks in the floors were a feature of those furnaces which were relatively free from slag but, in general, trouble experienced by way of failure of the floor refractories was negligible. A few cases of lifting of the floor blocks were reported but this could usually be attributed to poor workmanship and an insufficient expansion allowance.

Contraction of rammed plastic monolithic walls was more serious and cracking caused by shrinkage was the most common type of damage to such walls. It was often found that such cracks formed close by the surface cuts made when installing the lining and it seems that these are not particularly effective in controlling cracking. It is not known, however, to what extent such shrinkage cracks lead to more serious damage as none of the walls examined had seen more than about a year's service.

This tendency for cracks to develop in plastic refractory materials is difficult to avoid. In order to obtain an adequate degree of workability the bond clay which is necessary to bind together the prefired base material requires high plasticity. Unfortunately such a requirement in a clay usually also implies high drying shrinkage and, therefore, the greatest care in drying out and as slow a rate of heating as possible are necessary to obtain the best results.

Flaking

All the major causes of wastage encountered are covered by the preceding sections but a further type of damage due to blistering and flaking of the surface of the brickwork was seen occasionally. Although of a minor character this is largely avoidable. It was noted that it is a fairly common practice to wash over the surface of the walls with a coating of air-setting cement, sometimes as a routine, but more usually after making repairs to the lining. It appears that such coating materials are largely responsible for flaking owing to a difference in thermal expansion between the coating and the firebrick. The cement often adheres to the brickwork, however, and when such flaking occurs the surface of the lining is also removed, leaving a fresh surface exposed, as shown in Fig. 28 (Plate 6).

When applied to cracked and slagged surfaces coating materials can serve no useful purpose and when used on new brickwork the material should be chosen so that its thermal expansion is closely matched with that of the refractory lining. When the major cause of damage is thermal spalling, as is usually the case, coating materials are ineffective and those that cause vitrification of the brick surface probably increase the tendency for spalling to occur.

LIFE OF FURNACE LININGS

Comparison between Different Types of Construction

The life of a wall, or section of a wall, expressed as the time from the date of installation to the time when complete renewal is made may not give a reliable indication of the service performance, since the amount of patching and partial replacement may vary quite widely from one boiler to another. It was found that the allowable wastage before replacement was considered necessary, also varied considerably, depending on the service of the vessel. Information relating to the useful life of brickwork supplied by the shore maintenance staff and the ship's engineers often indicated comparable performance in similar types of boilers, however, and although such figures may be subject to some considerable variation depending on the design details and service conditions, they give some guide to the prevalence of damage and the sections mostly affected.

Burner quarl blocks were the items requiring by far the most frequent replacement. Only in one or two cases was the average life stated to exceed eighteen months and in the majority of boilers damage to the blocks was too great to patch-up after only eight to eighteen months' service. Isolated examples were reported where replacement was necessary after three to six months' service but such short life could usually be attributed to rough treatment in removing accumulated carbon deposits or faulty setting of the burners.

The tendency to discontinue the use of quarl blocks and to substitute a rammed plastic monolith was to some extent due to the difficulty of obtaining replacement blocks but in some cases this type of construction was adopted because of the rapid wastage of prefired refractory blocks. None of the monolithic front walls seen had been fitted more than eighteen months previously but, for the most part, the general condition was good and a reasonable service life seemed probable. The one that had been in service the longest time is illustrated in Fig. 19 (Plate 3); some patching had been found necessary but it was said that the performance of the monolithic construction compared very favourably with that of the bolted block construction originally fitted (as shown in Fig. 4), the life of the quarl blocks often being only about three months.

Plain exposed walls of 9-inch header construction were, in most cases, found to have a life of two to four years but, as pointed out above, it should be borne in mind that very often not all of the wall would have been in service for the whole time. The back walls of both Yarrow side-fired boilers and header type boilers were said to last longer than the end walls and usually required complete renewal after three to four years, by which time the thickness had been reduced by 3 to 4 inches. The end walls sometimes lasted as long as the back, but on the other hand, replacement was sometimes necessary after about two years. It was frequently stated that rapid wastage occurred in the first few months of service but there was a tendency for the rate of spalling damage to be retarded thereafter.

Of the few plain walls of rammed plastic monolithic construction seen, none had been in service long enough to obtain an estimate of its probable life.

Exposed walls of bolted block construction, except in positions where operating temperatures were evidently comparatively low, did not give such good service as walls built up of standard firebricks. In combustion chambers having a large area of water cooled surface, however, exposed walls usually gave better service than those in all-refractory furnaces. For example, the back wall of the Babcock-Johnson boiler in Ship S* which was constructed of 4-inch thick bolted blocks, was stated to have a life of nearly four years. It should be noted, however, that the distance between the back and front walls of this furnace was rather greater than usual.

Damage to the front walls of boilers of various types having water cooled furnace walls was usually confined to the sections adjacent to the burner openings. At such positions bolted blocks were commonly renewed after twelve to eighteen months' service, particularly in the superheater side furnaces of twin-furnace boilers.

Most of the boilers having walls of bolted tile construction screened by water tubes had been in service for only two or three years when examined. The refractories protected by closely pitched water tubes were found to suffer little damage but, where the tube spacing was increased to 5 or 6 inches partial renewal of the bolted tiles was sometimes necessary after little more than a year in service. These more troublesome zones represented only a small proportion of the total lining area, however, and the life of refractories fitted behind water tubes, as a whole, probably exceeds that of the brickwork in all-refractory furnaces.

In nearly all the boilers examined, the section of the lining requiring the least frequent replacement was the floor. One or two cases were reported where lifting of the floor had necessitated renewal but, for the most part, floor blocks were only replaced when damaged during removal of the slag coating, which often builds up to an excessive thickness after a few years in service.

Influence of Boiler Design and Operating Conditions

Apart from the actual dimensions of the combustion chamber and details of the lining construction, the main variable influencing the performance of the refractory lining affected by the furnace design is the furnace temperature. For any given percentage of excess air and a fixed combustion air temperature, the theoretical flame temperature remains constant for an oil fuel of given calorific value, but the temperature of the furnace gases may vary considerably from one design of boiler to another or in the same boiler at different rates of firing. Thus, the furnace rating, in terms of the heat released or the fuel burnt per cubic foot of furnace volume per hour, is, in itself, no indication of the severity of the operating conditions; boilers having identical furnace ratings but widely different proportions of heat absorbing surface exposed to the flames could have furnace temperatures differing by several hundred degrees. For similar types of boilers, however, the furnace ratings may form some basis for comparison.

* Particulars of the boilers examined are given in Table I, page 16.

Another design criterion, normally used as an indication of the heat loading of the furnace tubes, which gives a guide to the furnace temperature and hence the probable performance of the refractories, is the forcing rate. This is usually expressed in terms of the fuel burnt or heat released in the furnace per hour per square foot of projected radiant heating surface. In effect, the forcing rate can be considered as the furnace rating modified to take account of the ratio of radiant heating surface to furnace volume. Furnace ratings and forcing rates, together with other relevant data, are given for the boilers of the nineteen ships included in the survey in Table I.

The liability for spalling damage to occur largely depends on the frequency and rate of temperature fluctuations in the furnace. It would, therefore, be expected that the proportion of the steaming time occupied in manœuvring and the frequency with which the boilers are shut down would largely influence the extent of spalling of the brickwork. Accordingly, details of operation of the boilers are also given, as far as possible, in Table I. In many cases, however, it was not possible to obtain an estimate of the proportion of the time the boilers were operated under varying load conditions and, in larger ships, having a number of boilers, accurate figures were more difficult to obtain owing to the fact that one or two boilers were often shut down for part of the voyage.

The figures relating to boiler operation in Table I provide some useful information, however. Excluding the two cross-Channel vessels (A and N) and the tanker (Ship T), it will be seen that, with one exception, all the boilers examined were shut down between fourteen and twenty-four times per annum, with an average of nineteen. Little variation was found in the time normally taken to raise steam from a cold boiler; in nearly all cases this was accomplished in four to six hours although this time could if necessary be reduced appreciably in boilers having large water-wall areas. Rapid cooling after shutting down was always avoided as far as possible by closing all the air registers.

Since in all the ships of the passenger and cargo liner types only a small proportion of the steaming time was spent under manœuvring conditions, and the number of times the boilers were shut down did not vary greatly, differences in the extent of spalling damage cannot be attributed to the service of the vessel. The examples of severe local spalling encountered in some boilers were undoubtedly due to flame impingement on the brickwork or rapid cooling caused by the ingress of cold air. Only in one ship was it almost certain that fluctuating load conditions contributed to the breakdown of the refractories. This was in Ship A, a cross-Channel vessel fitted with four small end-fired Yarrow boilers, which made four trips every twenty-four hours, each involving a period of standing-by manœuvring at the terminal ports and about 2½ hours at full power. The frequent and rapid temperature fluctuations resulted in such severe damage that almost complete renewal of the lining was necessary after about seven months' continuous service. It should be noted, however, that the arduous operating conditions was not the only factor involved; the boilers had been originally designed to burn coal and the furnace dimensions were such as to make the avoidance of flame impingement almost impossible when burning oil.

In another cross-Channel vessel (Ship N) the boilers were shut down after every trip. The boilers were of the Foster Wheeler D type and, although spalling of the quarl blocks may have been rather more severe than in other boilers of this type which were examined, it is evident that linings which are largely protected by water tubes are not greatly affected by fluctuating load conditions.

The time spent under normal steaming conditions, excluding those ships mentioned above, varied from 40 to 67 per cent of the total time in service except for Ship R, in which only two out of three boilers were normally in operation. A greater variation was found in the total steaming time, however, mainly due to the fact that in some vessels it was necessary to keep steam on one boiler when in port; others had Diesel generators or an auxiliary boiler. The average time the boilers were shut down was 40 per cent of the total service time so that in most cases the actual operational life of the refractories would be of the order of 60 per cent of the times mentioned in the previous section.

It is evident that from the available data it is not possible to reach any definite conclusion on the influence of variations in boiler operation on the life of refractories; to do so would necessitate a close check being kept on a number of boilers of a similar size and type but engaged on widely differing services. There was a tendency, however, for damage to quarl blocks to be rather greater in the case of those burners used mostly for accommodating changes in output when manœuvring.

Again referring to the data given in Table I, it appears that there is some correlation between the forcing rate and wastage of the refractories. This is particularly noticeable in boilers of the Foster Wheeler controlled superheat type. It will be noted that in all the boilers of this type examined (Ships O. P and Q), the forcing rate in the superheater furnace greatly exceeded that in the saturated side furnace and the rate and extent of damage to the refractories could be said to occur in roughly the same proportions.

Comparison between different types of boilers on this basis is difficult owing to the widely different proportions of the furnaces and the varied construction of the linings. It appears, however, that the forcing rate may be taken as a general indication of the severity of the operating conditions affecting the performance of the refractories.

From Table I it will be seen that forcing rates under actual service conditions varied between 2·9 and 18·7 for the combustion chambers of all the boilers examined. In those in which this value was below about 8, with one exception (Ship P), it was evident that the furnace temperatures attained were not high enough to cause liquid slag formation. The superheater furnaces of the boilers in Ship P were exceptional insofar as severe slagging had occurred and burning of the brick bolts had caused partial collapse of the back wall. This could almost certainly be attributed to direct flame impingement, however.

The influence of the forcing rate on slag formation is clearly brought out when the three-pass header boilers of Ship F are compared with those of the same type in Ships D and E. The boilers of the latter vessels had forcing rates of 16·7 and 18·2 while the boilers of Ship F had a low forcing rate of 7·7; in the higher rated boilers a thick slag coating had formed which was viscous at the working temperature while the Liberty ship boilers showed very little sign of slag formation. Another example is Ship T where the forcing rate was only 5·9; in the boilers of this ship there was a coating of sintered ash, as shown in Fig. 29 (Plate 6). It was evident that the furnace temperature was high enough for the particles of ash to become tacky but not sufficiently high for liquid slag to form.

It would therefore appear that below a certain furnace temperature, which seems to correspond to a forcing rate of about 5, the ash particles do not adhere to the surface of the lining and pass out with the funnel gases. Above this temperature a coating of sintered ash is formed and at still higher temperatures, which occur for forcing rates above about 8, a viscous, glassy coating forms on exposed walls which slowly moves down the wall, finally forming a thick layer over the floor. From experiments carried out in the laboratory it is probable that the coating changes from one of static sintered ash to a slowly flowing viscous slag over the temperature range of 1,000 deg. C. to 1,200 deg. C. (1,832 deg. F. to 2,192 deg. F.). At higher temperatures the slag is increasingly active.

As mentioned earlier, other variables that influence the furnace temperature are the quantity and temperature of the combustion air. Rather more than half the boilers examined were fitted with air heaters. For those of the tubular type combustion air temperatures varied between 200 and 360 deg. F.; where regenerative type air heaters were used, air temperatures of 330 deg. F. and over were reported and in the single installation where a bled-steam air heater was used (Ship T) the air temperature at the registers was said to be 280 deg. F.

According to Kessler* the use of heated combustion air increases the furnace temperature by an amount equal to about one-third of the air temperature rise in the heater. It follows that even for an increase in air temperature of 350 F. deg. (195 C. deg.) the furnace temperature would only be increased by about 65 C. deg. (117 F. deg.). It is probable that furnace temperature differences of this order can be caused by a variation in the quantity of excess air supplied to the furnace, other factors remaining constant, and it therefore appears that the combustion air temperature is not of great significance in the performance of the refractories.

SUGGESTIONS FOR INCREASING THE LIFE OF COMBUSTION CHAMBER LININGS

The means of improving the performance of refractories in marine boilers may be considered from three aspects: design, installation and operation. Each of these is considered in turn.

Design

There appears to be scope for some improvement in the detailed design of the lining and the design of the combustion chamber from the point of view of refractory performance in most types of boilers.

Consideration of the factors governing the size and volume of the furnace and proportion of the wall area covered by water tubes is outside the scope of this paper but it seems that some comments on these points are relevant since they can have considerable influence on the life of the lining. Design details of the lining may have equal or even greater importance since failure of a small section of the lining may render a boiler unserviceable.

The main points under this heading may be summarized as follows:—

1. The distance from the centre lines of burners to adjacent refractory walls should certainly not be less than 2 feet and if possible this dimension should be at least 2ft. 6in. The depth of the combustion chamber, i.e. from the inside of the wall containing the burners to the opposite wall, should not be less than 8 feet and should preferably be 10 feet or more, unless closely pitched water tubes are fitted.
2. Much can be done to reduce the effects of rapid local heating of sections of the lining by the use of burners that are capable of maintaining efficient combustion conditions with a relatively short flame. Such burners are available but large numbers of boilers are equipped with burners that fall far short of the ideal.
3. Where bare-tube water walls are adopted and the tubes over part of the wall are more widely spaced, the thickness of the refractory should be correspondingly increased over such sections.
4. The use of bolted blocks in high temperature zones of the furnace is not recommended and, wherever possible, an alternative form of construction should be employed. In tiles fitted behind closely pitched water tubes, securing bolts are not necessary and their elimination would lead to considerable simplification.
5. Exposed walls made up of standard firebrick should be of header construction; stretcher walls, 4½-inches thick, are difficult to secure satisfactorily.
6. Projecting corners and any other irregular features should be dispensed with wherever possible. Where this cannot be done, the use of plastic refractories, by which a smooth outline can be obtained, is recommended.
7. Where the construction necessitates the use of special shapes or the cutting of standard blocks, plastic refractories should be substituted.
8. The use of a rammed plastic monolithic section to contain the burner openings shows the greatest promise of increasing the life of this part of the lining.
9. The aluminous firebricks in general use have adequate heat resistance for existing conditions when new, but contamination by slag may result in a lowering of their properties. To counter such action the use of special materials in certain situations might be considered but it is doubtful whether such refractories would justify their high initial cost.

Installation

When installing a new lining or during subsequent maintenance a high standard of workmanship and great care are necessary to obtain the maximum service life from the material. Details that require attention include the following:—

10. The composition and properties of all materials such as jointing cement and bolt hole stopping must be suitable for the purpose for which they are used. Air-setting cements containing a high percentage of sodium-silicate should be avoided.

    A detailed specification of all materials used in the construction of the lining should be supplied by the boiler designers and adhered to by contractors and maintenance staffs.
11. Joints between bricks should be as thin as possible and the practice of using only a wash of fireclay when laying the bricks is to be recommended.
12. Care should be taken to avoid breaking off the corners and edges of bricks or blocks as far as possible, as such damage increases the liability for spalling to occur.
13. When installing rammed plastic refractory materials, the greatest care is necessary to ensure that the material is properly consolidated and that the manufacturer's instructions are closely adhered to in regard to venting and firing.
14. Sections of the lining requiring repair should be properly prepared for patching. Care is necessary in fixing the extent of repair work since, if the adjacent lining is disturbed, patching may defeat its own end.
15. Cement washes applied to walls that have been in service serve no useful purpose. Unless carefully matched to suit the properties of the firebrick the application of coating materials may do more harm than good.

Operation

Since the major cause of the deterioration of oil-fired boiler furnace refractories is thermal spalling, any means of minimizing the severity of the operating conditions is likely to result in considerably increased life of the refractories. Possible ways of improving conditions include the following:—

16. Careful maintenance of burner tips and air directors to prevent the formation of an unsymmetrical flame is essential since direct flame impingement on the lining almost invariably has disastrous results.
17. The size of burner tips and the fuel temperature and pressure should be chosen to give the most efficient atomization and so promote rapid combustion and a shorter flame.

    It should be stressed that it is desirable for the fuel oil to be supplied to the burners at the highest possible pressure.
18. The axial position of burners and the setting of air directors should be adjusted, where this is possible, to avoid flame impingement on the burner brick tubes and refractory surfaces.
19. The routine for operation of the burners when manœuvring should be chosen so as to reduce temperature fluctuations in the brickwork as much as possible. Particular care should be taken during steam raising and when steaming at manœuvring speeds to reduce the rapidity of temperature changes in the brickwork.

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* Kessler, G. W. 1948. "Design of Marine Boilers", Trans.Soc. Nav.Arch., N.Y., Vol. 56, p. 184.

20. All attempts should be made to reduce the flow of cool air into the furnace through the burner brick tubes or any other openings.

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Discussion

MR. W. KILLNER, in opening the discussion, said the authors had covered a wide and troublesome field and given to the maker and user of refractories much very useful information.

The whole of the shipping world would readily agree that the problem of the deterioration of furnace refractories was a serious one, their repair entailing high maintenance costs in the case of all ships. Quite apart, however, from the high maintenance costs which resulted from such deterioration, there was the question of availability of the ships and the time necessary to effect repairs which were vital factors in wartime both for warships and merchant ships.

In merchant shipping, spalling appeared to be the main trouble, and where the securing device consisted of some form of bolt that was responsible for a considerable amount of spalling. The central bolt hole in a brick appeared to be the centre from which cracks radiated, and examples of those cracks were found even during the drying of the green bricks. There was no doubt that bolt holes in a brick were themselves a cause of weakness, and that was accentuated by bolts which were ill-fitting or too tightly screwed up. In his opinion, that form of cracking and the spalling which resulted could be eliminated by using a rectangular brick without bolt holes, similar to those enumerated in B.S.I. 1758:1951. Such bricks could be machine made and it might be that pressure moulding would produce a homogeneous brick which might be more resistant to thermal shock. The use of those bricks, if held by hook bolts, would avoid the danger of iron slagging due to anchor bolts becoming exposed.

The merchant service was fortunate in not having to contend with serious slagging. It was true that fuel oil might contain sodium compounds in small amounts, probably derived from a little sea water. It had been stated that good atomization produced an oil droplet of about 0·004 of an inch diameter. Allowing for a sea water content of the order of 1·0 per cent in the oil, the ash content might be about 0·07 per cent and the molten ash particles remaining after burning would be of the order of 0·000002 inch in diameter. It was probable that those would be airborne; they would not be thrown out of the air stream but would pass out of the funnel. Slagging, therefore, would be minimized when such small particles were present.

Where, however, owing to ballasting or displacement of fuel oil by sea water, the sea water contamination was heavier, slagging then became the primary factor in the deterioration of the furnace refractories. He had seen as much as 4½ inches thickness of slag on the floor of a boiler which had run down from the walls.

Where a firebrick had an open texture and slag was molten, penetration occurred, setting up differences in the coefficient of expansion through the brick, which promoted thermal spalling.

Spalling damage to quarls was a very serious trouble, and the authors had referred to three types. Where there was carbon build-up or oil dripped on to a quarl there was a likelihood of carbon monoxide penetration and a subsequent build-up of carbon in the texture of the refractory which caused disruption of the quarl. It would be interesting to know whether alteration of the shape of the burner throat, referred to by the authors, proved to be a success.

Whilst the authors had referred to shrinkage they appeared to have omitted expansion, which in some cases had given trouble, distorting walls and exerting sufficient pressure to cause cracking.

Mention had been made of the tendency to make the operating conditions more arduous, but he was not clear as to what was meant. There was sufficient margin between the working temperature of firebricks and the present furnace temperature to withstand an increase in the furnace temperatures. It was agreed that reduction in the size and weight of a boiler was desirable and that might necessitate shortening the flame. Control of the flame size and shape to avoid impingement was very necessary, and while that might be achieved under what might be called standard conditions, i.e. using the same equipment and the same fuel oil, it might be that a change in the type of fuel oil might cause what had been a "tailor made" flame to show considerable alterations in size and/or shape. That emphasized the suggestions of the authors regarding the importance of maintaining efficient combustion.

Reference had been made to plastic ramming mixtures. Those materials were very useful for emergency repairs or to apply where a whole brick could not be used, but he shared with the authors a little doubt about using such materials to replace the firebrick. The firing temperatures to which firebricks were submitted during manufacture caused changes which produced a ceramic bond and gave strength and cohesion throughout the fired body. The "green strength" of a plastic ramming mixture was not high, and it was in some cases lowered by a low firing temperature. In the furnace the hot face of a plastic ramming mixture might reach a sufficiently high temperature to develop a ceramic bond and the cold face might still retain its "green bond", but somewhere between there might be a weak area. Those conditions made the satisfactory anchoring of plastic ramming material somewhat troublesome. The temperature in the zone which had a ceramic bond was too high for a metal anchor, and the middle and cooler zone was too weak to be of much use. While a plastic ramming mixture might give good wear under certain conditions, where there was vibration or shock due to gun fire the securing might be found to be inadequate.

The suggestions which the authors had given for increasing the life of combustion chamber linings would no doubt prove to be most useful to shipping in general. There was, however, the problem which faced those who were called upon to assess the suitability of furnace refractories for service use. It was a simple matter to draw up a specification and lay down methods of test to be carried out in a laboratory, but unless material which passed the specification proved to give satisfactory service under operating conditions the specification was of little use.

There were features which caused the breakdown of furnace refractories which were diametrically opposed, such as spalling and slag attack. If the sources of trouble could be reduced, some decided headway could be made. Co-operation between manufacturer and users was essential. It might be that some changes in manufacture which affected texture, and so on, might be found desirable, but until the users of refractories got together with their problems and decided what they required to meet service conditions, progress in that direction would not be made. The present tendency might be towards tests which simulated service conditions, but those tests were long and tedious; from them, and the actual behaviour of furnace refractories in service, it might be possible to gain sufficient knowledge and experience to enable the laboratory to give more help to the shipping industry on their refractory problems.

Mr. W. R. Harvey (Member of Council) said the paper set forth in considerable detail the various troubles which had occurred in the furnaces of marine boilers over a considerable period of years but he was a little disappointed that the research had not been carried a step further, to the manufacture and the possible improvement which could be made in the bricks themselves so that they would stand up better to the hard treatment and high ratings which obtained in modern marine boilers. Whilst the details of the possible causes of failure were of great interest to marine engineers as a whole, the people concerned with the maintenance of marine boiler furnaces, the boiler designers, engineers and repair firms were already acquainted with the extent of the failures and despite considerable improvements in furnace design, severe spalling still obtained to an alarming degree and it was no longer satisfactory for a designer to specify a percentage of alumina in a firebrick as that alone would not ensure that a really first-class brick would be supplied.

In his experience, bricks with practically the same analysis could vary to an appalling degree, from a brick which was practically useless at any furnace rating to one which would stand up to severe conditions, and in his view sufficient stress had not been laid on the troubles caused by poor quality bricks, although he agreed that probably in all cases the manufacturers could insist that the percentage of alumina was correct. The time had come when more and more attention would have to be paid to that matter, even if it did mean that the end product would be more expensive, because with labour charges so high at the present time a slightly more expensive article would more than pay its way if maintenance could thereby be reduced by about half.

Research into that side of furnace troubles would be of great use to the Institute. If, for instance, investigation could have been made into the moulding and firing of each particular brand of brick in the furnaces examined, it might have been possible to obtain valuable information as to the most suitable product.

With regard to the question of slag attack, it was certainly the case that a dense and close texture resisted slag attack, and although a brick of that type tended to crack in its length, that was to be preferred as such cracks did not as a rule mean greater maintenance. On the other hand he could not agree with the authors that a fairly high porosity gave maximum spalling resistance, rather that if penetration could be avoided spalling would be prevented.

Undoubtedly the authors were correct in recommending that bricks be laid in header courses giving a thickness of 9 inches, but it would be appreciated that circumstances did not always permit of the designer arranging bricks in that way and that at times stretcher courses must be used. However, with a well-constructed furnace wall of very best quality bricks, and keys made of heat-resisting steel, an entirely satisfactory wall could be constructed. In his view the day of bricks secured by a bolt which passed right through the brick and covered by a plug of fireclay was over, and that method would not stand up to present conditions. There were various satisfactory ways of keying bricks without using that method and his own preference was for the construction indicated in item (b) of Fig. 8 of the paper. It was, however, important, particularly in high temperature zones, that the keys should be made of heat-resisting steel, and a possible cause of the trouble in many of the cases examined by the authors where the holding bolts had failed was that they had been supplied in treated mild steel, which was not sufficient.

Thermal spalling was certainly one of the major causes of deterioration, but as the manœuvring of a ship was in the hands of the captain and the engineers had to follow his telegraphed instructions, there was little that could be done in practice to reduce the wide variations in temperature in the furnace during manœuvring, and the real answer was for the brick makers to find a brick which would stand up to those conditions.

The authors had stated that spalling damage to the main walls of two-drum and multi-drum boilers, with the exception of those having all-refractory furnaces, was much less severe than that which occurred in three-pass header boilers, but that statement was misleading because the latter had all-refractory furnaces and were, therefore, on a par with the two-drum and multi-drum boilers with all-refractory furnaces. It was, of course, possible to build three-pass header boilers with a completely water-cooled furnace, but the authors would appreciate that many circumstances had to be taken into account when designing boilers for various ships, and from the point of view of price consideration, or possibly the type of machinery fitted, it was not always desirable to fit water-cooled furnaces.

There was no reason why a monolithic wall should not stand up to furnace conditions as well as a brick wall, but it was difficult to make comparisons unless full details were known of the respective qualities of the plastic refractory and the firebrick. Also the monolithic wall depended even more than the brick wall on the ability of the bricklayer; built by an expert a monolithic wall could be very good, but built by a novice it could be disastrous.

That raised the general question of the skill used in building furnaces, and while agreeing with all the authors had said on that subject, he wished to add that in his own experience there were far too many instances of carefully thought-out instructions being completely ignored when building the furnaces. The authors were absolutely correct when they stated that too much attention could not be paid to oil-burning, but there again the designer was in the hands of the operator, and the time had passed in modern boiler design when oil-burning systems could be installed and left to take care of themselves. Automatic control had gone a long way towards maintaining good combustion but it did not relieve the operator of such duties as adjusting burners to suit the fuel and keeping a constant watch for dirty or worn burners, and it was most important that, if the throats were to be made from plastic, great care should be exercised in maintaining the correct shape required by the makers of the oil-burning equipment.

The authors had shown a slide of a monolithic front wall and had stated that conditions had been improved because the burner openings had been made larger. That was quite possibly true, but it was also possible that combustion had been adversely affected because good burning depended not only on pressure and tip design but also on turbulence, and alterations to the quarl shape would definitely affect the burning.

With regard to sealing compounds, the most usual cause of trouble was that the compound was applied much too thickly, presumably on the basis that one could not have too much of a good thing, but that was a fallacy and such compounds should never be applied at a greater thickness than the thinnest practicable wash.

He had no hesitation in confirming that plastic chrome ore refractory on stud-tube water walls gave little trouble, and in his own experience, properly applied, it made the most satisfactory furnace lining. Also, using proper methods, patching was not at all difficult, but in the case mentioned by the authors as an unorthodox arrangement of securing lugs, he would draw their attention to the fact that it was not a studded wall. The arrangement had been made by another maker and presumably he had considered that it was better than a studded wall.

He also wished to draw the attention of the authors to the headings on the table at the back of the paper, where the columns "F", "G", "H" and "J" were said to refer to Babcock and Wilcox boilers, but in America there were three makers of header boilers and, whilst it was true that Babcock and Wilcox were responsible for the basic design of boilers for those ships, other makers were permitted to fit their own design of water wall construction; although from the outside all the boilers looked like Babcock and Wilcox boilers, in furnace details they were considerably different.

Finally, he did not think anyone could disagree with the authors' conclusions, although perhaps they had striven for perfection, which it was not always possible for the designer to obtain. However, that was as it should be when tendering advice.

MR. W. SAMPSON said the authors had obviously worked very hard and had sincerely tried to arrive at some definite conclusions which would be helpful to both designers and users. The trouble with an investigation of that sort was that it was almost impossible to correlate such variable factors as they had to deal with and, while he appreciated the care which the authors had taken, he believed that some of their conclusions could not be strictly supported.

For example, one very important conclusion appeared in the synopsis of their paper: "The influence of service conditions on the life of refractories is examined in a further section and it is concluded that the forcing rate (lb. oil/hr./sq. ft. projected radiant heating surface) may be taken as a general indication of the severity of the operating conditions". That, as a statement, meant that one could say that, if a furnace were rated twice as high as another one, only half the life would be expected, but that should not be taken literally at all.

In some of the boilers, the forcing rate had not been the true reason for the horrible examples which they had seen on the screen. He knew from experience that in many of those cases the real reason was that the fuel was not burned properly. They might get very good combustion at one particular rating and then have a manœuvring condition where, at low power the ratio of air to oil was affected; they might have maladjustments and variations between long flames striking the back wall and wide flames striking the side walls. In his opinion, it was an impossible requirement to ask any maker of bricks to make a brick on which they could burn the oil fuel on its face. Particles of oil burning on the face of brickwork were disintegrating in their nature. Even with the very best of bricks, if there were flaming on them or small particles of oil slowly burning, it would in a short time lead to the disintegration of the face. Most of the troubles experienced had been due to the fact that they had been burning oil on the bricks.

Regarding rating, if by that they referred to forced rating, it must be remembered that the speed of combustion went up with the temperature of combustion. With a high rating the first thing one saw was a shortening of the flame, and he did not want the meeting to feel that the conclusion given in the section of the paper dealing with design, that a furnace should be not less than 8 feet long, should always be rigidly adhered to. There was a boiler at Haslar where they experimented putting in a false wall and the flame got shorter and shorter as the wall was advanced towards the front. There were new ships in the merchant navy today with furnaces 6 feet long, and the designer, to suit his customer, should always aim at the shortest possible boiler and then ask the oil burner maker, "Can you burn oil in a 6-ft., 5-ft. or 4-ft. furnace?" Some could and some could not. There were ships in service now with very high ratings and the evidence so far was that they were even more satisfactory as regards their brickwork than at low ratings. So, although the inference was not to be denied that rating had an effect, it should not be taken as a rule that the punishment of brickwork went up proportionately with the rating. If it did, then they would be very badly off with naval boilers, where ratings were five or six times as high as the merchant service.

Conservatism entered into the design of boilers to a very great extent. In American boilers they had a water wall and simply placed the tubes so that they touched the brickwork, whereas there was a convention in this country that there must be a space behind the tubes. If the bricks did not touch the tubes, the farther away they were the more likely the punishment, whereas if the bricks would lie against the tubes there was a greater likelihood of having a cool wall.

DR. H. E. CROSSLEY said that, in the section of their paper concerned with slagging, the authors had mentioned a previous paper by Gray and Killner, dealing with the formation of deposits in boilers arising from the presence of brine in fuel oil. Deposits of this kind were common in power station boilers fired by mechanical stokers and burning coals of high chlorine content (greater than 0·3 per cent chlorine). They were less common in boilers fired by pulverized fuel but were known to occur with coals of very high chlorine content (greater than 0·7 per cent chlorine). These deposits became particularly vicious if the ratio of sulphur to alkali in the fuel was such that acid sulphates were formed, and this with coal required a ratio of sulphur to chlorine greater than 5 : 1. A further variety of chemical deposit which had affected oil-fired boilers was principally a mixture of vanadates, particularly metavanadates if sufficient sodium were present. Such deposits caused an appreciable amount of trouble in oil-fired boilers in Holland during the last war. It was well known that the occurrence of significant amounts of vanadium was characteristic of certain fuel oils, others being relatively free. As a matter for conjecture it would be interesting to know if fuel oils ever contained significant amounts of fluorine, and in this respect a few parts of fluorine per 100,000 parts of oil might be important. It could be expected that the fluorine compound present would be hydrogen fluoride during the combustion and this could cause serious pitting of silicaceous refractories. If this happened there would be no chemical evidence left on the refractory to indicate the cause of the damage. If fluorine occurred in fuel oil in significant quantities, it was likely that it would be accompanied by larger amounts of phosphorus and this could also cause slagging trouble due to the formation of bonded masses of the phosphates of the metals in the fuel ash.

It was appreciated that the most common cause of trouble on the refractories of boilers was slagged ash without any accumulation of particular chemical constituents of the fuel. It was unfortunate that the laboratory test for the determination of ash fusion point was not wholly satisfactory. This was not the occasion to discuss the determination of fusion point in detail but it would be sufficient to point out that the laboratory test was usually carried out on ash prepared in that laboratory and that this material commonly differed both physically and chemically from the ash present in a boiler system. Further, trouble of this kind inevitably began with the sintering of the ash and there was at present no recognized method for the determination of the sinter point of fuel ash. The British Electricity Authority had given much attention to this problem and it was hoped that a method would be put forward in the near future. The method would be intended primarily for coal ash and would probably be applicable to oil ash. For this purpose the most suitable material for testing was clearly unsintered ash from the boiler itself, if that could be obtained from a region very close to the combustion chamber.

With regard to the minimization of slagging, considerable interest was aroused by a paper* published in the Transactions of the American Society of Mechanical Engineers, describing the benefits obtained at Delray Power Station due to the introduction of steam into the combustion air. The humidification of combustion air had been applied previously but not specifically for the reduction of slagging in power station boilers. There had been, however, a previous statement in print in "Marine Engineering" for May 1949, which seemed to have escaped attention. This referred to the prevention of slagging in oil-fired boilers by the injection of superheated steam into the flame on six sides. In the original paper the Delray slag was said to be a bonded deposit due to the presence of sodium compounds but in private correspondence the authors had since admitted that this was not the case. There appeared to be a possibility that the deposits which were minimized were mainly sintered ash. Several applications of humidification of combustion air had taken place in power stations of the British Electricity Authority. The investigation was not yet complete but so far there had been no success where the deposits had been of the bonded type due to alkalis; there had been moderate success with phosphate type deposits and very considerable success at one power station—Llynfi—where the trouble was due to the fusible character of the coal ash. In this case saturated steam was introduced into the flame about 5 feet from the burners. The quantity of saturated steam used at Delray was eventually found to be approximately 20lb. per thousand pounds of combustion air, but the amount used at Llynfi so far had been considerably less. Moderate success had been obtained against similar trouble at Hams Hall "B" Station, admitting steam into the pulverized fuel burners. The mechanism of the effect was not known; it might be that it was due partly to increased turbulence in the flame in some cases but it was also possible that the effects were due to fundamental changes in the combustion due to the presence of the added moisture.

MR. L. R. BARRETT explained that he neither manufactured nor used refractories on an industrial scale but he was interested in both aspects; he believed it was correct to say that despite what had been said that evening it was no use thinking they would ever get away from refractories in boilers. Refractories would always be essential wherever they were going to burn a fuel of any sort efficiently.

It was necessary to have a refractory because to maintain combustion one needed some sort of envelope surrounding the hot zone which was reasonably insulated so that the walls of the combustion zone could reach somewhere towards the flame temperature; therefore it was no use expecting to be able to have complete water walls. Fifteen to twenty years previously there had been some discussion as to whether refractories would really be eliminated entirely from boilers and water walls take their place. The refractory envelope had to be held in place in some way or other: the floor did not present any difficulty, the walls not very much, but the roof always did present some difficulty, and it was rather a pity to see that the envelope had been held in place by those bolts which had given so much trouble. Refractory materials were very brittle and would not stand much uneven stress without cracking. They had no ductility worth mentioning, so if any accidental stress were brought upon them exceeding about 1,000lb. per sq. in., they would inevitably break, and a method which involved some very strong fastening, unless it were carried out with one hundred per cent certainty and with a certain amount of looseness, was bound to give trouble.

However, it might be going too far to say that putting a hole through the tile inevitably made it crack into four pieces. Some time ago he had been trying the effect of thermal shock on tiles of the same area which did not have a hole through them, and when they did break it was nearly always into four pieces. He had also found that the thinner the tile the longer it lasted in thermal shock testing. Tiles ½ inch thick would last very much longer than those which were 2 inches thick, purely from that point of view. There was, of course, the possibility that such thin tiles could be used if they were attached to insulating materials behind, but that idea, which had been put forward scores of times, never seemed to come off in practice. There were, however, possibilities—which he had seen adopted in a small way—of a type of refractory where the face was dense and the backing porous, and it might be that it could be applied to boilers†.

The type of bolt which appealed to him, as an outsider, was one which had already been given the prize that evening, namely, one which did not penetrate the face, because quite obviously uncovered iron in any form would form ferrous-oxide in the furnace, and there was no more cutting slag than that. The method used by the firm described in the illustrations, which used plastic concrete, also seemed to fulfil the need where there was no penetration of the surface. Probably a useful field of investigation for the authors of the paper would be to consider better means of attaching the tiles. Apparently the methods shown in Fig. 8 were already in use, and although he had no particular interest in them personally, that in Fig. 8(d) appeared to be quite a good method because it allowed each individual refractory tile to move about without being stressed in any particular way.

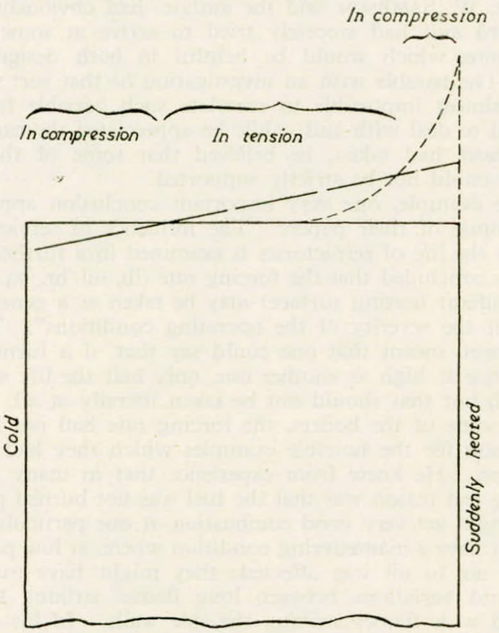

FIG. 30—*Effect of sudden heating on one face on the dimensions of a plane slab (shown in section).*
——— *Outline of unconstrained slab.*
- - - - - *Shape slab desires to reach after short period of heating on one face.*
— — *Shape adopted.*

The manner in which any sudden heating affected a refractory was rather as shown in Fig. 30; the face which was heated wanted to expand and would, if unrestricted, tend to stick out top and bottom. That happened in the first few seconds but shortly afterwards the next fibre or layer wanted to expand, although not quite so much, and so on, and one eventually got to the position where the tile wished to expand on the face by quite a pronounced amount but was unable to do so

*Murphy, P., Piper, J. D., and Schmansky, C. R. 1951. "Fireside Deposits on Steam Generators Minimized through Humidification of Combustion Air". Trans.A.S.M.E., Vol. 73, No. 6, p. 821.

†Barrett, L. R., Clements, J. F., and Green, A. T. 1940-41. Trans.Inst.Gas Eng., Vol. 90, p. 149.

because the back of the tile was relatively cool. What actually happened was that the tile expanded a little on the hot face but to an extent insufficient to relieve the stress, which was transmitted through the thickness of the tile to produce a compression on the cold back. The face was in compression because it could not expand as far as it wanted; the intermediate area of the tile was in tension, and stresses of the order of about 5,000 to 10,000lb. per sq. in. could be set up in that way in a 1-ft. square tile and cause it to break, because the tensile strength was only about 1,000lb. per sq. in. and the compressive strength perhaps 3,000lb. per sq. in. The larger the area of the tile, the easier it broke, and that was why units rather than large monolithic areas were used. If the thermal expansion or the modulus of elasticity could be reduced, then the stresses would be proportionately less*.

It was quite easy for academic people, of whom he was one, to talk as though that were a possibility, but it was quite uneconomic although there were possibilities of another sort which the poor manufacturer was expected to face. He could lower the modulus of elasticity of the material by incorporating coarser particles and, by further experiments in his own works, grade those particles in such a way as to give flexibility to the bricks or tiles. No doubt that had been done and manufacturers offered different classes of brick for different purposes, and presumably the designers of boilers took notice of those possibilities.

It was a fact that if a range of firebricks, taken from a variety of manufacturers, were tested, there was a wide difference in the thermal shock resistance, and it might be that sometimes a type of refractory was chosen by boiler users which was not altogether suitable. If one was obliged to open the texture, as the refractory manufacturer did, one was liable to reduce the slag resistance, and those two factors unfortunately could not be catered for simultaneously, but it might be that the washes which had been referred to would help there.

It was possible to use the washes, which were of a different chemical nature from the firebrick, but it was always a little dangerous to do so without proper knowledge. However, during the last war, the British Coal Utilization Research Association had done quite a lot of work on mobile gas producers which were lined with refractory and needed to be protected in some way from slag attack. They had adopted a lining of zircon sand, which was readily available although not as cheap as fireclay, and apparently it had met with considerable success. Zircon as a refractory had a rather similar coefficient of expansion to fireclay materials, although the latter varied in coefficient of expansion and even a zircon wash, if available, would not necessarily always fit; it might peel off. The same type of wash could be used to seal the refractory face and joints. As such washes were used in only very thin layers the cost was not prohibitive and they enabled one to try to get the best of both worlds, i.e. brick and tile, or maybe monolithic construction, of high thermal shock resistance with a certain amount of slag resistance on the face.

Although he had read the paper very carefully he felt a little out of his element in dealing with headers and the like, and if he talked about them he would probably drop too many bricks—of one sort or another!—but he did feel that when the authors were appealing to operators at sea to be kind to the refractories they were asking rather too much. It was really the designers who must be kind to them, the manufacturers who must do their best to comply with the designers' requirements, and the people actually in the boiler room who might exercise a little more care. The authors had shown what a lot could be done by careful placing of the burners and correction of any that were misplaced, and cleaning, and one speaker had put his finger on the whole trouble, which was that so often fuel was burnt on the refractories. The paper itself did not seem to bring that point out very strongly, but most of the illustrations suggested that only when fuel was burnt on the refractories was there any real trouble, so that if the operators, who actually saw what was happening from hour to hour, had a better appreciation of the peculiar properties of refractories something might be done to safeguard them.

He had been fortunate enough a week before to be invited to a City Company's dinner, and sitting next to him had been a young man in the twenties who apparently was taking a Stokers' Course in the Navy and was training to be an officer. Having just received the invitation to attend the reading of the paper under discussion he had taken the opportunity of getting as much information from the lad as possible, and it appeared that in the course, which was given to scores of ordinary stokers as well, they were told about slag attack, the constitution of the slag, and a good deal of other technical matter which his acquaintance had absorbed because he happened to be a Ph.D. in chemistry, but possibly not all the others had quite grasped it! He had not heard anything about instructions on preserving the brickwork from thermal shock, but possibly that came into the course at a later stage. He wondered whether the merchant service was doing anything of the sort to instruct their stokers in what refractories were like. Was there any sort of educational course for them ashore? Some people present might have influence in such matters and might consider the point.

MR. W. J. L. FOREMAN (Member) made some observations about the protection of boiler brickwork. This involved the practice of water washing, i.e. using high pressure water jets for removing deposits on the furnace side of boiler tubes—a practice now quite common in land and marine boiler installations.

It had been suggested that the sodium salts and sulphates in the deposits brought down by the water could contribute to early failure of the brickwork. Whether this were so or not, it was obviously desirable to find some means of preventing the wash water finding its way into the brickwork either through cracks or the pores of the bricks.

As far as he knew, only two methods of protection had been tried by shipping companies. One method was to rig suitable canvases over the brickwork prior to washing but this was laborious because it called for the "laundering" of the canvases after use, in order to prevent their deterioration in storage.

The other more successful suggestion was to use a bituminous protective solution applied by brushing or spraying the brickwork, this solution being burnt off immediately on lighting up the boiler. This method had been used in H.M. ships with some success, although a certain amount of extra work was involved where the brickwork was badly broken and cracked.

MR. C. A. SINCLAIR (Member) said that as a practical sea going engineer there were three questions he wished to put to the authors. The first was in connexion with the Wildish brick bolt illustrated in Fig. 7 and referred to in connexion with bricks on pages 173-175. Did the authors consider that the cracking of the bricks into four portions might have been due very largely to the ferrous oxide formed within the core of the brick? In his experience, when walls were dismantled in the hotter realms of the furnace, such oxide was found to be fairly highly compressed, and it led one to believe that an internal pressure was probably set up within the brick.

Secondly, the authors had referred briefly to the removing of slag from the floor, and he wondered whether they recommended that practice or whether it was best left alone, unless there were flame impingement on the floor through an excess of build-up?

Thirdly, a point had been raised by the last speaker in connexion with water washing or steam soaking of the boiler. As with modern watertube boilers many of the surfaces were difficult, if not impossible, to clean properly, apart from such methods, he would seek guidance as to what could be done to protect the brickwork, or information as to whether the

*Barrett, L. R., and Green, A. T. 1942-43. Trans.Inst.Gas Eng., Vol. 92, p. 178.

effects were in fact as serious as one was sometimes led to believe?

Finally, supposing the effects were not matters to be lightly dismissed, could the authors give any indication of the possible economics involved, bearing in mind the considerable retardation of heat tranference to be expected if the heating surfaces were not properly cleaned? Or did the conclusion of the matter appear to be that, after installing highly efficient boilers, they had to be prepared to operate them at less than designed efficiency, and was it not even possible that failure to clean these surfaces properly (because of considerations of refractory maintenance) might have been contributory to, or even responsible for, certain serious soot fires and even burnt out boilers?

Mr. G. VIVIAN DAVIES said he believed he had been of some assistance to the authors in the preparation of their paper by supplying them with a few sketches. He was not a marine engineer and although he had had a good deal of experience of boiler firing he rather hesitated to follow such distinguished predecessors, particularly Dr. Crossley, who was an acknowledged authority on the subject of slagging, but he felt compelled to take up a point raised by one speaker, who had rather emphatically inferred that in every case it was necessary to have a refractory envelope. Of course, that was not so. Modern power station boilers were often built at the present time with practically no refractories at all but complete watertube walls.

One point on which he wished to support an earlier speaker was the emphasis on the correct operation of the oil-firing equipment, particularly as regards the sprayer and orifice plates. Too often these were allowed to deteriorate, with the result that the flame lost its shape and the troubles followed which had been described in the paper.

Another very important factor was the need for a better control of combustion air, particularly with the modern type of balanced draught boiler such as the Foster Wheeler boiler, in which it was important to be able to control the combustion air to individual furnaces.

With regard to the question of refractories, he believed a good deal could be done because the clay-making industry of this country was one of the old craft industries which possibly had not adopted some of the modern methods in use in more exact industries like engineering. In his opinion there was a great need for closer control of quality and also for research into refractories, which should be made to suit particular needs such as were outlined in the paper.

The matter of water jets interested him a great deal because when he was at the Ministry of Fuel and Power during the war, he had made the suggestion that water jets might be tried in certain cases to clear furnaces that were badly fouled, and such jets had proved very successful.

He wondered if recent changes in oil refining processes, some of which were the result of the increasing demand for jet and gas turbine fuels, had had any effect on the character of residual oils, which might account for some of the troubles described in the paper. Only the fuel and refining experts could give the answer to that.

Correspondence

MR. F. J. COLVILL (Member) wrote that the paper, based on the results of observations made on the conditions of the refractory surface linings of a representative number of merchant steamships in service and on present knowledge of the refractories commonly in use on such boilers, confirmed that the main causes of deterioration of the refractory linings in use in merchant marine watertube boilers were now fairly well understood.

The investigation carried out by the B.S.R.A. was characteristic of the very sensible and practical approach to research problems associated with their work. The paper, to his mind, was an excellent one and he would offer no criticism. Both in its analysis and suggestions it provided valuable information and guidance for superintendent engineers and boiler designers.

He suggested that this paper and other existing literature on the subject, including the very interesting paper presented in 1951 by Mr. Clews, now provided material on which it could be decided what further research, if any, was desirable on this subject.

It was well to bear in mind, however, that the behaviour of refractory linings depended on many factors which were more or less outside the control of superintendent engineers and ships' engineers, such as furnace design which included shape, relative size, etc., and the absence or otherwise of cooling tubes in the walls. There was, of course, some choice in the case of a new ship, but the superintendent would be guided by his experience as much as by the advice tendered by the boiler makers, and conditions might, with the progress in design, be very different to any he had actually experienced. Oil fuel varied considerably and the best method of burning one sample in a particular furnace would not necessarily apply to another. This variation had to be accepted as inevitable and any further solution to this problem would have to be in spite of that variation.

MR. J. W. E. STANLEY considered that the authors' statement that "air setting is obtained by the addition of sodium silicate" was not generally applicable. The company with which he was associated, for example, made one or two special materials containing sodium silicate, but their standard range of air-setting castable materials contained no sodium silicate.

Whilst the authors were correct in saying "since the monolithic lining is fired hard only on the hot face, there will be a plane parallel to this where the material is relatively weak", in practice this weakness could be overcome by the use of specially designed securing devices which anchored the lining from the hard-fired part right back to the steel casing; they prevented bulging of the lining whilst permitting it to expand and contract relatively to the steel casing.

Whilst he agreed substantially with the suggestions for increasing the life of combustion chamber linings put forward by the authors in the light of their investigations, he believed that they had not investigated any vessel in which the boilers were provided with full-monolithic linings. Such vessels were operating and he understood that at least one of them had completed three years of service with practically negligible maintenance cost to date.

The use of full-monolithic linings was gaining wider acceptance and several notable vessels now under construction would have boilers so fitted. Although boilers for these ships would have full monolithic linings, they were designed for jointed brick linings and, in his opinion, this was a restriction imposed on design which was no longer necessary or desirable. Boilers designed for full-monolithic linings would, it was his belief, be a worthwhile advance. He would welcome the opportunity of discussing this with the authors of the paper and any boilermakers who might be interested.

Authors' Reply

Since several contributors to the discussion had referred to the possible development of more suitable refractory materials or the improvement of their method of manufacture in order to increase the life of boiler brickwork, the authors thought it as well to make some general comments on these points before making individual replies.

Whilst it was agreed that the properties of the materials used were of primary importance, it was the authors' opinion that less spectacular improvements were likely to result from the use of improved, and possibly much more expensive, materials than from improvements in design of the furnace lining and oil burning equipment. A great deal of work had been carried out over many years on the properties required of refractories to meet various operating conditions but until more was known of the actual service conditions which had to be withstood by the brickwork in marine boilers, little progress could be made. It was along these lines that further work on this subject was progressing and it was hoped to obtain information on the effect of various factors on such variables as the operating temperatures of furnace linings, rate of change of temperature, etc. With such knowledge it might be possible to carry out simulative tests on a laboratory scale. Such work would necessarily be a long term project and, as pointed out by Mr. Killner, the only way of determining the true value of any alternative materials would be to investigate their behaviour in service.

The authors thanked Mr. Killner for drawing attention to the importance of correct atomization of the fuel in regard to slag deposition. This emphasized the desirability of using burners which were capable of producing a short flame, whether spalling or slagging of the brickwork was the major problem.

Further to Mr. Killner's remarks on the effect of carbon monoxide penetration of quarl blocks, it was noted that in a number of the boilers examined oil had dropped on to the lower blocks from the burner tips. No evidence of carbon monoxide attack was found, however, although in some cases there was some erosion due to a concentration of fuel ash. With regard to the modification to the shape of the burner throats illustrated in Fig. 18, the evidence undoubtedly indicated a considerable improvement in life; the part played by the different material or whether this improvement was obtained at the expense of reduced efficiency could not be established.

Mr. Killner referred to the damage which might result from expansion but in none of the boilers seen was there any evidence of permanent after-expansion. In this connexion it was noted that the expansion joints provided in many linings were found to be rather unsatisfactory; instead of opening up when the brickwork cooled, it was not unusual to find that fresh cracks were formed.

The authors agreed that, from the point of view of laboratory tests, the normal firebricks used had an adequate margin of safety to allow for increased operating temperatures. It was a different matter, however, when such materials were built into a furnace lining where the method of construction often became of paramount importance. Reduction in the size of boilers with consequent increase in the forcing rate undoubtedly led to more arduous operating conditions. Increased operating temperatures might not affect the performance of the refractories directly but they led to difficulties in securing; they also increased the likelihood of slag penetration and therefore the liability to spalling.

Mr. Harvey raised a number of points that called for comment on the part of the authors. First of all they wished it to be made clear that the scope of the paper covered only one phase of the work on this subject and, as mentioned above, it was hoped to deal with the question of refractory materials at a later date.

Although the people concerned might be well acquainted with the extent of brickwork failures, as pointed out by Mr. Harvey, there had been found to be widespread ignorance of the causes of such failures. It was hoped that the present paper might go some way to remedying this.

It was agreed that the specification of only the alumina content was of little use in determining the quality of a firebrick; the proportion of impurities present was probably of greater consequence. The authors also agreed that there was probably considerable room for improvement in the control of manufacture and firing. It must not be forgotten, however, that the basic raw material from which firebricks were made was liable to vary considerably in composition and properties.

With regard to the effect of texture of the brick on its spalling resistance it should be pointed out that one of fairly high porosity gave good results only when free from slag. Increase in porosity obviously allowed slag penetration to occur more readily and the increase in vitrification might result in a surface that was more sensitive to changes in temperature than a denser and more impermeable brick.

The authors joined issue with Mr. Harvey on the question of the degree of control that could be exercised by the engineers over the temperature fluctuations in the furnace lining. Although the output requirements during manœuvring were governed by the orders from the bridge, a lot could be done to reduce the rate and magnitude of temperature fluctuations by the suitable choice of burner tip sizes and the choice of which burners were to be kept in and which were to be shut off as necessity arose. It was probably during manœuvring that most of the damage was done and this matter was therefore of the greatest importance.

Mr. Harvey's interpretation of the statement on page 173 regarding the relative severity of spalling damage in different types of boilers was correct, i.e. the extent of such damage in three-pass header boilers and multi-drum boilers with all-refractory furnaces was comparable. The statement was only misleading if it were not appreciated that the three-pass header boiler did not normally have wall tubes.

The authors agreed with Mr. Sampson and other contributors to the discussion that many of the more severe examples of damage were due to flame impingement on the lining; the importance of burner design and correct operation could not be overstressed in this connexion. By no means all the damage encountered could be attributed to burning of oil on the face of the brickwork, however (see Fig. 25 for example), and the authors still maintained that their conclusion regarding forcing rate being a *general indication* of the severity of operating conditions was justified over the range examined. It should perhaps be mentioned here that, for the most part, the boilers examined were not fitted with the improved short flame burners that had been developed in recent years.

It was not suggested for a moment that the life of a lining or the extent of damage was, in general, directly proportional to the forcing rate. Indeed, the authors had tried to make it clear that only in the boilers of one particular type that were examined was there a rough relationship between the wastage of refractories and forcing rate. With regard to Mr. Sampson's statement that the performance of brickwork in boilers having a very high forcing rate was better than in boilers having a low rating, it was suggested that this very satisfactory result could probably be attributed to the use of improved burners; whether the details of construction were the same in each case was not stated.

The curve shown in Fig. 31, which was reproduced from a paper* by Mr. Sampson, showed the relationship between

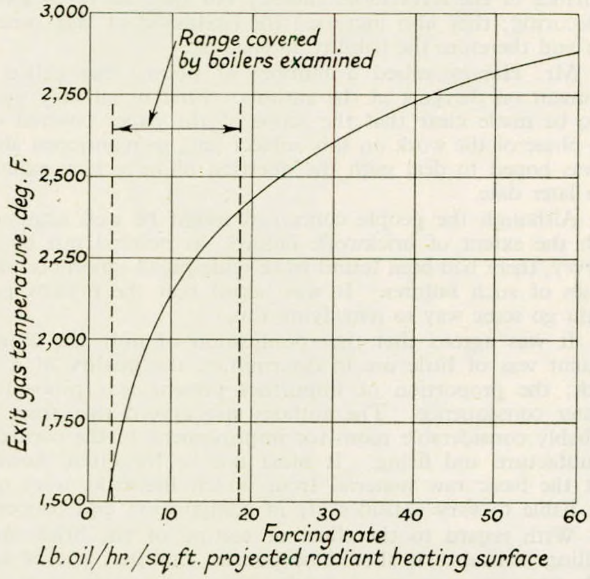

FIG. 31—*Relationship between furnace-gas exit temperature and forcing rate (15 per cent excess air).*

the calculated furnace gas temperature and forcing rate. It was possible that the curve of furnace lining temperature plotted against forcing rate would be of a similar form and this suggested that there would be a falling off in the rate of increase in temperature as the forcing rate was increased. Hence it would be seen that for forcing rates above about 20, i.e. in the range of naval practice, increase in forcing rate did not have a very great effect on temperature, whereas in the merchant ship range (indicated by the dotted lines) a small increase in forcing rate resulted in a comparatively large rise in temperature. Although the operating temperature alone could not be taken as a measure of the severity of service conditions, the curve in Fig. 31 might go some way towards explaining why considerable increases in the forcing rate in the higher range might not influence greatly the relative performance of the refractories. It was also worthy of note that at higher temperatures (above about 1,000 deg. C.) firebrick refractories were less susceptible to spalling owing to the development of a partially plastic state.

The authors' suggestion that the depth of the furnace should not be less than 8 feet, if troubles with the back wall refractories were to be avoided, was qualified by the statement "unless closely pitched water tubes are fitted". In both the boilers mentioned by Mr. Sampson, where the depth of the furnace did not exceed 6 feet, the back walls were covered with closely pitched tubes. Even though burners were available which were capable of maintaining efficient combustion within a furnace as short as 6 feet, in a boiler with an exposed back wall there was the possibility of flame impingement when manœuvring or steaming at reduced load.

The authors agreed with Dr. Crossley that the presence of vanadium in significant amounts in the fuel oil might play an important part in slag formation but, owing to the variable nature of the fuels bunkered at different ports, it was difficult to arrive at any conclusion on this matter from service data. They had no information as to the occurrence of fluorine in residual fuel oils.

Further to Dr. Crossley's comments on the minimization of slagging by the injection of steam into the furnace, this suggested that the use of steam atomizing burners might be beneficial in this respect. It would appear, however, that this procedure was effective only when the deposits were of sintered ash. Such deposits only occurred in marine boilers at comparatively low forcing rates and did not appear to have any deleterious effect on the refractories.

It was of interest to note from Mr. Barrett's tests that even tiles without bolt holes tended to break into four pieces and that thinner tiles proved to be superior when subjected to thermal shock. There appeared to be no reason why thinner tiles should not be used in practice behind water tubes. As Mr. Sampson had mentioned, there was some prejudice in this country against having the furnace lining in contact with the tubes but it would seem that, if that prejudice could be overcome, the use of quite thin tiles without securing bolts and backed with fairly high temperature insulating material might lead to improvements in performance.

In reply to Mr. Barrett's final remarks, the authors pointed out that the standard of training of the boiler room personnel in the merchant service was not comparable with that of naval stokers and it was hardly practicable to adopt a similar system. Both in ships trading with the eastern hemisphere, where the firemen were usually Asiatics, and in vessels where European firemen were employed, the men were not expected to have any technical knowledge. The operation of the boilers was supervised, of course, by the engineer on watch, who made any necessary adjustments to the fans or oil burning equipment. The authors did not consider it necessary for an engineer officer to have a detailed knowledge of the constituents of slags, etc., but it was essential that he should be aware of the main causes of failure of boiler refractories so that he could take all steps within his power to improve operating conditions.

Mr. Foreman had referred to the possible damage to brickwork from water washing and the authors agreed that this called for the most efficient protection of the brickwork that was possible. The penetration to the insulation behind the firebrick of water and deposits from the tubes of the types mentioned by Mr. Foreman could have serious consequences; effective sealing of deep cracks in the lining was therefore important and for this purpose the use of a bituminous protective material appeared to offer the best solution.

In reply to Mr. Sinclair's question regarding the oxidation of bolts, it was thought that this might contribute to the cracking of bolted blocks. It would appear that severe oxidation did not occur until after the failure of the bolted tile, however, and usually there was adequate clearance in the bolt hole.

Slag which built up on the floor was best left undisturbed unless it reached such a thickness that it interfered with efficient combustion. In this connexion the authors understood that it was sometimes the practice to remove slag from the floor at the junction with the walls, so forming a channel to prevent the further building up of the thickness of the layer of slag.

The question of the effect of water washing, which was also raised by Mr. Sinclair, had been referred to in the reply to Mr. Foreman. On the whole it appeared that this practice did not lead to any serious consequences if reasonable precautions were taken. The washing should not be carried out whilst the brickwork was hot; all steps should be taken to prevent the seepage of water into open joints and cracks, and

* Sampson, W. 1943-44. "Notes on Water Tube Boilers for Cargo Steamers". Trans.N.E.C.Inst.E. and S., Vol. 60, p. 77.

slow drying out was necessary. It was understood that some boiler makers made provision for the draining away of superfluous water, which should improve matters. The authors did not think that any engineers purposely allowed deposits on the furnace side of boiler tubes to accumulate in order to avoid the possibility of increased brickwork maintenance arising from water washing. It was noted in this connexion that recent trends in boiler design allowed easier manual cleaning.

Mr. Davies's remarks called for little comment but the authors wished to point out that in marine boilers it was essential for there to be some refractory surface; otherwise, when steaming at reduced power there would be overcooling of the flame and incomplete combustion would result. On the question of the quality of residual fuels used for boiler firing, it appeared that certain grades, as well as containing a higher percentage of ash, proved more difficult to burn with a short flame. In this way their use might contribute to brickwork wastage.

The authors thanked Mr. Colvill for his remarks, which did not call for any reply other than to express general agreement.

In reply to Mr. Stanley's first point regarding the composition of air setting materials, the authors pointed out that the statement that this property was obtained by the addition of sodium silicate did not refer specifically to castable refractories. The bond in such materials was formed by hydraulic setting. The addition of sodium silicate to a mix containing a small amount of raw clay produced an air set as the material dried out. Organic materials such as gum, dextrin, etc., provided an unfired bond without the need for an addition of raw clay but such a mix had little or no plasticity.

The question of securing methods for rammed plastic refractory linings had been referred to by Mr. Killner. The authors agreed with him that metal anchors could not withstand the temperature required to form a ceramic bond, which would be necessary to avoid the danger of a plane of relative weakness remaining in the monolith. They added, however, that they had seen no evidence of such weakness leading to failure of the lining in the few examples of such construction that they had examined.

It was noted that satisfactory results over a reasonably long period had been obtained from a full-monolithic lining; further performance data relating to this method of construction would be awaited with interest.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Institute on Tuesday, 12th May 1953

An Ordinary Meeting was held at the Institute on Tuesday, 12th May 1953, at 5.30 p.m., when a paper entitled "Service Performance of Boiler Brickwork—The Causes and Extent of Wastage", by Bryan Taylor, B.Sc.(Eng.), (Member) and H. Booth, was presented and discussed. Mr. Stewart Hogg (Chairman of Council) was in the Chair. Fifty-six members and visitors were present and eight speakers took part in the discussion. A vote of thanks to the authors, proposed by the Chairman, was accorded by acclamation. The meeting ended at 7.45 p.m.

Local Sections

Kingston upon Hull and East Midlands Section

A meeting was held at Selby on Friday, 26th June 1953, at which it was formally agreed to extend the activities of the Kingston upon Hull Local Section to include the East Midlands. Mr. Stewart Hogg (Chairman of Council) was in the Chair, supported by Mr. F. C. M. Heath (Vice-President for Hull) and Mr. G. H. M. Hutchinson (Chairman of the local Committee), and the Secretary.

Mr. A. A. E. Wise (Grimsby), Mr. T. M. Green (Leeds) and Mr. A. C. Gooder (Harrogate) were co-opted to serve on the local Committee until the next Annual General Meeting.

All members residing in the area are invited to enrol upon the Register and, for the time being, all enquiries should be addressed to the local Chairman, Mr. G. H. M. Hutchinson, at 27, Park Avenue, Hull, East Yorkshire.

Sydney

On Monday, 29th June 1953, at 8.0 p.m., the annual meeting for students and apprentices was held by the Sydney Local Section at Science House, Sydney. Mr. W. G. C. Butcher (Member) was in the Chair and welcomed the sixty-six students and apprentices who, with fourteen members, comprised the audience.

Mr. H. P. Weymouth (Member), Director of Shipbuilding for the Australian Shipbuilding Board, exhibited an excellent set of lantern slides, showing the various types of marine engines which had been built in Australia in recent years, and gave a brief description of each type. These included reciprocating steam engines with and without exhaust turbines, Doxford Diesel engines and smaller high speed Diesel engines.

Following this, Mr. C. McLachlan (Member) gave a talk on problems which might be experienced in the operation of steam engines; Mr. W. G. C. Butcher (Member) then discussed the operation of Diesel engines at sea and, finally, Mr. D. N. Findlay gave some very good advice on electrical work as it affected the marine engineer.

A good discussion followed and numerous questions were asked by the students and answered by the various senior members.

A vote of thanks was proposed by Mr. J. Munro, who is in charge of the marine engineering department at the Sydney Technical College; he expressed not only the thanks of the students but also of the college authorities to the Institute for arranging the meeting, which was eagerly anticipated by both the students and the staff.

Supper was served after the meeting and an opportunity was given for those present to meet and talk informally. Groups of young men surrounded the various senior members and questioned them about the operation of various marine engines and other problems connected with the propulsion of ships for a considerable time after the formal business was finished.

OBITUARY

William Henry Booth (Member 8835) was born in 1886. He served an apprenticeship with Richardsons, Westgarth and Co., Ltd., of Hartlepool, before joining the Anglo-Saxon Petroleum Co., Ltd., in 1911, being appointed fourth engineer in the s.s. *Clam*. He served in various vessels as fourth, third and second engineer until, in December 1914, he was promoted chief engineer. During the first world war he was chief engineer of the s.s. *Murex* when this vessel was torpedoed and sunk in the Mediterranean in December 1916 and, as a result of wounds he received, Mr. Booth spent a short time in hospital at Alexandria. In January 1919 he was a survivor from the s.s. *Gapershell* when this ship was wrecked off Mafamede Island, Portuguese East Africa.

In 1934 he served temporarily as superintendent engineer at the Shellhaven Installation of the Shell Refining and Marketing Co., Ltd., and, after returning to the Anglo-Saxon fleet for a few months in 1935, he was appointed an assistant superintendent engineer in September of that year. He supervized repairs to Anglo-Saxon vessels in various United Kingdom ports until June 1936, when he became the Company's resident superintendent engineer at Suez; he remained in that position until October 1938, when he returned to the United Kingdom and joined the marine technical department in the company's London office as engineer superintendent, until he retired in December 1946 after having completed more than thirty-five years with the Shell Group. He died, after a short illness, on 2nd July 1953.

Mr. Booth had been a Member of the Institute since 1939.

Walter Deans Carson (Member 9015) was born in 1876. He served an appprenticeship with Earles Shipbuilding and Engineering Co., Ltd., of Hull, and attended Hull Technical College. For about seven years he was at sea, mostly in vessels owned by the Ellerman and Wilson Line of Hull, serving as fourth and third engineer and, after obtaining a First Class Board of Trade Certificate, as second and then chief engineer. He came ashore to act as assistant to his father, the late Mr. Robert Carson of Hull, who conducted his own business as consulting engineer and acted as superintendent engineer to various shipping companies. Later he was employed for fourteen years by the British Corporation Registry of Shipping, for eighteen months as principal surveyor in Sunderland.

In 1920, Mr. Carson set himself up as a consulting engineer and marine surveyor in Hamburg, where he acted as superintendent engineer for the United States Shipping Board and surveyor for Lloyd's agents; in 1939, in view of the political situation and the inevitability of war, he returned to this country and established a business in London as consulting engineer but went to Glasgow in 1941 to take a position with the British Iron and Steel Corporation (Salvage), Ltd., leaving them in 1947 to resume business on his own account in London. As a result of ill health, he was unable to carry on his business and, after a long illness, he died on 5th November 1952.

Mr. Carson was a member of the Society of Consulting Marine Engineers and Ship Surveyors, his father having been a founder member of the society, and was elected to membership of the Institute in 1939.

Robert Thom Fyfe (Member 11582) was born on 8th March 1904. His apprenticeship was served with Fleming and Ferguson, Ltd., of Paisley, from 1918-23 and during this period he attended evening classes at Paisley Technical College. From 1924-26 he was a junior engineer at sea with the British India Steam Navigation Co., Ltd., during 1927 he was third engineer with Dawson Brothers and Rowan, followed by a few months in a similar position with Donaldson Brothers and the "D" steamers respectively. He obtained a First Class Board of Trade Certificate in 1929. From 1929-35 he was second engineer of the River Clyde dredging plant. He was employed from 1935 until his death on 10th June 1953 by the Clyde Navigation Trust of Renfrew, as assistant foreman engineer outside from 1939-46, as head foreman engineer outside from 1946-48, and then as assistant to the mechanical engineer.

Mr. Fyfe was elected a Member of the Institue in 1947 and was appointed to membership of the committee of the newly formed Scottish Local Section at their inaugural meeting on 27th March 1953.

Engineer Rear Admiral J. W. Milner, C.B.E., M.V.O. (Member) was born in 1875. From 1890-95 he was an engineer apprentice at the Royal Arsenal, Woolwich, and then went to sea as assistant engineer in H.M.S. *Victory*. He later served in H.M. Ships *Revenge, Melpomone* and *Weymouth* and during his service with the last of these he was in action with a German cruiser in the Refugi River action. He was appointed to H.M.S. *Renown* during the period in which she carried H.R.H. The Prince of Wales on tours to Canada, America, Australia, New Zealand and Japan, and for this service he was honoured by membership of the Royal Victorian Order. From 1923-27 Admiral Milner was chief engineer of the shore station at Gibraltar, and for two years thereafter he was Admiralty overseer in North-East England. He retired from the active list in 1930. During the second world war, however, he was recalled as chief engineer of H.M.S. *Belfast*, from 1942-45, and at the end of this service he was appointed a Commander of the Order of the British Empire. Admiral Milner died on 5th May 1953. He had been a Member of the Institute since 1928.

Alexander James Gibson Step (Member 7178), who was born in 1899, died on 7th November 1951. He served an apprenticeship with Mort's Dock and Engineering Company, Sydney, N.S.W., from 1916-21, and attended Sydney Technical College during this period also. For six months he sailed as junior sixth engineer in s.s. *Persic* and s.s. *Gallic*, owned by the White Star Line, and then joined the Union Steamship Company of New Zealand, Ltd., as third engineer of the s.s. *Kittawa* in March 1923. For the next ten years he served as third or second engineer in many of the company's ships, obtaining a First Class Australian Steam Certificate, with First Class Motor Endorsement. In 1936 Mr. Step obtained an Extra First Class Board of Trade Certificate, with Motor Endorsement. He was a member of the Institute of Marine and Power Engineers of Australia, and was elected to membership of the Institute of Marine Engineers in 1933.