# Boiler Refractories: Operating Temperatures and Recent Developments in Construction

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The British Shipbuilding Research Association and the British Ceramic Research Association have been carrying out jointly for some years a programme of research aimed at improving the life of furnace brickwork in marine watertube boilers. There are essentially three concurrent investigations and the results of each interacts on the other two; laboratory studies are made of the properties of refractory materials, the actual conditions to which materials are subjected in operation are examined, and the service performance of contemporary boilers is kept under constant survey.

This paper is concerned with tests carried out on a number of modern watertube boilers to determine the refractory hot face temperatures under service conditions, continuous records being taken in order to measure the rates of change of temperature as well as the maximum steady temperatures. The various factors that influence the operating temperature of a furnace lining are considered from a theoretical viewpoint, and comparisons are made with the test results.

The results show that the design and operation of the oil burning equipment, in so far as the degree of perfection of combustion is affected, have a marked effect on the brickwork temperature. Steady brickwork temperatures are likely to vary between the limits obtained with short flame burning and flame impingement; on exposed walls this may be a range of 500 F. deg.

The rates of heating and cooling were found to vary widely from one boiler to another. The most severe conditions occur in the burner quarl blocks and it was found that at this position the rate of change of temperature can exceed that which would cause normal firebricks to crack in laboratory tests.

The paper concludes with a survey of more recent developments in combustion chamber linings; the more prominent features noted include the increasing use of all-monolithic construction, the elimination of low side walls, and the welding of brick supporting keys to casings. Mouldable and castable materials are being widely used and there is an increasing tendency to use higher alumina brick. The need for care in the application of mouldable material is stressed and some indications of service experience are given.

## INTRODUCTION

The causes and extent of wastage of boiler brickwork were examined in a paper[1] presented before this Institute six years ago, and information was given there which had been gained from the examination of over forty boilers of eight different types. That survey was made in 1950/51, and at that time the after effects of the war were still evident; additional surveys of service experience have been made from time to time since then, and in this paper some of the more recent developments are noted and discussed. Laboratory investigation has been carried out during the same period on a large number of refractory materials and much information has been collected regarding their properties. The suitability for marine service of the various refractory materials that are available cannot be assessed, however, without detailed knowledge of the actual conditions to which such materials are subjected in operation. It was with the object of obtaining such data that the temperature tests described in this paper have been conducted. With the co-operation of shipowners, it was possible to conduct most of the tests under normal service conditions; where this could not be arranged conveniently, measurements were made during the trial trips of new vessels.

In marine boilers, the most important factors that determine the life of refractory materials, apart from details of design and installation, are the operating temperature, the rate and frequency of changes in temperature, and the degree of contamination by slag introduced by impurities in the fuel oil[2]. Of these, fluctuations in temperature, which cause thermal spalling or cracking, are by far the most common source of trouble. The influence of slagging on the extent of wastage is difficult to establish but it appears that the modifying action of slag on the hot face of the refractory might well be an important contributory factor in promoting spalling.

## DETAILS OF TESTS

Brief particulars of each of the boilers in which temperature measurements were taken are given in Table I. It will be noted that all the boilers except the first were of fairly recent construction and include most of the types commonly fitted in post-war British tonnage.

Boilers 7 and 8 were identical in design but had different types of combustion equipment; this enabled the effect on

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TABLE I—DETAILS OF BOILERS
(Unless otherwise indicated, figures given refer to designed service output)

| Reference no. | Type of boiler and date of construction | Output, lb./hr. | Furnace volume, cu. ft. | Effective radiant heating surface, sq. ft. | Oil fired, lb./hr. | Furnace rating; oil fired per cu. ft. furnace volume, lb./hr. | Forcing rate: oil fired per sq. ft. effective radiant heating surface, lb./hr. | Type of draught | Type and number of burners | Oil fuel | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Pressure, lb. per sq. in. | Temperature, deg. F. |
| 1 | Yarrow three-drum single flow, end fired (1934) | — | 630 | 160 | 1,400* | 2·2* | 8·7* | Forced (closed stokehold) | 2-Clyde | 80 | 160 |
| 2 | Babcock and Wilcox integral furnace (1952) | 60,000 | 800 | 285 | 4,120 | 5·1 | 14·5 | Forced | 5-Wallsend Z type | 185 | 205 |
| 3 | Babcock and Wilcox single-pass header type (1949) | 42,500 | 690 | 136 | 2,910 | 4·2 | 21·4 | Forced | 5-Wallsend F type | 95 to 100 | 185 |
| 4 | Yarrow three-drum twin-flow, end fired (1948) | 36,000 | 778 | 216 | 2,470 | 3·2 | 10·4 | Forced | 3-Wallsend Z type | 205 to 230 | 240 to 250 |
| 5 | Foster Wheeler D-type (1949) | 36,000 | 970 | 364 | 2,430* | 2·5* | 6·7* | Balanced | 4-Todd Hex-Press type | 150 | 190 |
| 6 | Foster Wheeler twin-furnace controlled superheat (1949) | 67,000 | 535 outboard 575 inboard | 275 outboard 270 inboard | 5,050 | 3·15 outboard 5·85 inboard | 6·1 outboard 12·5 inboard | Balanced | A.B.C. 3 outboard 4 inboard | 170 to 180 | 155 to 185 |
| 7 | Foster Wheeler twin-furnace, controlled superheat (1951) | 58,500 | 535 outboard 670 inboard | 275 outboard and inboard | 4,580 | 2·86 outboard 4·55 inboard | 5·56 outboard 11·1 inboard | Balanced | Todd W-type 3 outboard 4 inboard | 260 | 180 |
| 8 | Foster Wheeler twin-furnace, controlled superheat (1952) | 58,500 | 535 outboard 670 inboard | 275 outboard and inboard | 4,580 | 2·86 outboard 4·55 inboard | 5·56 outboard 11·1 inboard | Balanced | Wallsend Z-type 3 outboard 4 inboard | 150 to 175 | 180 |
| 9 | Babcock and Wilcox single-pass header type (1952) | 65,000 | 1,010 | 240 | 4,270* | 4·2* | 17·8* | Forced | 6-Wallsend Z type | | |

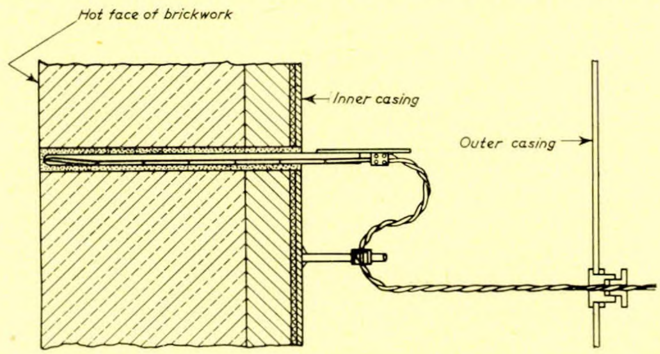
* At normal service power.

the brickwork temperature of differences in burner design and possible differences in operation to be investigated without any possibility of the results being obscured by variations in design of the boilers. The test on boiler 9 was devoted to an exploration of the temperatures at different points along one of the burner quarls.

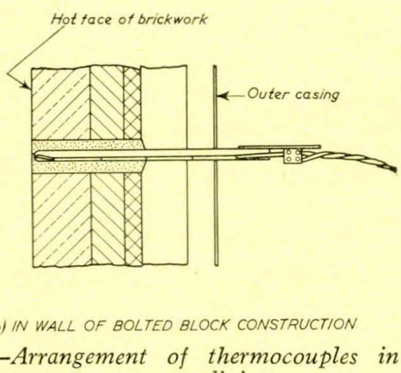
A preliminary investigation established that temperatures of the order of 2,550 deg. F. (1,400 deg. C.) could be expected, and that changes in temperature would be too rapid to follow with manually operated equipment at more than one or two positions. To meet these temperature conditions platinum-platinum rhodium thermocouples were used, and, in order to allow temperatures to be measured at a reasonable number of points, a six-channel automatic recorder of the galvanometer type was used in all the tests. The speed of this instrument was such that the temperature at each point was recorded at intervals of four minutes. Auto-compensating cable was used to connect the thermocouples to the recorder, which thus became the cold-junction, the instrument having automatic cold-junction compensation.

Although drawings of the boilers were usually available in advance it was found to be impracticable to fix precise positions for the thermocouples until an inspection had been made. The difficulty of access and the location of equipment outside the combustion chamber often imposed severe restrictions on the siting of the thermocouples, particularly in front walls and where air casings were fitted. In all the tests, however, it was found possible to locate at least one thermocouple in the area of the wall which appeared to reach the highest temperature. The method of installing the thermocouples is illustrated in Fig. 1.

Whenever possible the recorder was started soon enough to record the heating up of the boiler from cold and was operated continuously until the furnace had cooled down after the completion of the trip. A log was made of the number, position, and size of the burners in operation throughout the voyage, together with the oil fuel temperature and pressure.




*(a) IN WALL OF 9 INCH HEADER BRICK CONSTRUCTION WITH FORCED DRAUGHT AIR CASING*




*(b) IN WALL OF BOLTED BLOCK CONSTRUCTION*

FIG. 1—*Arrangement of thermocouples in typical furnace linings*

It was not possible, however, in most ships to record all burner operations during manœuvring because they changed so rapidly. Other information, such as air pressures and temperatures, furnace pressure, and power output, was also logged. The fuel consumption was normally determined from settling tank soundings which were taken at regular intervals.

The overall accuracy of the thermocouples and instrument under the prevailing conditions would be of the order of ± 0·5 per cent, so that in most of the tests the recorded temperature would be expected to be within ± 10 or 12 deg. F. of the temperature at the thermocouple. The calibration of the recorder was checked from time to time between tests and the thermocouples were calibrated before each test and renewed as necessary.

In addition to the small inherent inaccuracy of the recorder, the method of fitting the thermocouples introduced some inaccuracies in both the rate of change of temperature and the temperature gradients recorded, as well as giving temperatures under steady conditions less than those at the hot face. The effect of the various factors affecting the accuracy of the readings obtained has been investigated in the laboratory and in the discussion of results appropriate corrections have been made where necessary.

### BRICK FACE TEMPERATURES UNDER STEADY STEAMING CONDITIONS

During the period when raising steam and for a time after reaching full output the temperatures at different points through the thickness of a boiler furnace lining increase somewhat, as shown in Fig. 2. (In this simple case it is assumed

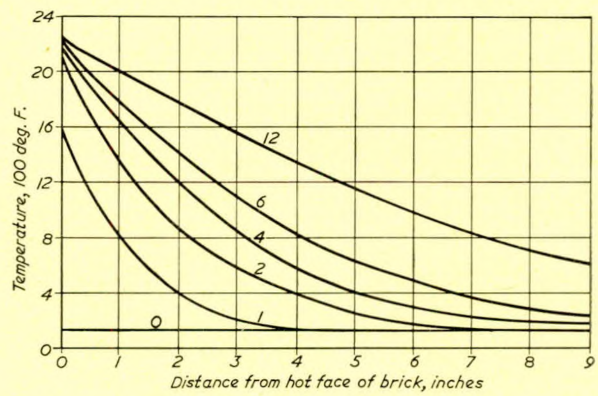



FIG. 2—*Typical temperature gradients through 9-in. header brick*

(Figures on curves indicate units of time after lighting burners)

that the lining consists only of one material which has uniform conductivity.) In the early stages there is a steep temperature gradient on the hot side of the wall and almost all the heat received is absorbed by the brickwork in raising the temperature of the wall. As long as the temperature gradient takes the form of a curve, heat is being absorbed by the refractory, but ultimately, when thermal equilibrium conditions are reached, the temperature gradient approximates to a straight line and no further heat is absorbed by the structure. Under these conditions the heat lost from the cold face is equal to that transmitted to the hot face if the brickwork temperature is uniform over the surrounding area.

The maximum brickwork temperatures attained under thermal equilibrium conditions in different types of boilers are now examined. Exposed walls and those protected by water tubes are considered separately. In each case the factors that affect the operating temperature are first considered from a theoretical viewpoint and the results of the tests are then compared with the theory.

Two different sets of conditions have to be considered. On the one hand the proportions of the combustion chamber and the type of combustion equipment may not be compatible, so that the avoidance of flame impingement on the walls becomes almost impossible. The same result can arise from maloperation of equipment that may be capable of maintaining better combustion conditions. With certain types of oil burning equipment, on the other hand, flame impingement can be avoided without difficulty. For convenience these two conditions are referred to respectively as long flame and short flame burning. It is, of course, highly undesirable for the refractory surfaces to be swept by flame and all possible steps should be taken in design and operation to avoid this condition.

*Exposed Walls: Theoretical Considerations*

In an oil fired boiler furnace the greater part of the heat transfer to the tubes and refractory walls is by radiation from the luminous flame; there is also a certain amount of radiation from the burnt gases and convection to the walls but for all practical purposes the latter can be neglected. The steady temperature attained by the refractory surface therefore depends on the radiation falling on the brickwork, the heat reradiated from the wall to the watercooled surface, and the heat transfer through the wall.

If the refractory surface is completely blanketed by flame there will be no heat loss from the brickwork by radiation to the tubes. In these circumstances it is obvious that the hot surface temperature of the brickwork would increase until it reached the temperature of the flame, if there were no heat loss through the wall. Such conditions might quite conceivably be approached in a boiler with long flame burners in which the furnace is filled with flame. On the other hand, under short flame burning conditions a proportion of the heat received by the brickwork will be reradiated to the tubes and the refractory will assume a temperature intermediate between that of the flame and that of the tubes.

Considering the first case, in which it is assumed that the only heat loss is through the wall, analysis shows that for normal types of lining construction the effect of heat loss through the wall on the hot surface temperature may be neglected. It might be expected, therefore, that where an exposed wall is swept by flame, the face of the refractory would approach closely the temperature of the flame. Unfortunately the temperature of the flame $t_f$ is not amenable to calculation; indeed, as used in the present context, it cannot be defined precisely as the temperature of the flame varies along its length. It can be assumed, however, that $t_f$ represents the temperature of the outer zone of the flame and would therefore be expected to exceed the mean radiating temperature ($t_m$), which is that used in design to assess the radiant heat transfer to the tubes.

When there is no flame impingement on the wall, theoretical considerations indicate that the maximum brickwork temperature should be somewhat less than the mean furnace radiating temperature and should vary in proportion to the mean radiating temperature, provided that the areas of the absorbing (tubes) and radiating (flame) surfaces and their shape and relative orientation have a constant relationship. This can be expressed in the form

$$t_{r(e)} = Ct_m$$

where $t_{r(e)}$ is the equilibrium temperature of the exposed refractory surface for short flame burners, $C$ is a factor dependent on the absorbing and radiating surfaces and $t_m$ is the mean radiating temperature.

*Exposed Walls: Test Results*

It has just been shown that if flame impingement on the wall is avoided, the brickwork temperature should be proportional to the mean radiating temperature. This, in turn, is related to the total heat release rate per unit of effective radiant heating surface*. As the calorific values of fuel oils vary very little, this heat release rate can be expressed in terms of the fuel fired per hr. per sq. ft. of effective radiant heating surface (forcing rate), and it is on this basis that all calculations have been made and the test results compared.

Refractory hot face equilibrium temperatures for exposed walls were obtained from boilers 1 to 4 and boiler 6. The maximum temperatures recorded are plotted in Fig. 3. These

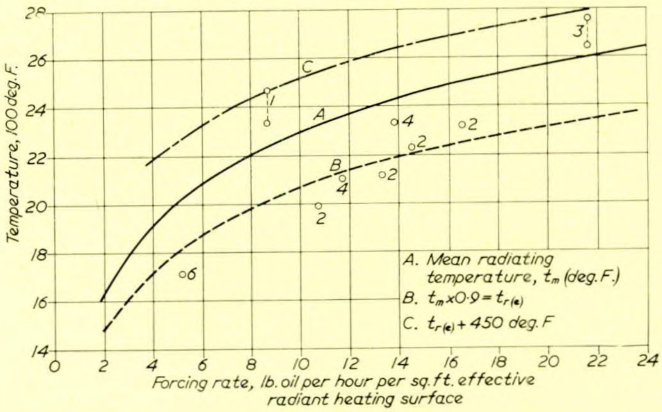



FIG. 3—*Maximum refractory hot face equilibrium temperatures. Test results from boilers with exposed walls (air at 240 deg. F.) (Numbers adjacent to points indicate boiler number)*

results probably represent the maximum brickwork temperatures attained in the respective furnaces, as care was taken in boilers that had been in service to place a thermocouple as close as possible to the area which, by inspection, appeared to be subjected to the highest temperature. With one exception all the results plotted in Fig. 3 were obtained from either the back or side walls of the different boilers; the single point plotted for boiler 6, however, indicates the temperature attained by the front wall of the outboard furnace.

It should be noted that a correction has been made to the recorded temperatures where necessary to allow for variations in the temperature of the air supply; all the temperatures plotted in Fig. 3 are those which would be obtained with combustion air at 240 deg. F., which represents an average value for all the boilers tested.

Curve A in Fig. 3 shows the variation of the calculated mean radiating temperature with forcing rate. It will be noted that this curve divides the plotted results into two groups; the maximum temperatures recorded in boilers 1 and 3 lie above the curve, while those from boilers 2, 4 and 6 fall below it. It is noteworthy that in the two boilers first mentioned long flames were produced and the furnaces were more or less filled with flame when steaming at outputs approaching full power. The other three boilers (2, 4 and 6) were fitted with oil burners of more recent designs which were operated at considerably higher pressures. Shorter flames resulted and it was observed that in these boilers the extent of the flame envelope could be distinguished quite clearly and flame impingement on the back walls of the combustion chambers was avoided. Thus the two groups of points above and below the curve A may be taken as representative of the two sets of conditions previously discussed, i.e. long flame and short flame burning respectively.

Working on the assumption that the refractory temperature when short flame burners are used is proportional to the mean radiating temperature, as indicated by the theory, curve B in Fig. 3 has been constructed. A value for $C$ of 0·9 has been chosen to give a curve which passes through the group of experimental points and it will be seen from Fig. 3 that reasonable agreement is obtained. It is therefore suggested that under good combustion conditions the maximum temperature of exposed walls in boilers of conventional design can be taken as 0·9 times the mean radiating temperature (deg. F.).

Considering now the conditions where the walls are swept by flame, it was suggested that at such positions the temperature is likely to exceed the mean radiating temperature. This

* The effective radiant heating surface is the area of the projected surface of all water tubes exposed to radiation from the flame. Allowance is made for reradiation from the refractory where water wall tubes are fitted.

is confirmed by the test results plotted in Fig. 3. No means are available for estimating this difference in temperature, however, and resort must be made to empirical methods to obtain an expression for the maximum hot face temperature under conditions of flame impingement.

The flame temperature $t_f$, being intermediate between the adiabatic flame temperature $t_a$ and the mean radiating temperature, might be expressed in the form $t_f = Pt_a + Qt_m$, $P$ and $Q$ being suitable constants. As $t_a$ is constant this resolves into $t_f = Qt_m + R$.* This expression should apply also to the maximum brick face temperature since it has been shown earlier that this temperature might be expected to approximate to $t_f$ under conditions of flame impingement.

Using a value for $Q$ of 0·9 (the same as $C$ in the previous case) and 450 F. deg. for $R$, curve C in Fig. 3 is obtained. It will be noted that the results from boilers 1 and 3 show close agreement with this curve for the maximum values, although lower temperatures were also recorded in these two boilers in areas swept by flame. (The range of temperatures is indicated in each case by the two points joined by dotted lines.)

From the details given in Table I it will be noted that boilers 1 and 3 were of entirely different design and there was a wide difference between the proportion of exposed refractory surface in the furnaces; it might be argued therefore that the results from these two boilers cannot be compared on the same basis. On the other hand, in neither of these boilers was there any watercooled surface in the immediate vicinity of the flame which would have a cooling effect on the flame; it is considered that where there is flame impingement the relative areas of cooled and refractory surfaces are of secondary importance. Nevertheless, it is obvious that the agreement between the two results from boilers 1 and 3 with the semi-empirical curve C in Fig. 3 does not provide sufficient confirmatory evidence on the validity of the assumption made in the construction of this curve. However, it is shown in Fig. 4, where curves B and C from Fig. 3 are extended to a forcing rate of 40lb. oil/hr./ft.$^2$ E.R.H.S., that the results of published work by Sherman, Taylor, and Karch(3) agree quite closely with the proposed curve of maximum brickwork temperature at forcing rates considerably higher than any encountered in the marine boilers tested in the present investigation. (The plotted results in Fig. 4 represent the maximum temperatures attained by the side wall of an oil fired, header type, power station boiler where there was evidence of flame impingement.) Furthermore, the results from the tests on boilers with waterwall tubes, which are given later, also lend support to the accuracy of the maximum temperature curves given in Figs. 3 and 4.

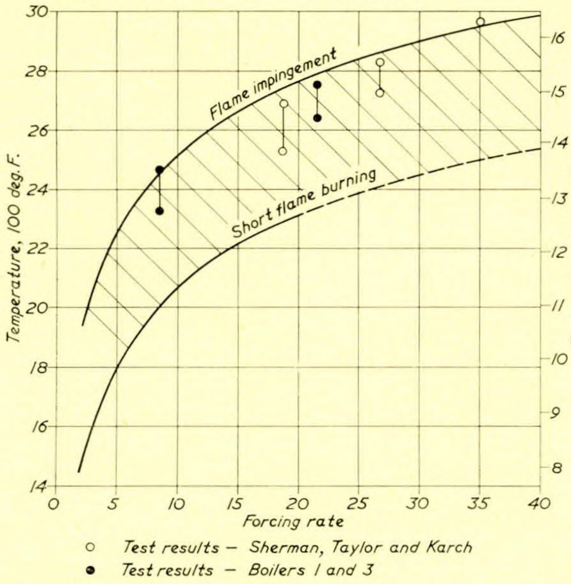



FIG. 4—*Maximum refractory hot face equilibrium temperatures: exposed walls. Air temperature 240 deg. F., excess air 30 per cent*

The shaded area enclosed by the two curves in Fig. 4 indicates the range of temperatures likely to be obtained at the hot face of exposed refractory surfaces up to a forcing rate of 40. This figure is considerably in excess of the forcing rates commonly adopted in merchant service practice at the present time and the diagram may therefore provide some guidance in estimating the operating conditions of the brickwork in possible future merchant-ship boiler designs. Depending largely on the design and operation of the burners, the brick face temperature will approach the upper or lower limits of this band. Where there is direct flame impingement, temperatures might be expected to reach values given by the upper curve but improvement in combustion would lead to a lowering of the brickwork temperature. In this connexion it should be noted that there is no experimental evidence to confirm the accuracy of the lower limit of the temperature zone shown in Fig. 4 for forcing rates above about 16. As it seems likely that brickwork temperatures might be affected to some extent by changes in the design of boilers using short flame burners, it would appear prudent to assume that maximum refractory temperatures would approach the top limit, particularly in those positions where flame impingement might possibly occur, even when the design and operation of the burning equipment leaves little to be desired.

The curves shown in Fig. 4 apply only to boilers with an air supply temperature at 240 deg. F. and 30 per cent excess air; for different conditions some adjustment is necessary. To give some indication of the effect of these two variables, curves are shown in Fig. 5 for air temperatures at 100, 240 and 350 deg. F. and 15 and 30 per cent excess air. It will be noted that the amount of excess air supplied is likely to have a considerable effect on the brickwork temperature but an increase or decrease in the air temperature only results in a change in the refractory temperature equivalent to less than half the change in air temperature.

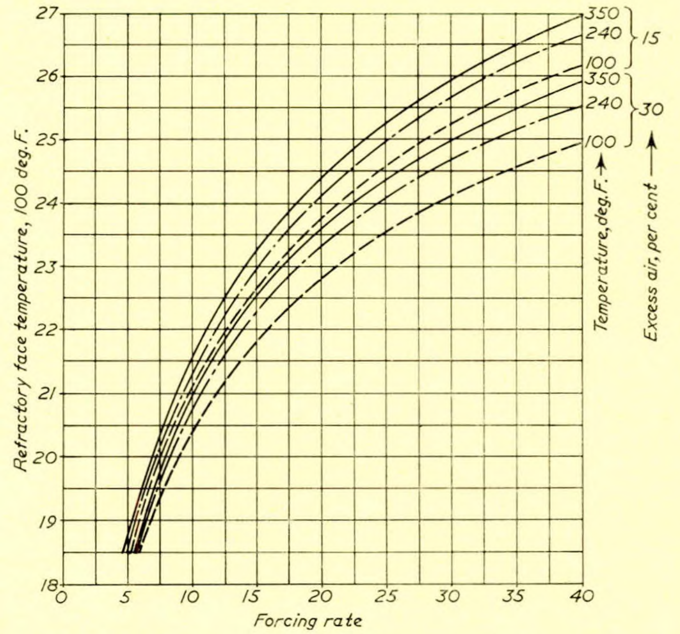



FIG. 5—*Effect of excess air and air temperature on refractory temperature. Exposed walls—short flame burning*

* While it is realized that this is perhaps an over-simplification, the use of this expression, as will be shown, gives results which are in agreement with the observations.

Again referring to Fig. 4, it will be noted that at forcing rates greater than about 20 the rate of increase of temperature is much less than at lower rates. It is in this range, however, that the limiting temperature of the aluminous firebricks that are commonly used at present is reached. For continuous operation at forcing rates greater than 25 it appears that, in order to ensure a reasonable life, superior refractory materials would be needed, particularly in areas where any possibility of flame impingement existed.

From the results of this section of the work three main conclusions can be drawn. Firstly, the maximum operating temperature of exposed refractory surfaces is related to the forcing rate and depends to a large extent on the design and operation of the burners. Secondly, the maximum equilibrium brickwork temperature when short flame burners are used is approximately equal to nine-tenths of the mean furnace radiating temperature for forcing rates up to 16lb. oil/hr./ft.$^2$ E.R.H.S. and possibly higher. Lastly, where there is flame impingement on the wall the temperature is likely to be raised by up to 450 F. deg. over that which would obtain were short flame burning conditions maintained.

*Effect of Water Wall Tubes: Theoretical Considerations*

Water tubes set in front of a refractory wall, besides partially shielding the wall, have the combined effect of cooling the wall by direct radiation from the brickwork to the tubes and causing indirect cooling by reducing the temperature of the furnace gases. If it can be assumed, as would appear reasonable from the results given earlier, that the effect of flame cooling can be taken into account by relating furnace temperature with forcing rate, it remains to determine the effect of direct radiation from the brickwork to the water wall tubes.

For purposes of analysis it will be assumed that the flame can be replaced by a radiating plane parallel to the wall and at a temperature equal to the equilibrium temperature $T_{r(e)}$* of an exposed refractory wall under the given conditions. The system can be represented diagrammatically as shown in Fig. 6,

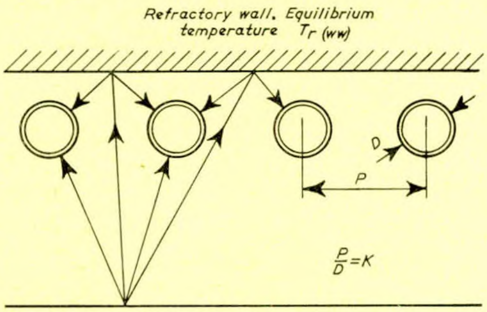



FIG. 6—*Diagram illustrating conditions when water wall tubes are fitted*

from which it will be apparent that, compared with an exposed wall, only a fraction of the heat radiated from the flame is received by the refractory, the remainder being intercepted by the tubes. This case has been investigated by Hottel(4) who has shown that the fraction intercepted by the tubes, $\overline{F}$, is given by

$$\overline{F} = \frac{K + tan^{-1}\sqrt{K^2-1} - \sqrt{K^2-1}}{K},$$

where $K$ is the ratio of tube centre spacing to tube outside diameter.

By making the same assumptions as before, it can be shown that the refractory equilibrium temperature $T_{r(ww)}$ is given by

$$T_{r(ww)} = T_{r(e)}\,(1-\overline{F})^{\frac{1}{4}}$$

* Temperatures expressed by $T$, with corresponding suffices, denote deg. F. absolute.

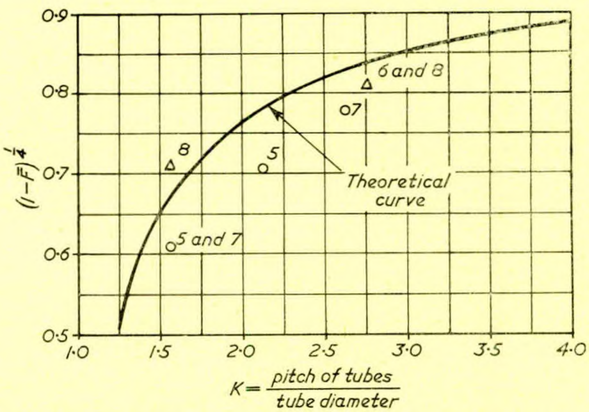



FIG. 7—*Effect of tube spacing on reduction in temperature of refractory, compared with exposed wall*

○ Values obtained from tests on boiler with long flame burners
△ Values obtained from tests on boilers with short flame burners
Numbers adjacent to points indicate boiler number

In Fig. 7 the term $(1-\overline{F})^{\frac{1}{4}}$, i.e. the ratio of water wall equilibrium temperature to exposed wall equilibrium temperature, is plotted against the tube spacing ratio $K$, and from this curve it will be readily seen that for tube spacing greater than about three times the tube diameter the reduction in the operating temperature of the brickwork compared with an exposed wall will be comparatively small. Also plotted in this diagram are values of the ratio $T_{r(ww)}/T_{r(e)}$ obtained from the results of tests on boilers 5, 6, 7 and 8 at a forcing rate of 6lb. oil/hr./ft.$^2$ E.R.H.S., by assuming that in the absence of water tubes the walls would have attained temperatures given by curves B and C in Fig. 3 for the same forcing rate. There is quite good agreement between the test results and the theoretical curve, which suggests that this method of estimating the reduction in refractory hot face temperature resulting from the use of water wall tubes is reasonably accurate. It also lends support to the methods outlined earlier for estimating the temperatures of exposed walls for short and long flame burning.

*Effect of Water Walls: Test Results*

In boilers 5 to 8 particular attention was paid to the determination of the operating temperatures of refractories protected by water wall tubes. All four boilers were of Foster Wheeler design; boilers 7 and 8, except for the combustion equipment, were identical in all respects. The details of construction were generally similar in all the boilers, the wall tubes being 2-in. outside diameter throughout; tube pitches varying from 3 to 5½in. were encountered in different boilers, so it will be seen that the results cover the range of $K$ values most generally used. As before, at least one thermocouple was located in the areas which appeared to be subjected to the most arduous conditions in order to obtain maximum temperature values.

Boilers 6 and 8 were fired under short flame conditions, while in the other two boilers long flames were produced which reached the back walls of the furnaces. None of these burners was operated at a particularly low pressure; indeed those fitted in boiler 7, although long flames resulted, were operated at a higher pressure than the short flame burners. The ratio of watercooled surface in the furnace to the total surface area, including the refractory, was almost the same for all the boilers tested. This suggests that there should be little variation in the results due to differences in design.

The most comprehensive series of tests were conducted on boilers 7 and 8, and for this reason the results are given in detail in Fig. 8 for each thermocouple point. Air heaters were not fitted to these boilers and it should be noted that the temperatures plotted are for an air supply temperature of about 90 to 100 deg. F.

It will be at once apparent from Fig. 8 that at all the

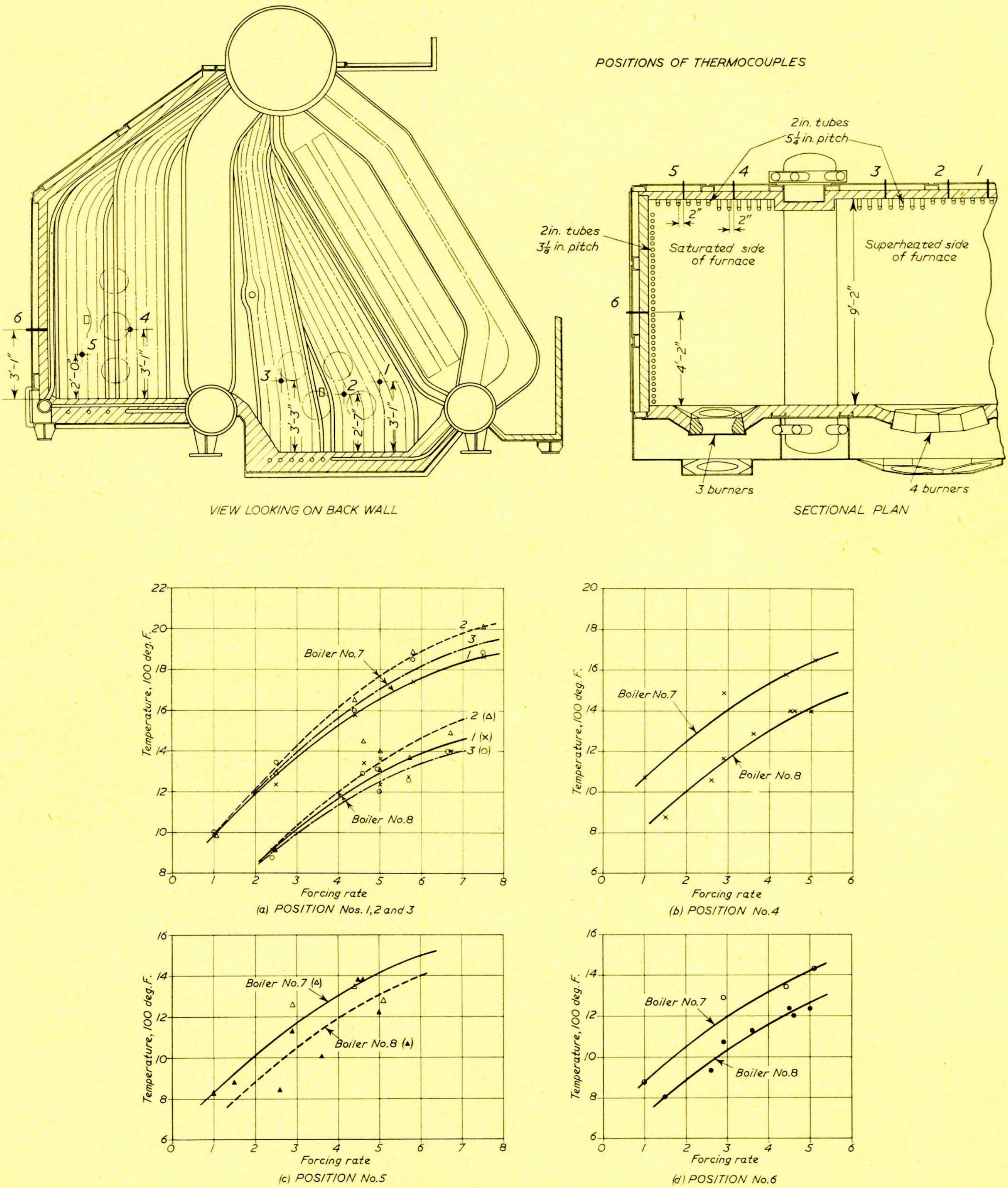



FIG. 8—*Refractory hot face equilibrium temperatures in boilers 7 and 8*

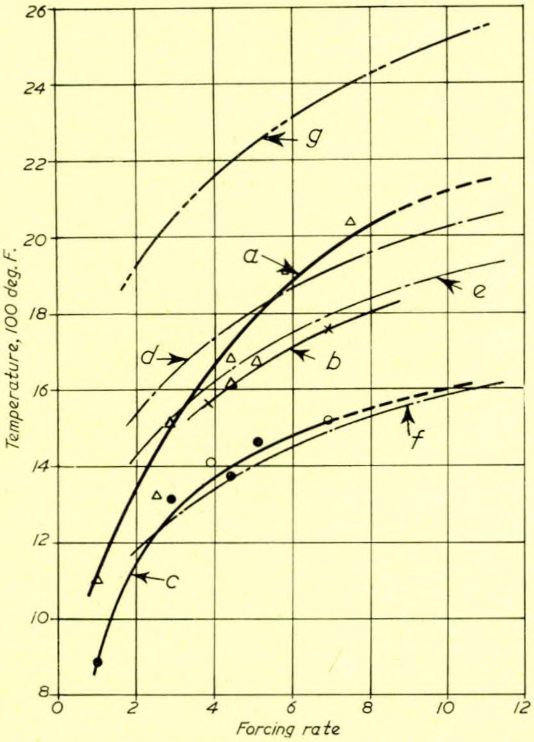



FIG. 9—*Effect of water wall tubes on refractory hot face temperature—long flame burners. (Curves drawn for air at 240 deg. F., 2-in. outside diameter tubes)*

a) $5\frac{1}{4}$-in. pitch tubes △ positions 2 and 4, boiler 7
b) $4\frac{1}{4}$-in. pitch tubes × position 3, boiler 5
c) 3-in. and $3\frac{1}{8}$-in. pitch tubes ● position 6, boiler 7
○ position 1, boiler 5
d) Theoretical curve, $5\frac{1}{4}$-in. pitch tubes
e) Theoretical curve, $4\frac{1}{4}$-in. pitch tubes
f) Theoretical curve, $3\frac{1}{8}$-in. pitch tubes
g) Exposed wall temperature

positions examined the temperatures recorded in boiler 7 were higher than those at the corresponding forcing rates in boiler 8. This demonstrates most clearly the influence of burner design and operation on the brickwork temperature; from the results for the inboard furnaces (thermocouples 1, 2, and 3) it will be seen that improvements in combustion conditions can lead to a reduction in the refractory hot face temperature of up to 500 F. deg. The difference is less marked in the outboard furnace (thermocouples 4, 5 and 6), which was to be expected, as it was noticed during the course of the test on boiler 7 that the flame in this furnace tended to be shorter than that in the inboard furnace.

In Figs. 9 and 10 are plotted the maximum temperatures recorded in the four boilers which had water wall tubes. In view of the wide difference in temperatures obtained with long flame and short flame burning the results from the two boilers where flames reached the walls (5 and 7) are shown in Fig. 9 and those from boilers 6 and 8, which had the short flame burners, are plotted in Fig. 10. Referring first of all to Fig. 9, curves (a), (b), and (c) show the test results for $5\frac{1}{4}$, $4\frac{1}{4}$ and 3 (or $3\frac{1}{8}$) in. pitch tubes, respectively. These can be compared with the corresponding theoretical temperature curves (d), (e), and (f) which have been calculated by multiplying the assumed exposed wall temperature, given by curve (g), by the corresponding value of $(1 - \overline{F})^{\frac{1}{4}}$ obtained from Fig. 7 for each value of tube spacing. The curve of exposed wall temperature (curve (g)) used in deriving the theoretical curves was obtained by the same method as the upper curve in Fig. 4. It will be seen that for tube pitches of 3 and $4\frac{1}{4}$in. there is very close agreement between the calculated and test results, but for the $5\frac{1}{4}$-in. pitch tubes there is greater divergence between the curves at forcing rates less than 3; this can most probably be attributed to the greater amount of excess air supplied at reduced outputs.

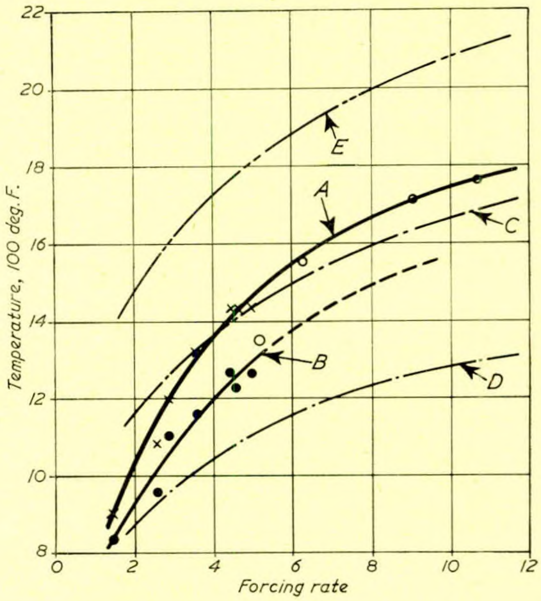



FIG. 10—*Effect of water wall tubes on refractory hot face temperature—short flame burners. (Curves drawn for air at 240 deg. F., 2-in. outside diameter tubes)*

A) $5\frac{1}{4}$-in. and $5\frac{1}{2}$-in. pitch tubes × position 4, boiler 8
○ positions 4 and 5, boiler 6
B) $3\frac{1}{8}$-in. pitch tubes ● position 6, boiler 8
C) Theoretical curve, $5\frac{1}{4}$-in. pitch tubes
D) Theoretical curve, $3\frac{1}{8}$-in. pitch tubes
E) Exposed wall temperature

Turning now to the results obtained from the boilers with short flame burners plotted in Fig. 10, it will be seen that there is reasonably close agreement between the test results for $5\frac{1}{4}$ and $5\frac{1}{2}$-in. pitch tubes (curve (A)) and the corresponding theoretical curve (curve (C)). On the other hand, the hot face temperature of that part of the lining in boiler 8, which was protected by $3\frac{1}{8}$-in. pitch tubes, was considerably above the estimated value except at very low forcing rates (curves (B) and (D)). This may possibly be accounted for by the proximity of the flame to the side wall thermocouple compared with those in the back wall (see arrangement drawing in Fig. 8).

In estimating the refractory temperatures shown by curves (C) and (D) the procedure was the same as that used in deriving the theoretical curves in Fig. 9, but instead of the exposed wall temperatures being taken from the upper curve in Fig. 4 they were taken from the lower one. It seems, however, that this method is liable to underestimate the temperature of side walls when short flame burners are used, although it should be borne in mind that curve (B) in Fig. 10 is based on the results from only one boiler. In this particular example (boiler 8) the results lie between the theoretical curves for short flame and long flame burning. It therefore seems likely that when using short flame burners at higher forcing rates, the side wall may attain a temperature approaching that when long flame burners are used.

On reviewing the results of this part of the investigation it appears that the steady maximum operating temperatures of refractories shielded by water tubes may be estimated with sufficient accuracy for all practical purposes by multiplying the temperature that would be attained by an exposed wall under similar conditions (from Fig. 4) by a factor which depends only on the spacing and diameter of the tubes (see Fig. 7). For the side walls of furnaces in which short flame burners are fitted it would appear safer, however, to assume that the temperature would reach the same value as would be reached under conditions of flame impingement.

TEMPERATURE DISTRIBUTION

Although the primary object was to determine the conditions in the sections of furnace linings that are exposed to the most severe temperature changes, the opportunity was taken in several tests to explore the temperature distribution in other parts of the brickwork. As the number of recording points was limited it is not possible to present a complete picture of the temperature distribution over the whole furnace lining; the results presented below, however, give some indication of the extremes of temperature that occur under steady steaming conditions.

Boiler 4 had short flame burners and the difference between the maximum and minimum temperatures measured was only 250 F. deg. Similar results were obtained in boilers of other types which had short flame burners. One of these was boiler 2 (Babcock and Wilcox integral furnace type) in which the temperature of the front wall at the level of the burners was about 170 F. deg. less than the maximum temperature measured on the back wall; at a point 5ft. above the hottest zone of the back wall the temperature was only 100 F. deg. less. The results from boiler 6 (Foster Wheeler twin-furnace type) form another example illustrating this point. In this boiler two thermocouples in the front wall, one level with the burners and the other nearly 6ft. above, showed a difference of only 200 F. deg.

Considerably greater temperature differences were observed in furnaces where there was flame impingement on the walls, as would be expected. The results from boiler 1 provide an example of severe flame impingement; temperatures at different points in the side walls of this Yarrow three-drum boiler differed by as much as 700 F. deg. This suggests that areas of refractory swept by flames attain a temperature up to about 500 F. deg. higher than would obtain if flame impingement could be avoided. This corresponds roughly with the width of the band shown in Fig. 4.

In boiler 3, the maximum temperature difference recorded was 470 F. deg. This was not a case of localized flame impingement as in boiler 1, since at full power the furnace was filled with flame. The cooling effect of the tubes probably accounts for some of the drop in temperature found at the higher levels of the furnace. The main point of interest from this test was the uniformity of the results from positions at the same level in the furnace. This was rather unexpected as in most boilers of this type severe localized damage occurs at the centre of the end walls and it might be expected that the temperature at such positions would be higher. In fact one thermocouple was placed in the centre of an area where severe wastage had taken place, but the temperature recorded at this position was slightly less than that at corresponding points on the back wall. It must be concluded, therefore, that the spalling damage that occurs at this position is due to the more frequent temperature fluctuations in this region.

It appears that in furnaces where the walls are not swept by flame the hot face temperature of exposed walls, or walls with uniformly spaced water tubes, is fairly uniform over the greater part of the lining; the maximum temperature differences recorded were of the order of 200 to 300 F. deg. Where flame impingement occurs, however, the temperature of localized areas may be increased by something of the order of 500 F. deg.

RATE OF CHANGE OF TEMPERATURE

It has been shown that below a certain temperature, the strain set up in a refractory body is directly proportional to the temperature gradient in the body[5]. The temperature gradient at the hot face depends, in turn, upon the rate of heating or cooling (see Fig. 2) and therefore the occurrence of spalling is governed by the rate of change of temperature of the refractory.

Whenever possible the temperature record included the initial heating up and the final cooling down. Most of the records could be divided into five sections: steam raising, manœuvring out of port, steaming at normal full power, manœuvring into port, and cooling down. Sections of some

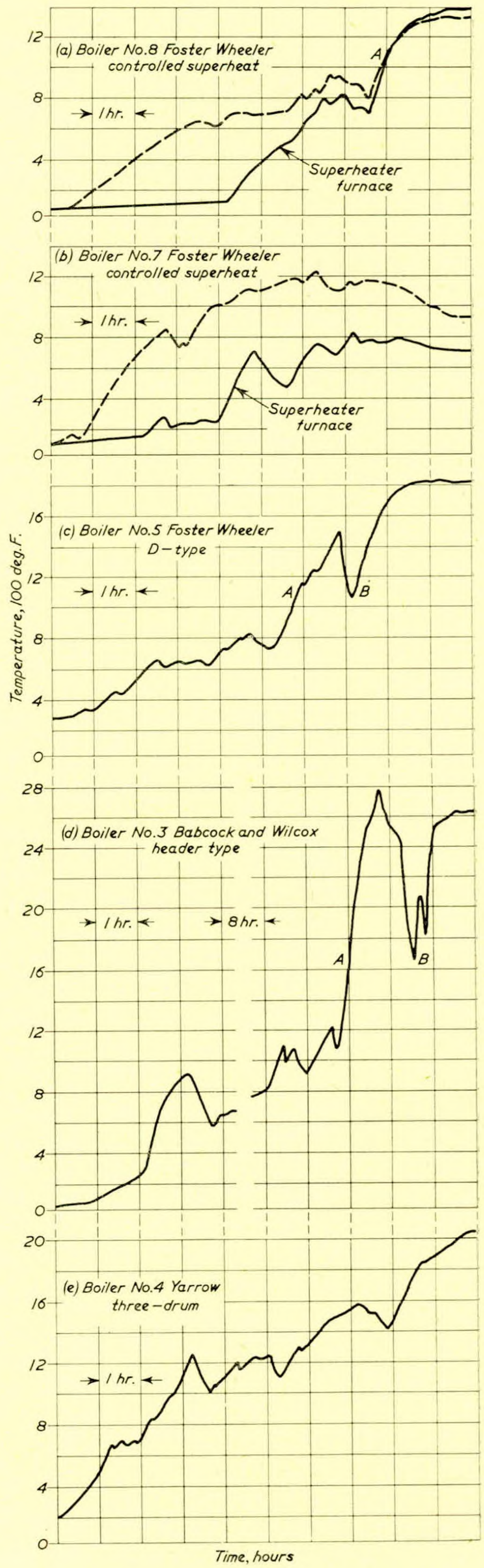



FIG. 11—*Typical records of back wall temperatures during steam raising and manœuvring*

typical temperature records, covering the end of the period of steam raising and the subsequent manœuvring period, are illustrated in Fig. 11; these are all from thermocouples situated in back walls opposite the burners. Temperatures varied very little when the ship was steaming at full power. Such routine operations as soot blowing and burner changing caused a small variation in the maximum steady temperatures but this did not normally amount to more than 100 F. deg.

It was observed in several ships that a small general change in temperature, either up or down, coincided with the times of changing the engine room watch. This change was usually permanent for the duration of the watch and would appear to be caused by small alterations to the settings of fans and burner registers by different personnel. Under steady conditions of power output, different combinations of burners and sizes of burner tips caused some variation in the brickwork temperature at any point. This accounts for some of the scatter of the results obtained from boilers 7 and 8 (plotted in Fig. 8).

*Furnace Walls: Steam Raising*

The normal practice in all ships was to allow some five to six hours to bring a boiler up to the working steam pressure from cold. For the first three to four hours one burner with a small tip was used, and sometimes its position was changed at intervals. During this time the lining temperature seldom reached more than 200 to 300 deg. F. Towards the end of this period additional burners were put into operation, intermittently at first, and larger tips were used. The result was a more rapid rise in the temperature of some sections of the lining, particularly front walls and the area within reach of the flame.

Although an adequate overall time might be taken to heat up the boiler, rapid local heating of some sections of the lining over the temperature range of 300 to 900 deg. F. was often found. In twin-furnace, controlled superheat boilers the lining of the superheater furnace was subjected to a more rapid rise in temperature owing to the fact that steam is raised by means of burners in the outboard (saturated) furnace only. As will be seen from Fig. 11 (a) and (b), the temperature of the superheater furnace lining (solid line) did not exceed 150 to 200 deg. F. until the burners in this furnace were put into operation.

*Furnace Walls: Manœuvring*

Manœuvring in and out of port was indicated on the temperature record by a period of fluctuating temperatures. The duration of this period was a characteristic of the particular port. Where locks and long river passages had to be negotiated, several hours were necessary to work up to full temperature, as at (e) in Fig. 11.

The end of this period, when the "full-away" order was received, was shown on the record by a sudden rapid rise in temperature at all positions, sometimes to temperatures above the normal steady maximum values (shown at A in Fig. 11 (a), (c), and (d)). This increase in temperature was of the order of 600 F. deg. in boilers with water wall tubes (Fig. 11 (c)) and up to 1,600 F. deg. in boilers with unprotected linings (Fig. 11 (d)). The time taken for this increase in temperature did not normally exceed about 30 minutes, and in most boilers was the fastest recorded rate of heating. The temperature record for the period of manœuvring into port was very similar, with a sudden fall in the temperature followed by a more gradual cooling in a series of fluctuations, corresponding to the record at the start of the voyage. Cooling rates were generally somewhat less than the heating rates.

Another characteristic feature of the temperature records was a sudden fall in temperature when the ship was stopped to drop or pick up a pilot. This was followed by an equally rapid return to the normal temperature and will be seen in several curves in Fig. 11, particularly at B in Fig. 11 (c) and (d).

*Furnace Walls: Cooling*

When the boilers were shut down after docking, the temperature records became normal cooling curves, the cooling rates being proportional to the temperature. In all the boilers tested, at least 24 hours were necessary for the lining to cool to 75-100 deg. F. At the end of the manœuvring period the lining temperature varied from about 1,100 deg. F. for exposed linings to 900 deg. F. for linings behind water tubes, and thereafter the average rate of cooling did not exceed 60 F. deg. per hr. When necessary this rate of cooling for the last few hundred degrees could safely be increased by forced air circulation.

*Quarl Blocks*

One test (boiler 9) was devoted to the determination of the temperature conditions at a number of points along one of the burner throats of a Babcock and Wilcox single-pass header type boiler. This boiler had a back wall of stud tube construction and was fitted with six burners. The thermocouples were fitted in the second burner opening from one end. Five thermocouples, at intervals of 2in., were cemented into a shallow groove cut into the face of one of the lower quarl blocks, as shown in Fig. 12. A continuous record was taken during the course of the trials of the ship and a reproduction of the complete record is shown in Fig. 13. The extremely rapid changes of temperature that can occur at the face of the quarl blocks will be apparent from this diagram.

During the initial heating-up stage only the centre burners were used, but later No. 2 burner was used intermittently for about 10 minutes every half-hour. This resulted in a series of fluctuations in temperature of about 200 F. deg. at all positions along the quarl. With the size of burner used for manœuvring, the temperatures at positions 1 and 5 reached 2,020 and 1,200 deg. F. respectively after about an hour's operation, but with the larger burner, used for full power output, the temperatures at these positions rose to maximum

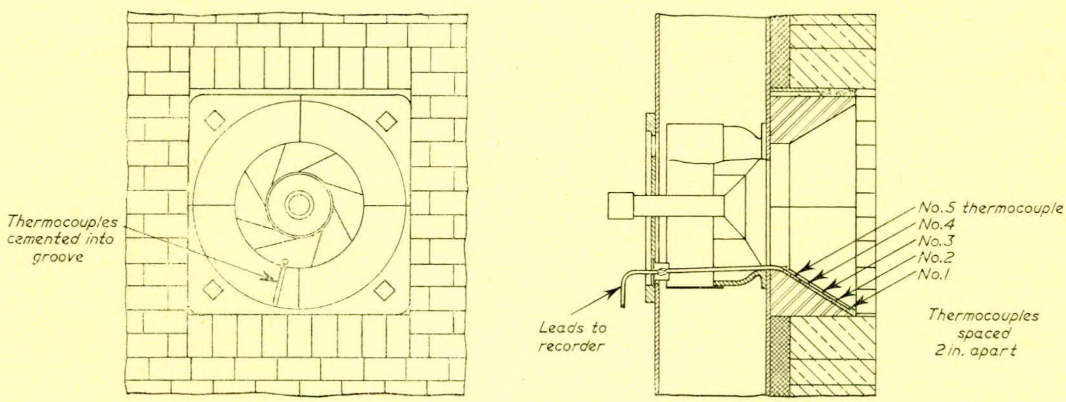



FIG. 12—*Arrangement of thermocouples in quarl block, boiler 9*

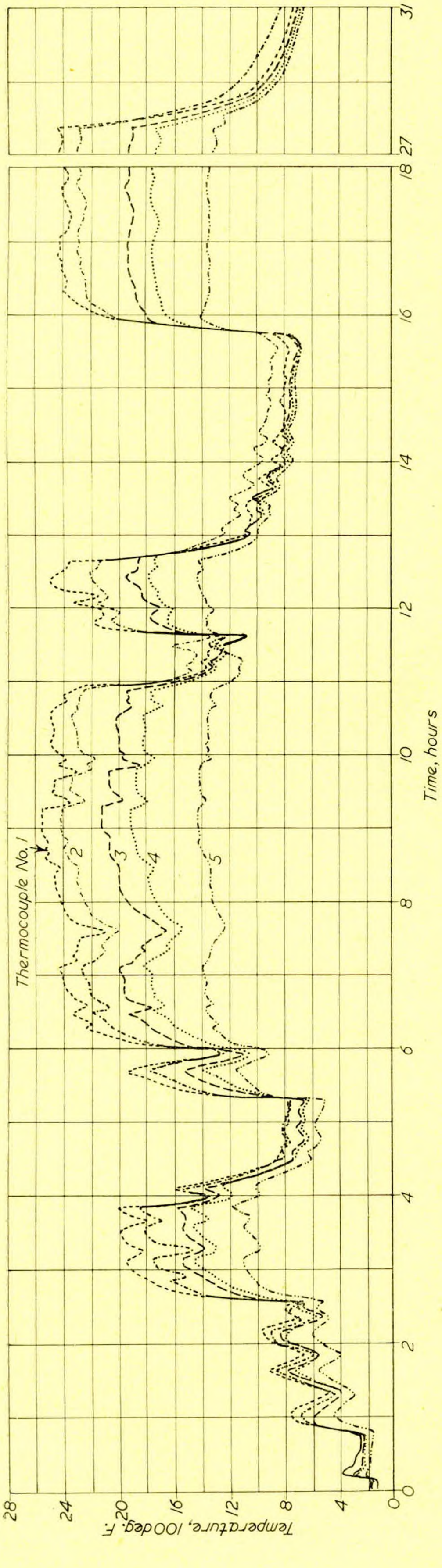



FIG. 13—*Temperature record from quarl block, boiler 9*

values of 2,550 and 1,420 deg. F. On shutting off No. 2 burner with the other burners in operation, the temperatures fell to 770 deg. F. at position 1 and 660 deg. F. at position 2. With the larger size burner tips in use the flame appeared to fill the cone formed by the quarl blocks. The lower maximum temperatures recorded with a small burner tip would appear to be largely due to the flame not touching the surface of the quarls. To illustrate the magnitude of these changes in temperature more clearly, the heating and cooling curves shown in Fig. 14 have been drawn; these show the effect on the

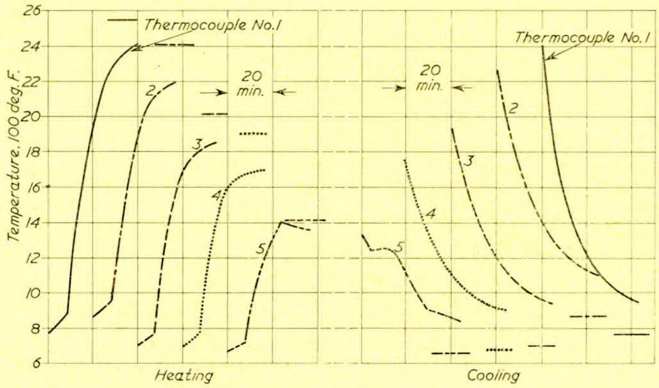



FIG. 14—*Heating and cooling curves for points along quarl block, boiler 9*

quarl-block temperature of shutting down the burner from full power and lighting up again while the other burners were in operation. The curves indicate a maximum rate of heating of the order of 100 F. deg. per min. The initial rate of cooling was much the same, but below a temperature of 1,200 deg. F. the cooling rate was very much slower, about an hour being required for the temperature to fall over the next 400 degrees. The high rate of cooling of the quarl block might, in part, have been caused by the presence of the watercooled back wall.

In Fig. 14 the short horizontal lines show the average

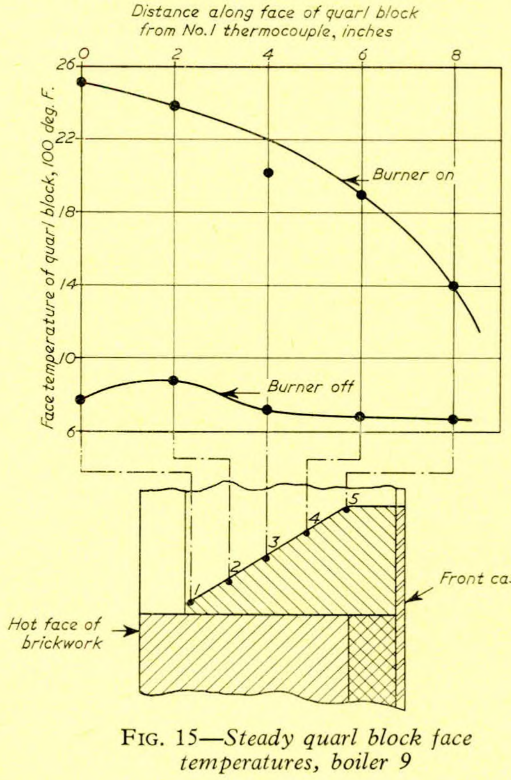



FIG. 15—*Steady quarl block face temperatures, boiler 9*

maximum and minimum temperatures attained at each point after conditions had been maintained steady for periods exceeding two hours. These values have been plotted in Fig. 15 to show the differences in equilibrium temperatures along the quarl. From this diagram it will be seen that the temperature increases along the face of the block when steaming at full power; this has the effect of imposing additional stresses on the refractory material.

*Summary of Results of Tests on Rate of Change of Temperature*

The maximum rates of heating and cooling recorded during the tests for a temperature change of not less than 500 F. deg. are given in Table II. These figures apply to temperature changes below 1,800 deg. F. The heating and cooling rates tabulated do not represent the absolute maximum values recorded in many cases. In most boilers more rapid changes were found to occur over a limited temperature range of 100 to 300 F. deg. but these have been neglected as the strains set up in the refractory would be relatively small.

Recent laboratory work on the spalling resistance of firebricks has emphasized the importance of the size of the test sample; larger pieces tend to spall more readily than smaller ones. It is therefore difficult to state accurately the maximum safe rate of heating of a firebrick, especially in the case of a quarl block of irregular shape. It has been found, however, that firebricks, $9 \times 4\frac{1}{2} \times 3$in. or $9 \times 6 \times 3$in. in size, will crack when heated from one end at rates in excess of 10 to 15 F. deg. per minute. The crack usually appeared parallel to the hot face at a position where the temperature is below 1,800 deg. F.

The results of the heating-up rates given in Table II indicate, therefore, that the conditions in boilers were often such that cracking of the firebricks could be expected. Once a crack had formed, then vibration, continued temperature fluctuation and shrinkage of the brick, caused by slag pick-up, would tend to cause the cracked portion to fall away from the lining.

When considering the results presented in Table II it must be borne in mind that the recorded rates of heating depend to a large extent on the service conditions of the ship and it is therefore difficult to draw any general conclusions. The extremely high heating rate in boiler 1, for example, may be attributed to the fact that the time taken from leaving the quay to working up to full power amounted to only a few minutes. There appears to be no correlation between the types of burners used and the rates of heating recorded owing to the variations in practice from one ship to another. But to a certain extent, the rates of change of temperature are proportional to the maximum operating temperature, as would be expected.

TABLE II—MAXIMUM MEASURED RATES OF HEATING AND COOLING FOR A CHANGE OF TEMPERATURE EXCEEDING 500 DEG. F.

| Boiler no. | Type of boiler | Position in furnace | Heating rate, deg. F./min. | Cooling rate, deg. F./min. |
|---|---|---|---|---|
| 1 | End-fired Yarrow | Back | 100 | 65 |
| | | Side | 70 | 40 |
| 2 | Babcock and Wilcox integral furnace | Front | 55 | 35 |
| | | Back | 40 | 30 |
| 3 | Babcock and Wilcox header type | Back | 50 | 60 |
| | | Side | 50 | 40 |
| 4 | End-fired Yarrow | Back | 15 | 10 |
| 5 | Foster Wheeler D-type | Back | 30 | 15 |
| | | Side | 50 | 10 |
| 6 | Foster Wheeler controlled superheat | Outboard furnace front | 40 | 5 |
| | | Outboard furnace back | 30 | 5 |
| | | Inboard furnace front | 20 | 15 |
| | | Inboard furnace back | 30 | 20 |
| 7 | Foster Wheeler controlled superheat | Outboard furnace back | 5 | 15 |
| | | Inboard furnace back | 10 | 20 |
| 8 | Foster Wheeler controlled superheat | Outboard furnace back | 10 | 10 |
| | | Inboard furnace back | 15 | 10 |
| 9 | Babcock and Wilcox header type | Quarl block | 110 | 70 |

The maximum rate of cooling is governed largely by the temperature from which cooling commences but it is also influenced by the design of the boiler, i.e. the area of heat absorbing surface exposed to radiation from the refractory. Another important factor is the effectiveness of the air shut-off on the burners. The slower rates of cooling in boilers 5 to 8 are due mostly to lower operating temperatures. In this connexion it was noted that the rate of cooling of refractory protected by the water wall tubes was, in general, much the same over the first 200 to 300 F. deg. as in boilers with exposed linings, although the initial temperature was usually considerably lower.

## RECENT DEVELOPMENTS IN LINING CONSTRUCTION

Important changes have taken place in both design and materials during the past eight or nine years. All-monolithic construction has largely replaced the previous bolted block practice in boilers having water tubes in front of the walls; mouldable material is used for exposed sections such as floors and front walls, and castable material for the cooler parts of the furnace. In other types of boiler without water walls, monolithic construction is now fairly common practice for front walls, but brickwork remains most usual for the rest of the furnace lining.

The term "monolithic" is used to describe linings or parts of linings made from mouldable or castable materials which are installed *in situ*. A monolithic lining is one constructed from a continuous mass of material as distinct from a lining made of small prefired units. If the same material were used throughout, joints could be entirely eliminated. In practice, however, some joints are necessary since it is often desirable to vary the type of material used in different sections of the lining.

Mouldable materials consist of mixtures of prefired clay, or grog and raw clay, similar to those used for making firebricks, with sufficient water added to provide the necessary workability. Although a mouldable mix may have a similar chemical composition and much the same refractoriness as a firebrick, it has significant differences in other respects. The relatively weak bond provided by the raw clay is converted to a strong ceramic bond during the manufacture of firebricks by firing to a temperature of 1,300 deg. C. (2,370 deg. F.) or more. The shrinkage that accompanies the formation of the ceramic bond having thus already taken place, firebricks are volume stable at service temperature.

Stability in mouldable mixes is provided by the grog which will constitute some three-quarters or more of the dry weight of the mix. Careful grading to obtain the maximum bulk density is necessary to reduce the drying and firing shrinkages. The prefiring temperature of the grog must be high to provide stability at service temperatures. Since the proportion of clay must be the minimum necessary to provide adequate workability, the clay itself must be very plastic. Adequate refractoriness is also required to prevent shrinkage at the hot face.

Because there must be a temperature gradient through the lining, the hot face will develop a ceramic bond while the material at the cold face will retain its unfired bond. Between these two extremes there will be a zone of weakness within the lining where the unfired bond has been destroyed and no ceramic bond formed. The presence of this weak zone requires the use of securing devices buried in the lining during construction. To be effective these anchors must be carefully designed and accurately positioned in the lining. An example of a securing device is shown in Fig. 16; this employs a ceramic key and is giving good results in service.

The mix must be well hammered into position during the building up of the lining so that each piece added is thoroughly incorporated. To prevent any possibility of laminations parallel to the hot face, ramming must always be carried out at right angles to the face. The material must be solidly packed around the anchors and securing devices. These requirements can only be achieved if the consistency of the mix is exactly right.

The correct thickness may be obtained by ramming in excess material and then slicing off the surface to the required line. The surface should not be pounded or trowelled smooth as this will retard the drying out. To control and limit the extent of cracks, which may form on drying and heating, surface cuts to a depth of 1in. should be made at distances of about 4ft., both horizontally and vertically. Vent holes made by pushing a $\frac{1}{4}$-in. pointed rod right through the lining will assist the escape of water vapour during drying and firing.

Mouldable material develops mechanical strength after it has been fired. Prolonged air drying is undesirable and the boiler should be lit up within 24 hours after completion of the installation if this can possibly be done. A period of low temperature heating followed by a gradual increase until the maximum working temperature is reached is recommended.

The foregoing remarks concerning the installation of mouldable material are by no means comprehensive. It is essential that the correct procedure be used in the application of this material if satisfactory results are to be obtained. With this in mind the Marine Boiler Refractories Committee, which is a joint committee of the British Shipbuilding Research Association and the British Ceramic Research Association, has prepared a report setting out recommended methods for the application of mouldable and castable refractories.

The increased resistance to thermal shock observed in monolithic linings would seem to be due to the absence of a rigid glassy bond. Although a considerable number of fine cracks form in the material it does not disintegrate to any extent except in the thinnest sections. Slag attacks the matrix isolating the larger grog grains, and in this respect firebricks are more resistant. Slag penetration in depth is reduced by the steep temperature gradient through the lining.

One of the outstanding features of monolithic construction is ease of repair; damaged sections in a mouldable wall

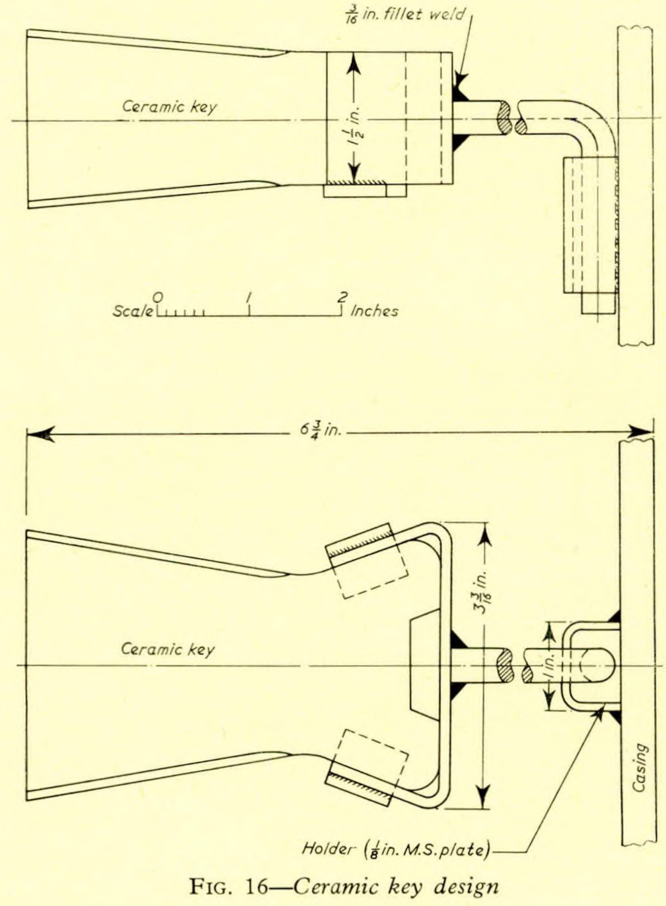



FIG. 16—*Ceramic key design*

FIG. 17—*Back wall of D-type boiler (four years' service)*

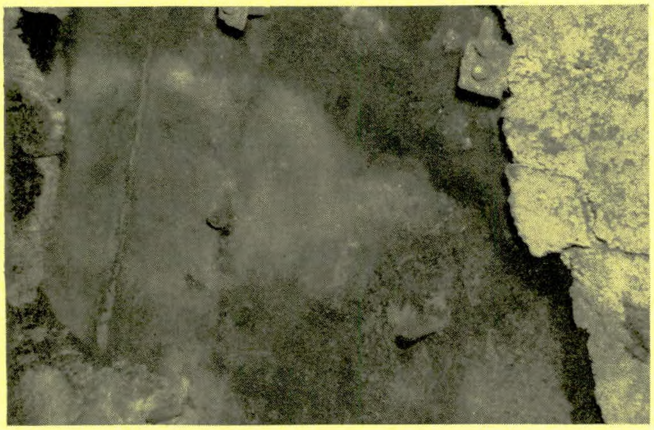


FIG. 18—*Back wall of single-pass header type boiler stripped for replacement of rammed plastic lining (four years' service). Note burned-off anchor bolts*

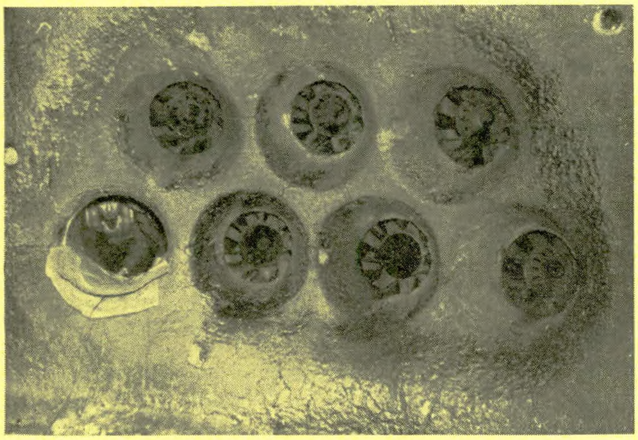


FIG. 19—*Burner arrangement in a controlled superheat boiler showing dish shape including quarl tubes*

can easily be cut out and replaced with new material, provided that patches are well keyed in to the adjacent material. There is no need to disturb undamaged sections. It has been noted, however, during the inspection of furnaces, that there is a widespread tendency for spalling wastage to be repaired by small "surface" patches, applied directly to the damaged surfaces, with little or no keying to the rest of the lining. This patching technique is extremely quick and cheap to carry out, but most of these patches tend to break away from the surrounding material owing to shrinkage and lack of effective keying, and further repairs are required after three to four months' service. This method, which is costly in labour and material, is favoured mainly due to reluctance to cut out damaged sections in case this should cause collapse of the remaining material. Fig. 17 shows the temporary type of patch applied to repair an area of spalling directly opposite the burners in a cross-channel passenger vessel. Very severe operating conditions obtained in the boilers of this ship since a large percentage of steaming time was spent in manœuvring; however, there were frequent opportunities for boiler inspection and repairs, and therefore the type of patching was sufficient to maintain the lining in service. In contrast to this, Fig. 18 shows a back wall with the lining stripped for major repairs and replacement after four years' service. From information supplied by the ship's engineers, spalling damage similar to that illustrated in Fig. 17 had occurred in this case, allowing flame penetration to the anchor bolts, some of which had burned through. Service conditions on this vessel (a cable ship) limited opportunity for repairs of this nature to once every four years, hence the need for complete stripping and replacement of any damaged sections of lining material to ensure trouble-free service between overhauls.

Floors constructed with mouldable material are relatively few, being found only in boilers where complete monolithic linings have been fitted; even in some of these, tile or brickwork construction has been retained for the floor. From the smooth appearance of most slag coatings, it is thought that the surface reaches a liquid or semi-fluid state under operating conditions, and that temperatures will be sufficient to soften slag layers to a depth of about 1in. A few instances have been observed where undercutting of front walls has occurred, probably due to the erosive action of a surface layer of liquid slag stirred up by the ship's motion. No failure of mouldable refractory floor linings has been observed or reported, even in material which has seen up to six years' service. In some cases, however, removal of the refractory has been necessary owing to the impossibility of separating it from fused slag accumulations when these are being cut out to reduce floor

FIG. 20

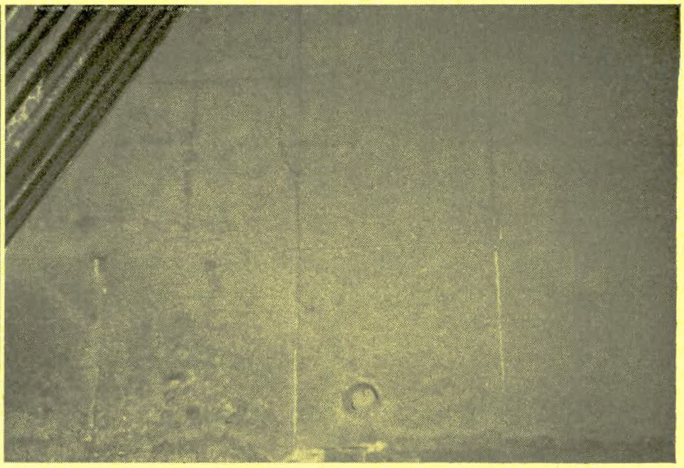


FIG. 21

*Front walls above burners in controlled superheat boilers showing very little damage after two years' service* thickness. It is doubtful whether in the case of floor linings the extra cost of monolithic construction is justified.

As already mentioned, the bolted block practice has been replaced by all-monolithic construction and this is perhaps the most conspicuous of the changes in design. There have been a number of other changes in practice, however, less conspicuous but no less important. In addition to the successful use of ceramic keys to support monolithic materials, improved keys of heat resisting metal are now used to support brickwork. Much improvement has resulted from the practice of welding the keys to the casing instead of drilling the casing for bolts and the maintenance of an airtight casing has thus reduced the failure of the keys by oxidation.

In new ships it is evident that short flame burning is being obtained; great improvement in the life of the lining (with the exception of the front wall) results from this condition.

The use of monolithic linings has simplified the construction of front walls containing closely grouped burners. The ease with which a concave shape can be made has enabled burner blocks to be angled and adequate clearances between the flame and the lining to be maintained, and this in turn has enabled floor levels to be raised so that troublesome low side walls have tended to disappear. An example of a concave front is shown in Fig. 19.

Monolithic front walls above burners generally show very little sign of damage except for a few irregular contraction cracks which do not follow the expansion cuts made in the material before firing. Figs. 20 and 21 are typical examples. These cracks do not, however, represent serious failure, as it is thought that they close when the linings reach operating temperature. Repairs required in service are relatively few compared with those common in brickwork construction.

Mouldable and castable materials are now very widely used for burner quarl blocks. Whilst the mouldable material normally gives the better performance, castable material generally proves more convenient from the repair aspect. Blocks can be cast in a shore establishment and carried as spares, in the manner used for prefired blocks. More care, however, is needed in handling blocks made of materials intended for high temperature use. The suitability of materials for quarl blocks is being examined by the joint B.S.R.A./B.C.R.A. team in laboratory and field tests and this appears to be leading to a better understanding of the properties required of materials for this application.

The state of moulded burner quarls after service varies widely between different boilers and is mainly dependent on boiler operating conditions and the extent of maintenance received in service. An outstanding example of burner quarls in very poor condition owing to lack of care in boiler operation and maintenance is shown in Fig. 22. Here the front wall-burner quarl assembly had been in service about three years, and patches had been applied to repair spalling damage after each voyage. The burner-cone shapes had deteriorated so much owing to the repeated patching (Fig. 23) that bad misalignment of the quarls relative to the burners had resulted, leading in turn to flame impingement, further spalling damage, and more patching. There had been no attempt to retain the original designed shape by re-forming the quarls, and the boiler was kept in service only by the ease of patching which is characteristic of the material.

FIG. 23—*Burner quarl showing repeated patching leading to loss of shape and misalignment (three years' service)*

By way of contrast Fig. 24 shows a burner quarl after four years' service in a boiler of similar type with perfect retention of designed shape and little evidence of damage by spalling or slag erosion.

Where very severe conditions exist, e.g. in frequent manœuvring of highly rated boilers, some spalling damage and cracking has been observed in the quarl tubes and in the sections of material between burners (Fig. 25, D-type boiler installed in a cross-channel passenger vessel).

Close examination of these cracks revealed that most were the result of thermal contraction on closing down the boiler, and that at operating temperatures they would be partially or completely closed up. The cracks were very irregular in direction, so that many of the cracked pieces of lining material remained quite firmly keyed in position even when cold. In these circumstances no repairs were considered necessary, and the linings could be left undisturbed unless large pieces of material became dangerously loose.

Slight wastage by spalling has sometimes been noted with boilers of the type shown in Fig. 19, particularly on the upper

FIG. 22—*Burner quarls in very bad condition after three years' service due to poor maintenance*

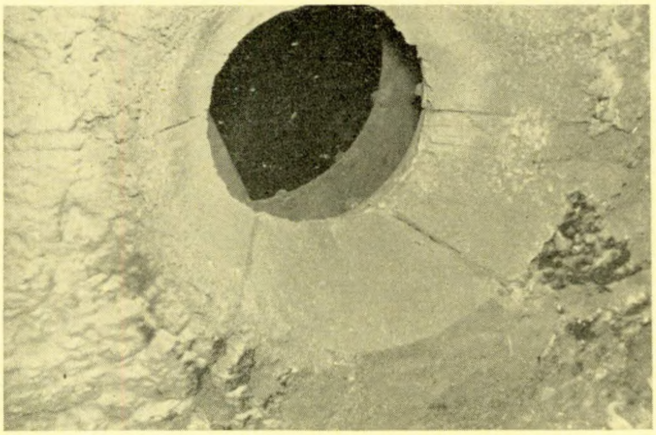


FIG. 24—*Burner quarl in good condition after four years' service*

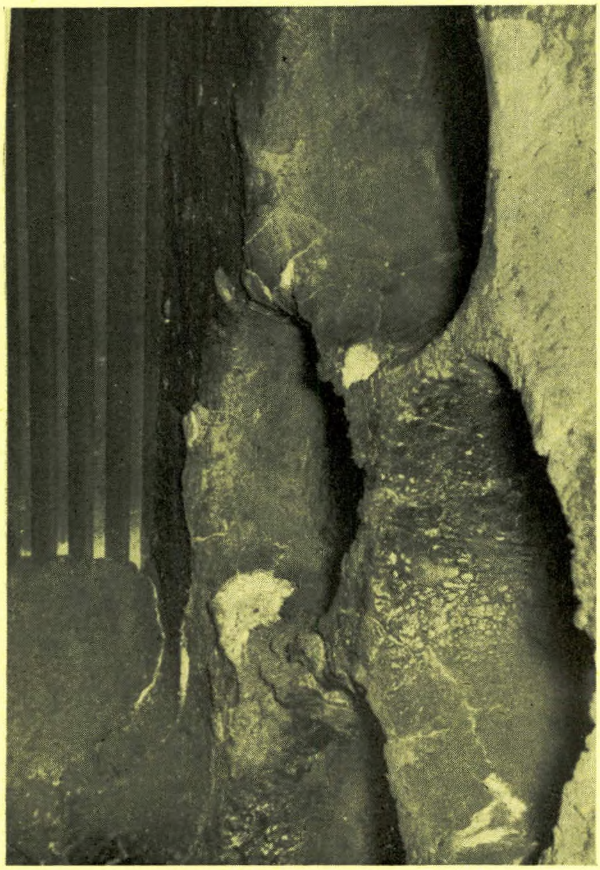


FIG. 25—*Burner quarl section in a D-type boiler (four years' service)*

surface and edges of the dish shape above the top row of burners, as shown in Figs. 26 and 27. Evidence of molten slag on these areas (Fig. 27) indicates high operating temperatures, possibly due to flame swirl within the dish shape causing impingement.

Slagging on quarl blocks themselves is not a problem, even where heavy slag deposition is found on back and side walls. In the assessment of the suitability of refractory materials for burner throats, slag resistance should have a very low priority and no other properties should be sacrificed to obtain it.

Where prefired brick is still used in new construction, there has been an increasing tendency to use higher alumina brick, this material now being used in the form of standard 9-in. bricks and not for making bolted blocks and special shapes. Firebrick of South African and Australian origin is being used, and although this may have come about as a matter of expediency, very satisfactory performance is being obtained. Although there has only been relatively short experience of china clay high duty bricks in back and side walls, these seem to be proving a worth while investment.

Many relinings have been made with higher grade firebrick and other prefired material, the thickness of the lining often being increased at the same time. It is not possible, however, in many older boilers to modify the arrangement of the lining with prefired material, and the use of mouldable material is often the only means available for increasing lining thickness or making structural changes.

It is very difficult to generalize on the life of lining materials since almost all ships differ in operating conditions, and modifications are often made during relining. It has been found to be the general opinion, however, that both prefired and mouldable materials of high quality are resulting in worth while economies. At the same time the use of lower grade castable material to replace 42 per cent $Al_2O_3$ firebrick does not reduce life in boilers with water walls, because in many boilers of this type the hot face temperature never exceeds 1,000 deg. C. (1,800 deg. F.) over large areas of lining. Another modification in new boilers of this type is that the water tubes are all equally spaced from the face of the lining, whereas in older boilers this distance was very much increased over part of the wall, with the result that the lining in this section operated at a much higher temperature and these zones often proved troublesome.

## CONCLUDING REMARKS

The design and operation of the oil burning equipment, in so far as the degree of perfection of combustion is affected, have a marked effect on the brickwork temperature. Steady brickwork temperatures are likely to vary between the limits obtained with short flame burning and flame impingement; on exposed walls this may be a range of 500 F. deg. In furnaces where the lining is not swept by flame the hot face temperature of exposed walls, or walls with uniformly spaced water tubes, is fairly uniform over the greater part of the lining. The importance of avoiding direct flame impingement on refractory surfaces cannot be over-emphasized as, under such conditions, the higher operating temperature is not the only factor to be

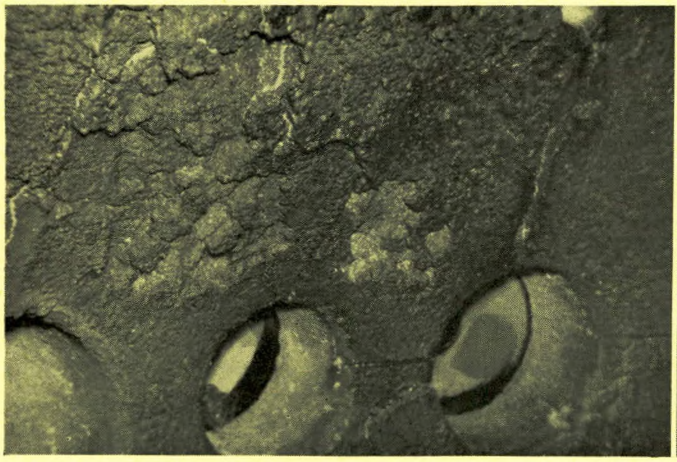


FIG. 26

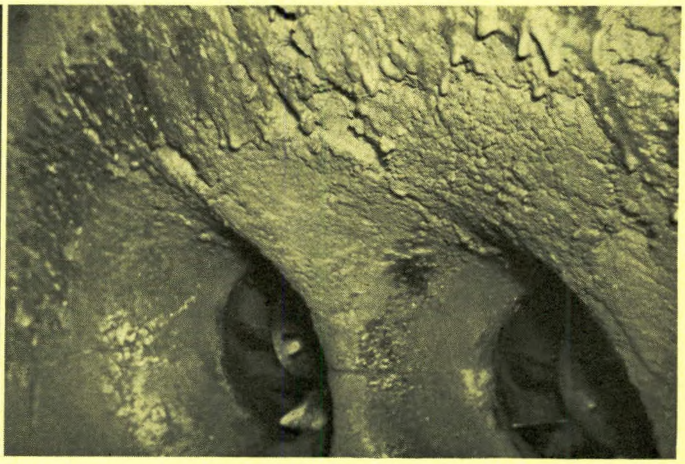


FIG. 27

*Spalling damage to upper surfaces of dish shaped burner sections* considered; reaction between the firebrick and the fuel oil ash or the constituents of sea water that may be contained in the fuel contribute to the rapid deterioration of the furnace lining.

The maximum hot face temperature attained by an exposed wall can be related to the forcing rate (lb. oil per hr. per sq. ft. effective projected radiant heating surface) at which the boiler is operated. Under short flame burning conditions an estimate of this temperature can be obtained by multiplying the mean furnace radiating temperature ($t_m$) by 0·9. The steady maximum operating temperature of a refractory wall protected by water tubes can be estimated with sufficient accuracy for all practical purposes by multiplying the corresponding exposed wall temperature by a suitable factor.

The rates of heating and cooling vary widely from one boiler to another. The most severe conditions occur in the burner quarl blocks and at this position the rate of change of temperature can exceed that which would cause normal firebricks to crack in laboratory tests.

There is much evidence of an increasing appreciation of the properties of refractory materials among shipowners as well as boiler designers. The previous practice of lining combustion chambers throughout with one class of material is ended. Mixed construction with high grade material where necessary, and less expensive material elsewhere, now appears to be the current practice. The spalling resistance of mouldable materials has greatly increased the life of front walls as well as reducing the cost and time of maintenance. The introduction of precast quarls of castable material has provided a means of satisfactory maintenance when the time available for repair is short. Finally, boiler designers have given much attention in new building to improving the operating conditions of combustion chambers.

The great interest shown in boiler refractory problems by owners' representatives has been impressive, and their willing co-operation and help has been greatly appreciated.

ACKNOWLEDGEMENTS

The author's thanks are due to the Councils of the British Shipbuilding Research Association and the British Ceramic Research Association for permission to publish this paper.

They also wish to acknowledge the assistance of the shipowners who provided the ncessary facilities, and the engineer officers concerned.

Acknowledgement is also made of experimental and other data contributed by various colleagues.

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# Discussion

MR. W. R. HARVEY (Member of Council) congratulated the authors on the paper because he knew it was the result of much practical research work on the subject, and felt that the fact that the research had been done under service conditions greatly enhanced the value of the results. However much one tried under trial conditions, research could not be carried out properly, as until a job had settled down it was not worth while and afterwards it was receiving special attention and the results were not the same. Laboratory tests were extremely valuable in ascertaining the ultimate temperature bricks would stand but service conditions could not be reproduced in a laboratory.

The boilers on which these tests were carried out were designed some years ago; if he remembered rightly the most up to date boilers tested were in a ship built in 1952 so that the design was of the order of 1949. Since these days there had been many changes in furnace design.

It was now standard practice to watercool side and rear walls which confined the problem of refractories to the front wall and floors. Nevertheless there were so many ships at sea with completely refractory lined furnaces that this paper was a valuable aid as to the best way of reducing maintenance which undoubtedly was a serious problem.

He did not propose to criticize the curves included in the paper or the deductions from these curves, partly because he found himself in agreement with the methods adopted and the conclusions drawn. He also had no doubt that many people present would have something to say about them. The results obtained however showed there were no worse conditions in the furnace than had been expected by the designer, and described to brickmakers when they supplied the bricks, and therefore the bricks should have been satisfactory.

He could not help feeling, and he would like the authors' opinion on this, that a considerable amount of trouble experienced at sea had been due to inferior quality bricks. It was not enough to specify bricks of 42 per cent alumina; what mattered was the way the bricks were made. On the other hand, he did not like the suggestion at the end of the paper that with a water cooled furnace a lower grade of material could be used. Did this mean it could be used behind the water walls? He himself would be against using lower quality material in the front walls, and it was a pity that more attention was not paid in the research to temperatures at the front walls as it was there that the major problem arose in modern designs with water cooled furnaces.

It was a remarkable fact that pre-1939 front wall troubles did not exist, pre-1946 they were not very serious, but since that date the maintenance had risen alarmingly and this was difficult to understand unless it was that the burner manufacturers endeavoured to get shorter flames, which in general meant wider angle flames. Was this the cause of the present trouble? He would like the authors' opinion on this point.

The paper suggested dispensing with what were called short side walls. He himself saw no reason for this if they were required in the boiler design, and suspected that any troubles on these walls were due to designers being too optimistic in the distance provided between the wing burners and these walls.

The boiler maker always had before him the problem of making boilers smaller and smaller, and in consequence was tempted to accept the minimum distance given him by the manufacturer of the oil burner. Perhaps they had been at fault in doing this, but he did not think there was anything wrong with the principle of a side wall.

Some surprise seemed to have been felt that damage on rear walls did not necessarily occur where the temperature was highest—but was this so very surprising? Did not the damage occur opposite the burner and was it not possible that this was caused by unburnt oil thrown on to the rear walls rather than by any temperature effect?

A point on which he would like more information, particularly in an all-refractory furnace, was the effect of $CO_2$ on the temperature of the brick faces. Did a difference of, say, 14 per cent and 13½ per cent make any appreciable difference to the temperature?

One could not disagree with the conclusions drawn on long flame burners *versus* short flame burners, yet it must be recognized that a reasonably short flame could be obtained from any reputable make of burner, and he had a strong suspicion that long flames very often resulted from bad maintenance, particularly of the oil burner tips. He did not think that they received the attention they should have had, bearing in mind the care that was taken in manufacture.

On page 251 the authors mentioned the practice of welding the keys to the casings. This was possibly a mistake, as one would not under any circumstances weld a key to the casings. A small holding plate was welded to the casings, leaving the key free to move with the expansion and contraction of the wall. There was no doubt whatever that monolithic construction had been proved to stand up to furnace conditions better than prefired bricks, with the proviso that this was not looked upon as a cheap and easy way of making a furnace lining and that it was only satisfactory if the right quality of material was supplied and the right application used. The authors knew this was a fetish of his, but he could assure them that it was only after much tribulation and the spoiling of much good material that he had reached that conclusion.

MR. N. W. HINCHLIFFE also congratulated the authors on their presentation of the paper. The results of their work showed very clearly, he said, what were the major problems concerning refractories for the furnace of a marine boiler.

Mention had been made of monolithic refractories, and he was convinced that in the long run the correct use of monolithic refractories was the most economical and most satisfactory means of lining a boiler, particularly an exposed wall.

The temperatures indicated for quarls and exposed walls were right on the top limit for the best quality Scottish firebricks, which were well established and had a world wide reputation for ability to stand up to arduous conditions. At these limiting conditions a refractory brick could only be expected to have a limited service life and it was necessary, therefore, where better life was required, to use a higher duty brick. The cost of producing these higher duty prefired refractories rose very steeply with increasing limiting service temperatures because better quality raw materials were required, their fabrication was more difficult, and the higher kilning temperatures necessary to ensure stability and strength were very costly.

The production of special shapes, such as quarl blocks, was in many cases a very difficult operation. However, he was convinced that monolithic refractories were the answer. Field experience and laboratory tests had shown that they had far better thermal shock resistance. In marine boilers more failures occurred due to thermal shock than ever occurred due to slag.

The selection of the most suitable monolithic material for a particular job required careful consideration, especially in the case of castables, because these materials generally had a safe operating temperature range of only some 250-300 deg. C. (482-572 deg. F.) below the maximum service temperature. For example, a castable refractory having a limiting service temperature of 1,300 deg. C. (2,372 deg. F.) would not be expected to be strong at 1,000 deg. C. (1,832 deg. F.) and would almost certainly have shrunk and cracked at 1,350 deg. C. (2,462 deg. F.) Plastic refractories had a much wider maturing range and were more widely used for complete linings. The wider maturing range also meant that even in the lower temperature front wall applications, such as were encountered in boilers with tangent tube walls, long flame burners and moderate forcing rates, it was possible to use the same high duty plastic refractory with a wide margin of safety against maloperation of the boiler as could be used in a boiler operating under the severest conditions.

The major advantages of monolithic refractories had already been indicated in the paper and there were others, such as rapid availability and freedom from stocking several patterns of prefired bricks. Shipboard spares were a very minor problem, as only a few drums of plastic refractory need be carried in case of emergency.

Like every material with so many advantages, monolithic refractories had some disadvantages. It was necessary to anchor them into position, and the method of anchoring was very important. Mr. McClimont had mentioned the ceramic anchor. It had been found to give particularly good service and it was better than any of the heat resisting steel anchors often used.

The second and perhaps more important disadvantage of the monolithic refractory had already been touched upon, and he would like to elaborate on it a little; it was the question of installation.

It was very important that a monolithic refractory, particularly a plastic refractory, should be properly installed. The majority of reputable refractory manufacturers issued comprehensive instructions on how to use their products, and he welcomed the report prepared by B.S.R.A. and B.C.R.A., giving a full outline of how a monolithic refractory should be installed. At least one refractory manufacturer had provided the services of a field engineer to visit ship repair yards in order to ensure that his products were properly used. He made no charge for this service.

There was one point on installation on which he disagreed with Mr. McClimont. It was said in the paper that a wall was built rather thicker than was required and the excess was cut off on completion. It was his own experience that a properly installed plastic refractory was very difficult to cut back to the correct thickness. He felt sure that it must damage the anchoring to the wall when this was done. He preferred to build the wall to the correct thickness and brush the surface with a wire brush or the edge of a scraper to remove the skin.

In the earlier days of using monolithic refractories, failures due to faulty installation were not uncommon, and he had a slide showing the type of thing that could happen, on a new vessel, before she even completed dock trials.

Figs. 28 and 29 showed the boiler wall before repair and after a period of service. On that small section of wall, the original construction used 11 cwt. of material. On repair 15 cwt. of material was put on in the same space. It did emphasize the need for a really well consolidated material.

He thought it was fair to say that the importance of sound installation was becoming widely realized and very few failures or difficulties were now experienced. He knew of over 100 vessels using monolithic refractories which were in regular service, and over the past three years he could not recall one instance of trouble at sea necessitating the shutting down of the boilers.

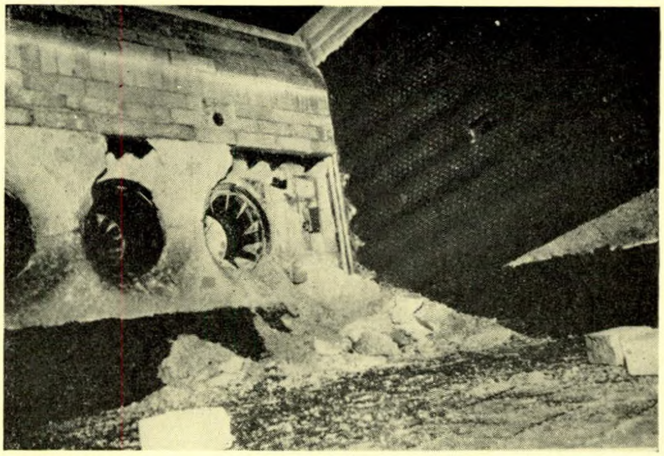

FIG. 28

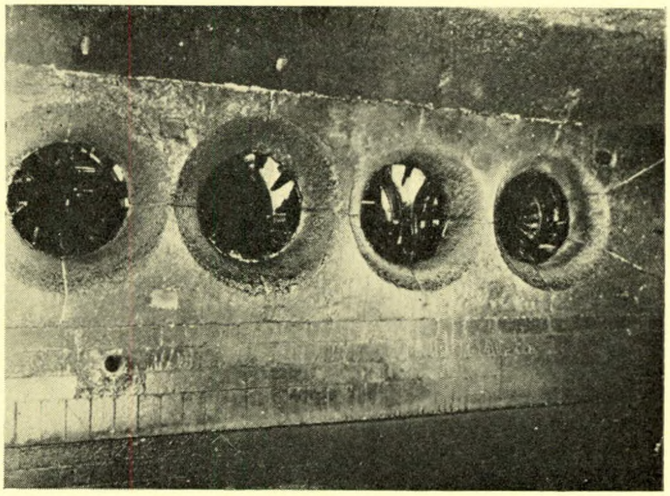

FIG. 29

He was certain that the work the authors of the paper had done and the work done by their respective research associations, B.S.R.A. and B.C.R.A., in conjunction with the Marine Boiler Refractories Committee, comprising shipowners, boiler designers, refractories suppliers, and so on, would ensure that the refractory linings available to British shipowners were as good as any in the world and would remain so for many years to come.

COMMANDER V. M. LAKE, R.N. (Member) said that the paper must be welcomed as a contribution to the greater understanding of the conditions existing inside marine boilers. But he hoped it was in the way of an interim report, since his main criticism was that the ground was covered far too thinly to make the paper of any really great use to the operator and the designer who wished to understand exactly what was happening inside the furnace.

The Admiralty could fill in some of the data required in boilers of higher forcing rates, and that was the object of Fig. 30. He would be loath to draw any hard and fast conclusions either from his points plotted or from those produced in the paper.

No attempt had been made in the paper to correlate the

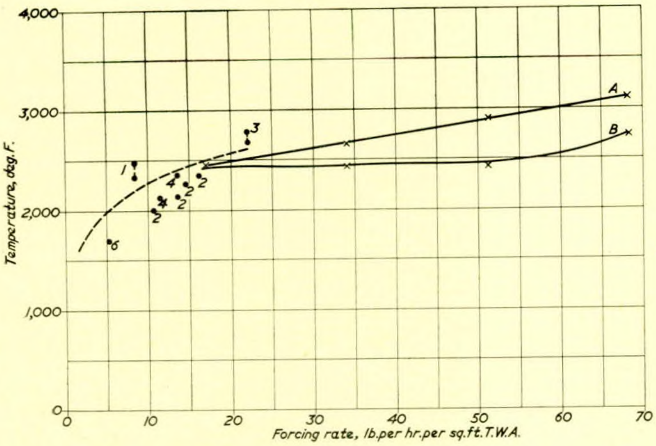


FIG. 30—*Comparison of naval boilers with merchant ship boilers*

variables in a form which would make the results directly applicable to other boilers, and this was essential if the data were to be used for practical purposes. The results plotted represented "statistics" for eight different boilers, and they were all very different. Any one variable could upset these points. The correlation between the dots and crosses, the latter taken from two identical boilers with different combustion equipment, was rather surprising, but he pointed out that they were single points.

He would not care to fill in the points below those shown as crosses. He would not guarantee any points below quarter power because they would be down to one burner or part of one burner. The temperature in the furnace was anything one liked to make it, dependent upon where it was taken. All sorts of other variables like $CO_2$ (a big factor at low powers), type of fuel, viscosity of the fuel, emissivity of the flame, which could vary with the type of flame, whether short or long, played an important part. Cold fraction in the boiler was not really mentioned. From their own calculations in naval boilers he thought there could be a difference of 50 degrees in brick face temperature with quite a small variation in actual radiant cooling surface in the furnace. In fact, in the two different ships quoted there was a wall difference in the boiler of about three tubes per screen. This was negligible on the radiant heating surface, but it could make a difference of 50 degrees in a calculated temperature. This showed that in using a curve such as Fig. 3 in the paper, when one was interested in temperatures within 50 degrees, one had to be extremely careful where the temperature was taken. If, as Mr. Hinchliffe said, the question of supports was important, a 50-deg. increase in temperature with heat resisting material could make all the difference between safety and destruction. It was therefore essential to know the factors controlling surface temperature, and he would have liked a little more emphasis on this in the paper.

The difference between boiler A and boiler B in Fig. 30 was entirely in the combustion equipment, apart from the small difference in radiant surface. (The full power spot for boiler A was extrapolated.) Boiler A had shown signs of going straight up to the maximum theoretical furnace temperature. The other boiler gave a surprising result, being practically flat over the range and then leaping up suddenly at full output. Here the change in flame shape had been marked. At low outputs the flame was long and billowy. At higher outputs it was very short, tight and bright, and exceedingly intense. The difference between the short and long flame was thus demonstrated. In one case, the furnace was full of flame and in the other it was not; but there was emissivity to be taken into account and this might explain the even temperature.

The flame temperatures now being achieved—and this would apply in the Merchant Service as well—with better combustion equipment were approaching the maximum theoretical. It was therefore essential to know within 50 degrees either side what was the temperature on the brick face in order to choose the correct grade of refractory.

Before one could discuss flame impingement it was essential to define a "flame". This the authors did not do, and it was not sufficient to accept the visible boundary of a flame as being the clear cut line of danger. Luminous gases occurred at the outer surface of a flame. The edge of the flame was not necessarily as hot as the inner part or the oil particles actually burning. Therefore it was possible to have the so-called flame impinging either on the brickwork or on the screen with perfect safety. The effect of flame thickness was vitally important, because this determined the amount of heat radiated to the brick walls. This varied with different boilers, different draught losses, different types of combustion equipment. It was well known that even from the best equipment one could get long flames whether one intended to or not. This depended on the individual operator.

The authors mentioned in their paper that radiation was of major significance in the furnace. He did not altogether agree with that, because there was evidence from gas turbine combustion that a cooling effect on the flame could be obtained from the brickwork. Heat was transferred by convection to the gases, and this again, certainly in naval boilers, could mean the difference between safety and destruction. Thus brick face was lower than one would calculate because of the effect of the flames sweeping the brickwork.

In Fig. 7 the authors showed the effect of water wall tubes. It was a pity that that figure did not continue down to cover the tangent tube case, which was becoming common practice. Here again the problem could become very complex. With the tangent tube, the actual temperature of the tube was of significance in regard to radiation to and from the refractory behind. This introduced another variable into combustion chamber brickwork temperature—namely, boiler pressure.

In the trials from which his graphs were taken, temperatures were obtained in various positions in the furnace, and these agreed in general with the authors' figures. But he would be interested in their findings with regard to variation in temperature in specific parts of the furnace with different burners in use. This again must affect brick face temperature. It had been found in naval boilers that the hottest place was not towards the front of the boiler but towards the back of the boiler on the sides. The temperature here was actually higher than in the wall opposite the burners. One could not draw any particular conclusion from this yet. Far more points were wanted before any law could be laid down as to what was happening.

They had not been worried at the Admiralty about the effect of rate of change of temperature on brickwork, since this had not been a limitation in their ships. They had found that spalling could be controlled by the choice of refractory. They had achieved control by specification and the adoption of the United States Navy simulative service test. This supported Mr. Harvey's view that good material fulfilled the task. The authors did not state whether the spalling was on cooling or heating. This could be distinguished by the type of failure if one got there quickly enough. Was it possible that the spalling witnessed in the Merchant Service was due to malpractice; that was to say, admitting cold air to the furnace on shut down in order to get the boiler cooled so that someone could do something else? This was a form of thermal shock with which refractory manufacturers should not be expected to deal.

With regard to the introduction of the improved brickwork mentioned by the authors, he was particularly interested in complete lining in plastic refractory. Most people—certainly in naval circles—preferred prefired brick, because it had superior qualities reproducible at all times. Provided one specified and carried out the proper tests, one could be absolutely certain of getting the same article every time. Plastic was known to be less resistant to slag attack, which was not in its favour. It was extremely difficult to erect, and this could depend again upon the operator. The United States Navy had practically eliminated the use of plastic, in front line warships, except as patching material. They had solved their logistic problem with regard to the number of shapes they had to carry and they believed they got superior material in this way.

It was only retained here, he thought, because of logistics. The problem of quarls of standard shape which could be used in any quarl size had not been solved and plastic was a quick and easy way of putting up a front. This was about the only place it was used now. It would become more and more unpopular as the monolith increased in size. In this respect, he would challenge the authors' statement regarding the necessity to fire within 24 hours. This was a popular fallacy and in naval experience 48 hours did not spell destruction. It was difficult to insist on firing within 24 hours when it took seven days to erect a monolithic front. Thus there was a practical limitation on the size of the monolith one could build.

Finally, the key shown in Fig. 16 was of Admiralty design and he thought he could say it was an excellent key. It had shown extremely good service over a number of years and was made in different grades of refractory with success. It had good life in arduous service. The chamfering of the edges shown in the sketches was essential if stress concentrations were to be avoided. Cracks would start from these points if this were not done. He saw that Mr. Hinchliffe did not agree but that was their own experience. This key worked very well irrespective of the material with which it was made and with which it was associated.

MR. J. P. CAMPBELL (Member), said it had been stated that the cost of repairing brickwork in boilers was a major problem from the shipowner's point of view.

There was a time when the greatest expenditure on boilers was caused by tube troubles, but these had been cured by accepting advice from the chemical industry on boiler feed water treatment.

In light draught ships engaged on short international voyages working to a time schedule requiring service speeds varying from 20 to 25 knots ahead, and 15 knots astern, a certain amount of vibration caused by rapid manœuvring must be accepted; this, and occasional pulsation of boiler casings, made onerous demands on brickwork and the anchoring of same.

He did have an experience of a wall collapsing at sea but thanks to the ceramic industry, repairs were effected without taking the ship off service and the boiler was operating at full power within 4 hr. of the completion of the repairs.

With reference to the authors' statement that "prolonged air drying is undesirable" there must be many occasions at builders' and repair yards when prolonged air drying must be accepted.

Monolithic linings were proving a boon to shipowners, as storage space no longer required on ship and ashore for bricks of the many different shapes and sizes formerly required, could be used to better advantage. Quarl blocks were the only shapes he now held in stock.

He had experience of operating pre-war vessels originally fitted for coal burning with mechanical stokers, but which had been converted to oil firing post-war. The cost of repairs to boiler refractories had been slight. The boilers differed from typical post-war built oil fired ones in so far as the removal of the mechanical stokers resulted in very large combustion chambers.

The temperature records given in Fig. 13 were extremely interesting and gave an indication of the magnitude of the thermal stresses to which refractories might be subjected.

In view of trouble experienced from failure of superheater supports made of heat resisting steel, he was, on the boiler designers' advice now using monolithic ceramic supports reinforced with welding rods for this purpose and these appeared to be satisfactory.

MR. L. J. CULVER, B.Sc. (Member) asked whether the authors could add to Table I the area of the exposed refractory surfaces in each of the designs illustrated. This would give a better picture of the furnace loading in relation to refractory life and maintenance.

He admired the way in which the results had been neatly classified into long and short flame conditions and he wondered whether the authors had attempted to prove this by trying to produce long flames instead of short flames and moving points in Fig. 3 from curve B to curve C!

It would be interesting to know the emissivity factors used for the theoretical curve A in Fig. 3, and also to see the $CO_2$ figures applicable to each of the tests, since combustion conditions obviously played such a large part in furnace behaviour.

In Fig. 6 the distance of the tubes from the wall was not shown although this also affected the amount of heat absorption and the brick face temperatures. Boiler tubes placed on a fairly wide pitch and away from the brick face did not give adequate protection to the refractory and in practice they allowed flame or hot gas to scour the wall face. In consequence closely pitched waterwalls were fitted on most modern boilers.

He agreed with much of the operating experience reported in the paper and in particular would comment on the behaviour of the brickwork illustrated in Fig. 8. The front wall, as was usual in many boilers, was the coolest exposed refractory and it was disappointing that the test could not have included points on the much hotter sloping wall alongside the intermediate water drum. On earlier designs this wall projected further into the furnace with theoretical flame clearances that were soon proved to be non-existent in practice.

The problem of repair and maintenance should be emphasized and the authors were fortunate to be able to deal with the subject without reference to the multiplicity of trade names by which lining materials were known. If he might make a humble appeal to suppliers, it would be most valuable if the description of the material in their titles could include some key to their characteristics, such as maximum working temperature, whether they were mouldable or castable and whether heat setting or air setting. There was a great danger in selecting the wrong material and by way of an example it had been known for chrome ore to be used instead of the required grade of refractory material to insulate boiler drums or headers exposed to furnace conditions.

With regard to quarl temperatures it would be of interest to know whether the boiler 9 used for the quarl temperature experiments had long or short flames, because when good combustion depended on filling the quarl with flame, the quarl temperatures would probably be higher. In this connexion it would be interesting to see the effect on quarl life with the new types of combustion equipment now coming into service where the air to fuel ratio was maintained by the design of the air register and the quarl face protected by air flow.

MR. J. WOOLLISCROFT said it was generally considered that temperature changes in the range of 1,400 to 1,800 deg. F. were more prone to give rise to spalling than more violent changes, providing they were of short duration, at +2,500 deg. F. He would like the authors' views on this matter.

In the paper no mention was made of cement jointing of bricks. Had the authors any experience with both air setting and heat setting? If so, which gave better results?

Were the South African and Australian bricks referred to on page 252 of clay/grog or grog/clay composition and were they made plastic or dry press?

MR. J. B. PEACOCK, B.Sc. (Member) said that operational experience was always of interest and value, both to boiler designers and superintendent engineers, and this paper was of greater value than most in view of the fact that the experience had been spread over several operators and a wide range of service requirements.

The temperature to which refractory materials in a boiler were subjected depended on a number of factors; many results still depended upon the human factor and, without doubt, the operators were responsible for some of their own troubles.

He was particularly interested in boiler 6 in the paper. Some years ago, in a vessel belonging to the company with which he was associated, on which such a boiler was installed, difficulty in controlling the superheat temperature during astern operation was reported. On investigation, it was found that the operators had been using only the lower burners in the boiler during manœuvring and no doubt there was unbalance and a number of hot spots in this particular boiler installation. As the arrangement and size of the burners in use had a considerable influence on the disposition of hot spots, he would be interested to learn if the authors had a record of the size of the burners and their location during steady steaming conditions reported for boiler 6. In boilers of this type, it was unusual to have a symmetrical arrangement of tips at full power.

The position of the thermocouples in the outboard furnace in Fig. 8—if they had been sited in way of the local hot spot—would suggest that there was a tendency for the operators of this boiler to use the two lower registers only.

The lesson from both the above simple examples was that boiler designers should endeavour to arrange the registers so that each could be manipulated with equal ease from the firing platform. With the introduction of burners with large turndown ratios, this was now possible even in controlled superheat boilers of the type referred to above.

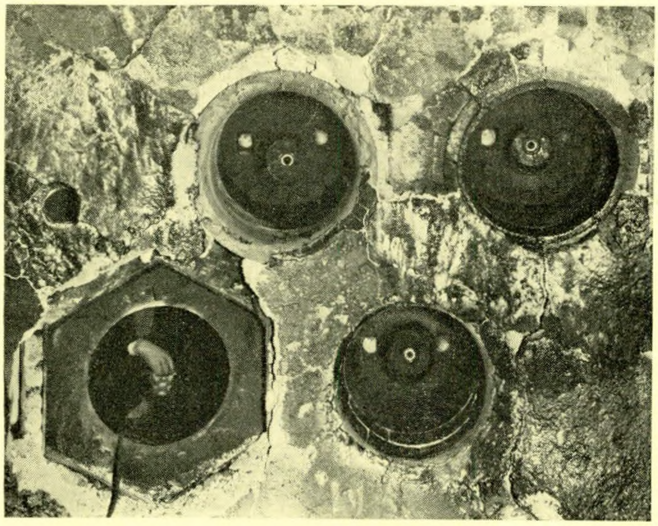

FIG. 31.—*"Carbofrax" segments—s.s.* Peleus—*after two years' service*

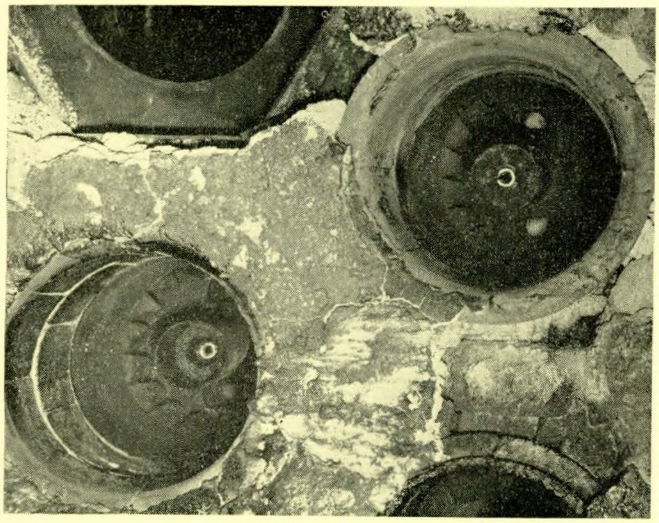

FIG. 32—*Enlarged view of* FIG. 31

It was not surprising that the authors had found in their investigations that the quarl blocks were subjected to extremely severe conditions. Some years ago, his company had experienced considerable difficulty in maintaining the shape of the quarls in their controlled superheat boilers. After many experiments the material which ultimately proved to be the most suitable was "Carbofrax" segments set in plastic refractory. Figs. 31 and 32 showed a boiler fitted with this type of segment, the quarls having been in service well over two years.

The correct and consistent operation of oil burning equipment was difficult to control. The problem could be illustrated by a case drawn to his attention recently on a twin-boiler installation. Considerable difficulty in adjusting the superheat temperatures and boiler outputs had been experienced for some time, although everything appeared to be in order when checked over. A capacity check on all the burner tips revealed that the atomizer tips used at normal full power had been running with up to a 30 per cent variation in output. It was at first thought that this variation was a result of normal wear and tear, and some of it was for this reason, but a number of new tips were tested, and considerable variation was also found in in the new tips. Since then they had introduced a regular and rigid inspection of tips and the result had been beneficial both as regards boiler performance and refractory repair costs.

MR. E. F. BARTON (Member) thanked the authors for an informative paper upon a subject of importance to the members of the Institute.

Reference was made, he said, to the great interest shown in boiler refractory problems by representatives of shipowners. This interest was and must be stimulated by the frequent recurrence and high level of maintenance costs involved. An analysis of maintenance charges against ten boilers in the fourth, fifth, sixth and seventh years of service had shown that refractories had contributed between 26 and 47 per cent, averaging 37 per cent, of the total cost of maintenance and survey of the boilers. It was doubtful whether the refractories represented even 3 per cent of the capital cost of the boilers, and thus they might be considered to fall far short of the general standard of durability required for marine service.

The analysis referred to boilers similar to number 3 of Table I with exposed refractory walls constructed mainly from high duty 42/44 per cent aluminous fireclay bricks. It was therefore with this type of boiler in mind that he had examined the contents of the paper.

Fig. 3 indicated that the maximum temperatures might range from 2,800 to 2,300 deg. F. according to whether or not flame impingement occurred; the recommended maximum service temperature for the particular refractory used was about 2,400 deg. F., and indications of exceeding this had been few and confined to the development of fissures perpendicular to the hot face in bricks forming the pillars between burner openings in the front wall. It was thought that this might be "after contraction", a consequence of exceeding appreciably the temperature to which the bricks were initially burnt in the kilns, but the views of the authors would be appreciated.

Regarding flame impingement on side walls, it was often difficult to convince oneself from visual examination whether or not this was happening; spalling was taken to be confirmation. In one particular vessel, the opinion was that impingement was not happening yet severe spalling was frequent. The expedient of angling by 5 degrees the tips of the wing burners was adopted and this appeared to have had the desired effect, as the severity and frequency of spalling had been markedly reduced. The effect of angling might be expected to have increased any critical clearance by only 3 or 4in. Nominally, the distance from the side wall face to the burner centre line was 30in., which was generally considered to be adequate. It could be that both temperature and rate of change of temperature of a refractory surface were significantly affected by change in the proximity of the flame when the clearance was of a small order. When regulating combustion conditions, one received the impression, true or not, that the attainment of short flame burning was accompanied by an increase in flame temperature. If true, this effect was neglected by the authors in their consideration of side walls.

Spalling was without doubt the major problem, and the section of the paper relating to rates of change of temperature evoked the greater interest. In Table II, rates occurring above 1,800 deg. F. had been excluded, and it would add materially to the value of the paper and the discussion if the authors were to elaborate upon the reason for this. Some sources quoted 1,470 deg. F. as the temperature above which the glassy constituents of fireclay bricks had sufficient plasticity partially to relieve stresses due to thermal gradients. It was noted that the authors excused themselves from quoting the maximum safe rate of heating for a firebrick if spalling were not to occur. At the same time, they stated that spalling could be induced at heating rates of between 10 and 15 deg. F. per minute applied to one end of a brick in laboratory tests. Would the authors state further details of the laboratory tests such as temperature range, the associated cooling rate, the number of cycles to failure, and the nature of the spall? Unless the number of cycles to separation were appreciable, the higher rates of heating quoted in Table II were alarming.

In discriminating to select the significant rates of heating, was it correct to neglect the more rapid rates over an arbitrary limited range of up to 300 deg. F.? He would anticipate that the coefficient of expansion varied with temperature and perhaps other thermal properties, and equivalent strains might be established by different heating rates at different temperature brackets.

Considering slag attack, it was agreed that this was not of direct importance in merchant boilers. It was suggested by the authors that it might be a contributory cause of spalling once the fracture was established. This was a change of opinion of some importance, for in the paper* on the causes and extent of wastage published in 1953, it was suggested that slag penetration could promote spalling. It was generally understood that whilst greater porosity would improve the spalling resistance, the effect could be lost in service by greater susceptibility to penetration by deposited slag.

The authors' statement on the greater resistance to thermal shock of the rammed plastic materials was endorsed, but in consideration of the importance of maintaining the correct form of quarl openings it was thought that this could only be ensured by the use of a prefired or preformed material in renewable sections. A considerable advance, however, in spalling resistance was required.

Thirty years ago zirconia bricks were considered an ideal refractory, apart from a low slag resistance and a tendency to form carbides and nitrides at high temperature. The insensitivity to thermal shock of this material was quoted to be such that white hot bricks might be plunged into cold water without risk of fracture. He would be grateful for the opinion of the authors regarding the suitability of zirconia bricks for quarl linings. Fig. 24 was remarkable, and illustrated a moulded burner quarl in almost immaculate condition after four years' service. The authors had confirmed however during the presentation of the paper that it was intended to emphasize that the correct form could be maintained in spite of intermediate repairs.

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* Taylor, B., and Booth, H. 1953. "Service Performance of Boiler Brickwork—The Causes and Extent of Wastage". Trans. I.Mar.E., Vol. 65, p. 165.

## Correspondence

Mr. H. Oliver congratulated the authors on providing such valuable data on temperature distribution and variation through the refractory structure during operating conditions.

The development of field research whereby data was obtained on the various aspects of operating conditions to which the refractory materials were subjected, was welcomed by all producers of refractory materials, no matter for what process the refractories were being applied. Progress in the improvement in service life would be materially accelerated by such knowledge, since a better appreciation of the strains imposed on the refractory materials would be gained.

The figures given in Table II gave a valuable clue to the intensity of such strains which were to be found in some installations and in certain positions, due to very high rates of change of temperature. Such conditions demanded the maximum possible resistance both to tensile and compressive forces within the refractory materials.

It was pleasing to note that an assessment of the suitability of materials for quarl blocks was being made by the joint B.S.R.A./B.C.R.A. team and one looked forward to some pronouncement on this subject at an early date.

In the meantime, he would ask the authors whether they had examined the possibility of using chemically bonded mouldables for boiler walls and quarls, since some of these materials apparently had greater strength than clay bonded mouldables at temperatures below that at which the development of the ceramic bond of the latter took place.

Such materials, though less strong at higher temperatures than the ceramic bonded material, might still be adequately strong on the hot face and have greater resistance to spalling at points within the structure at which the clay bonded material would fail.

# Authors' Reply

The reference to the use of lower grade materials in water cooled furnaces on which Mr. Harvey commented was, of course, intended to apply only to the sections of the furnace where conditions are not so severe.

The suggestion had been made that a lot of the troubles in the immediate post-war years were due to the use of inferior bricks. Mr. Richardson had been brought up by a very forthright Director who would not allow him to talk about inferior quality bricks. To withstand boiler conditions, one must choose the correct bricks; some good bricks might have failed because they had been used under unsuitable conditions. When the conditions in the boilers were known, the life of the furnace could be improved, and this was being done in some cases.

Mr. Harvey made reference to the 42 per cent alumina firebrick. It was dangerous to speak about 42, 32 or 30 per cent alumina firebricks. They contained other oxides as well as alumina, such as alkalis, lime and iron oxide. Other properties should be considered as well as the alumina content.

Several speakers had commented that the investigation of the temperatures in front walls had been neglected. The reason was purely practical. To fit temperature measuring equipment in a boiler in a ship which had to sail at a certain time was quite formidable. To fit equipment in the front walls was pretty hopeless at times, and thermocouples were fitted in the back and side walls purely from the point of view of expediency. Mr. Taylor could speak from practical experience of the difficulties of crawling inside the air casing to fit up this gear and it was thought that this answered a number of criticisms regarding other data which had not been obtained during the tests. This work was not a research programme as normally understood, where the conditions were controlled. The tests were carried out under normal service conditions, and it was a case of gleaning as much information as possible from the normal equipment fitted in the ship. However, a renewed effort was being made to obtain data regarding front wall temperatures and very comprehensive tests had been put in hand with the help of friends in the shipping industry, some of whom were present. The authors would welcome assistance from others who would be willing to make facilities available.

It had been said that the temperature of the front wall was lower than that in other positions in the furnace. It was true that the temperature was often lower than elsewhere, especially round the quarl blocks, but it was not the maximum temperature that mattered so much as fluctuations in temperature. It was suggested that the increased maintenance of front walls which had become necessary since 1946 was due to the general increase in the ratings of boilers; side and back walls tended to be protected by water tubes and hence most deterioration occurred in the front wall.

It was agreed that, basically, short side walls should not be a worry, but Mr. Harvey would agree and Mr. Culver endorse that there had been troubles in the past, due, no doubt, to insufficient burner clearance. When one got rid of short side walls one got rid of the trouble.

Mr. Harvey had asked about the effect of unburnt oil thrown on to the rear walls. It was possible that this unburnt oil could cause temperature fluctuations. At first a cooling of the brickwork could take place and then subsequent burning of the oil could cause a rather rapid increase in temperature. The deposition of carbon, from semi-burnt oil, between the brick grains might possibly cause a weakening of the brick structure.

The effect of $CO_2$ was covered in the paper, as would be seen from Fig. 5.

The authors agreed with Mr. Harvey about maintaining freedom of movement of keys; perhaps in the text it had not been made clear that the anchors were not rigid fasteners but it was thought that Fig. 16 would illustrate the point.

The authors thanked Commander Lake for the additional information given in Fig. 30. It was noted that the additional points showed remarkably close agreement with the extrapolated curves in Fig. 4 and reproduced in Fig. 33; this would

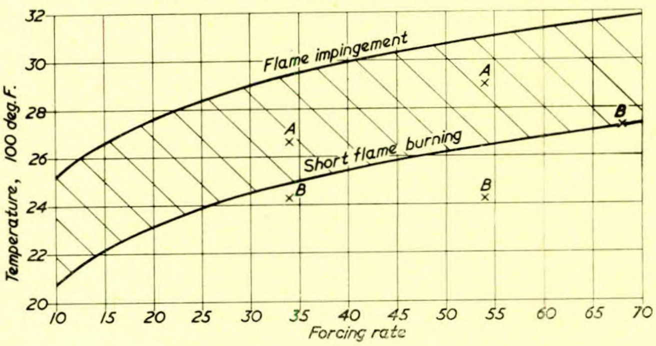


FIG. 33

appear to confirm the conclusion drawn by the authors that differences in boiler design did not have as great an influence as might be thought. The full-load point for boiler B fell right on the curve for short flame burning, whilst the two part-load points for the same boiler both fell below the same line, due, no doubt to greater excess air at part-load. The authors disagreed with Commander Lake's statement that the results in the paper are not of practical use; as far as was known, this was the most comprehensive survey of brickwork temperature ever carried out under service conditions. It was fully realized that variables depending on operation of burners, etc., would have an effect but it would not be so marked as Commander Lake had suggested.

It had never been intended that the curves given in the paper should be used to estimate working temperatures within 50 deg. F. Commander Lake had pointed out that variations in the operation of equipment could cause wide differences and hence it was hopeless to expect to be able to predict temperatures to such close limits. On the other hand operating temperatures did not need to be so close to the safe limit of refractories that such precise information on operating temperatures was necessary.

The authors regretted that they could not understand Commander Lake's remarks about convection to the gases and they felt sure that his statement that the brick face temperature was lower than one would calculate because of the effect of the flames sweeping the brick work was not to be taken seriously.

Commander Lake had referred to maximum temperature and very high rating for boilers; once again, the fluctuation was the important factor. For the high temperatures listed, it was possible to choose suitable refractories to withstand them. But unlike Mr. Hinchliffe, the authors did not think temperatures were always higher than those which could be withstood by Scottish firebricks. In many cases the temperatures were very modest. It was because of prevailing low temperatures that castable materials containing many fluxes could be used. The hydraulic cement in castables often had a low melting point, and castable walls and castables in the front wall and especially behind tubes withstood conditions very well indeed. The choice of castable material was undoubtedly very important. It was not always advisable to choose a high refractory castable, because in the position in which it was used the temperature of maturity might not be reached and the material would be friable and weak. If the temperature in various parts could be ascertained, it would be possible to choose a castable which matured at that temperature. Mouldable materials increased in strength and had a longer maturing range. Reference had been made to the spalling of bricks and refractories; in many cases mouldable materials would withstand fluctuating temperatures much better than firebricks.

Commander Lake had referred to the U.S. spalling test. No doubt he meant the panel spalling test in which a panel was first heated to a high temperature and then subjected to temperature fluctuations. This often changed the structure of the brickwork. This test was not always favoured in the refractories industry. If the brickwork never reached such a high temperature in service then it would not vitrify to such an extent in service as it did in this test. A spalling test was not easy to do in a laboratory and many attempts had been made to evolve a satisfactory test. As a result of some of these tests, figures of 10 to 15 F. deg./min. had been quoted and it had been stated that bricks tend to crack when heated at greater rates. These figures were obtained in a panel test in which a panel of bricks was heated from room temperature at controlled rates of 1 C. deg., 1½ C. deg., 2 C. deg./min. and so on. Many bricks when heated at 3, 4 and 5 C. deg./min. up to 1,200 deg. C. (2,600 deg. F.) showed a crack parallel to the hot face and vibration would help this crack to develop and pieces might fall away. A sonic spalling test had also been tried in which a test piece was vibrated until it reached its natural frequency of vibration and this frequency was picked up on an oscilloscope. During the heating of one face of a smallish test piece, it was possible to ascertain how the frequency changed. When there was a sudden change in frequency it was known that a crack had developed although it might not always be possible to see the crack. Bricks would crack at 10 F. deg./min., whereas mouldables would withstand 40 or 100 F. deg./min. in small test pieces.

It was important to know the size of the test piece. Small pieces would withstand thermal shocks more easily than large areas. In the photographs shown by Mr. Peacock (Figs. 31 and 32) where the quarls had given very good service and looked in very good condition, the segments were small; this was a step in the right direction.

Figures for rates of change of temperature up to 1,800 deg. F. were mentioned in the paper, and the question had been asked why this limit had been chosen. There was a theory that at higher temperatures the bricks would vitrify and that strains were dissipated, giving the brick more resistance to temperature change. The authors believed that the higher temperature to which the brick was heated before the temperature was caused to fluctuate, the more easily it would crack. In some of the laboratory tests, pieces had been heated at 5 C. deg./min. to 400 and 500 deg. C. without cracking; when they were heated to 1,200 deg. C. at 2 C. deg./min. they cracked.

It would have been gathered from the paper that the authors were very much indebted to Mr. Campbell for the facilities he had provided and they hastened to add that none of the adverse criticism applied to any of his boilers.

In reply to Mr. Culver, who asked for the areas of exposed refractory surfaces, the authors gave the data in Table III.

Mr. Culver's point about studying the effect of long and

TABLE III

| Reference | Type of boiler and date of construction | Area of refractory surface exposed to the furnace, sq. ft. $A_r$ | Effective radiant heating surface, sq. ft. $A_c$ | Ratio $\frac{A_c}{A_c + A_r}$ |
|---|---|---|---|---|
| 1 | Yarrow three-drum single flow, end fired (1934) | 222 | 160 | 0·42 |
| 2 | Babcock and Wilcox integral furnace (1952) | 233 | 285 | 0·55 |
| 3 | Babcock and Wilcox single pass header type (1949) | 388 | 136 | 0·26 |
| 4 | Yarrow three-drum twin flow, end fired (1948) | 298 | 216 | 0·42 |
| 5 | Foster Wheeler D-Type (1949) | 195 | 364 | 0·65 |
| 6 | Foster Wheeler twin furnace controlled superheat (1949) | 160 inboard<br>130 outboard | 270 inboard<br>275 outboard | 0·63 inboard<br>0·68 outboard |
| 7 | Foster Wheeler twin furnace controlled superheat (1951) | 175 inboard<br>130 outboard | 275 inboard<br>275 outboard | 0·61 inboard<br>0·68 outboard |
| 8 | Foster Wheeler twin furnace controlled superheat (1952) | 175 inboard<br>130 outboard | 275 inboard<br>275 outboard | 0·61 inboard<br>0·68 outboard |

short flames in the same boiler was a good one but unfortunately the opportunity was not available to experiment with burner equipment as the ships were in regular service.

The emissivity factors used in the calculation of the theoretical curve A in Fig. 3 were all unity, all surfaces being assumed to be black. The individual $CO_2$ values for the tests were no longer available.

Boiler 9, used for the quarl temperature tests, had short flames. The suggestion that quarl temperatures could be kept down by flow of air was significant. Mr. Campbell had talked about the severity of operation on cross-channel ships; one of the interesting things about these ships was that the actual quarl face temperatures were remarkably low. That appeared to be due to the very considerable amounts of air pushed in along the faces. It had been thought that on these highly rated boilers there would be worse quarl conditions than on the more usual modestly rated boilers, but in recent work the reverse had been found.

The South African bricks about which Mr. Woolliscroft asked a number of questions appeared to be of normal quality; they were merely taken aboard as needed and were not necessarily chosen because of their properties or texture. No work had been done on jointing cements, but in positions where the temperature was likely to be low an air setting cement should give good service.

The authors were glad to note that Mr. Peacock, unlike Commander Lake, thought that the results given in the paper were very useful. The number, location and size of burners in operation at any time were recorded, though it was difficult to keep track during rapid manœuvring of which burners were lit up and turned off every few seconds. Unfortunately, after the lapse of time, the original records were no longer available for boiler 6.

The segments referred to in Figs. 31 and 32 had given good service, probably because of their relatively high thermal conductivity and, therefore, good resistance to thermal shock. The long lives quoted might make them an economic proposition but long lives have also been given by mouldable refractories.

In reply to Mr. Barton, who had mentioned fissures in brickwork at 1,300 deg. C. on the front wall and had suggested that the bricks might have been heated in service to temperatures higher than that at which they had been fired, the authors said that, if such heating had occurred, the bricks were likely to shrink and shrinkage cracks were likely to occur.

The authors agreed that short flame burning appeared to be accompanied by an increase in flame temperature. Unfortunately the flame temperature was not amenable to calculation and could not even be defined precisely, as the temperature of the flame varied along its length. In the context used in the paper, the flame temperature had been assumed to represent the temperature of the outer zone of the flame. Clearly this must depend on the emissivity factors involved and in the simplified treatment adopted these had been assumed to be unity. This was considered to be valid as the absolute values of flame temperature had not been involved in the final expressions.

Zirconia would be a very expensive material to use. Mr. Barton had referred to a white hot brick remaining intact in cold water. There was a well known manufacturer of silica bricks which are known to spall very readily from 0 to 500 deg. C. who would take a silica brick from his kiln and put it into a bucket of water and it stayed intact. That test might not be all it appeared to be. Zircon would stop the wetting of the refractory by the slag; it had a very high melting point but it was not necessary to use such material in a marine boiler.

The authors believed that slag absorbed on the surface of a brick would cause the spalling tendency to increase. The brick became vitrified and would then crack more readily when fluctuating temperature was encountered.

Chemically bonded mouldables were being used in quarl block trials but only one result had been obtained and it was, therefore, too early to make a statement about their suitability, although indications were that this particular mouldable had not developed sufficient strength at the working temperature.

# INSTITUTE ACTIVITIES

**Minutes of Proceedings of the Ordinary Meeting Held at the Memorial Building on Tuesday, 14th April 1959**

An Ordinary Meeting was held by the Institute on Tuesday, 14th April 1959 at 5.30 p.m., when a paper entitled "Boiler Refractories: Operating Temperatures and Recent Developments in Construction" by W. McClimont, B.Sc. (Member), H. M. Richardson, B.Sc., and Bryan Taylor, B.Sc. (Eng.) (Member), was presented and discussed. Mr. R. Munton, B.Sc. (Chairman of Council) was in the Chair and ninety-six members and visitors were present. Eight speakers took part in the discussion which followed.

A vote of thanks to the author, proposed by the Chairman, was accorded by acclamation. The meeting ended at 7.55 p.m.

**Section Meetings**

*Bombay*

A joint meeting of the Bombay Section and the Institution of Marine Technologists was held on Wednesday, 8th July 1959 at 6.0 p.m., in the B.E.S.T. Conference Hall. There was an audience of 150, including members, visitors and engineer cadets.

*Mr. G. E. Kerr (lately Local Vice-President, Bombay) in the centre, with (left) Mr. N. Chakraborty (Associate Member) and (right) Mr. S. Kasthuri (Member)*

On behalf of the Council of the Institute, Mr. G. E. Kerr (Local Vice-President) made the following presentations:

The Institute Silver Medal to Mr. N. Chakraborty (Associate Member) for obtaining the highest marks in the Ministry of Transport and Civil Aviation's examinations in 1958.

A prize of £10 to Mr. S. Kasthuri (Member) for his essay entitled "Petroleum in Engineering, 1859/1959: A Centennial Review".

A paper entitled "Generation of Power from Nuclear Energy and Its Application to Ship Propulsion" was then presented by Mr. S. Kasthuri and was followed by a lively discussion in which Rear Admiral T. B. Bose, I.N., and Messrs. M. G. Datar, N. J. D'Sylva, N. Chakraborty, R. K. Gortu, M. S. Tambe and N. Subramaniam took part. The author replied to the points raised in the discussion.

*British Columbia*

The 1959 Committee for the British Columbia Section has been constituted as follows:

*Local Vice-President, Vancouver*: W. Dey
*Committee*: J. Caldwell
Commodore(E) A. C. M. Davy
E. J. Jones
L. L. Lawrie
J. S. Logie, B.Sc.
J. A. Stewart
*Representing members in Victoria*: Cdr.(E) J. S. Osborn, C.D., R.C.N.(ret.)
*Honorary Secretary*: J. McPherson
*Honorary Treasurer*: R. G. Boomer

*Durban*

The 1959 Committee for the Durban Section has been constituted as follows:

*Local Vice-President*: T. Ratcliffe
*Chairman*: H. T. V. Horner
*Committee*: P. F. Balfour
C. T. Glover
S. J. Harrison
W. W. Hutchinson
R. M. Murray
L. M. Olsen
*Honorary Secretary*: D. McGregor Clark
*Honorary Treasurer*: J. R. Holdsworth

*South Wales*

The Annual Golf Meeting of the South Wales Section was held in fine weather on Friday, 12th June 1959 at the Glamorganshire Golf Club. Fifty members and guests were present and fourteen cards were returned. Mr. W. B. James (Member) won the David Skae Cup with a net score of 66 and Mr. B. Watkins, who was second with 71, was awarded a consolation prize. Amongst the guests Mr. J. Naylor was first with 71 and Mr. S. G. Haskins second with 73 and they received appropriate prizes.

These and other consolation prizes were presented by Mr. D. Skae (Vice-President). The Chairman of the Golf Committee, Mr. F. F. Richardson, thanked the members and guests for ensuring by their wholehearted support the success of the meeting. A vote of thanks to the Captain and Members of the Glamorganshire Golf Club was proposed by Mr. T. C. Bishop (Member) and the Captain, Mr. S. R. Harrison, responded.

*Sydney*

On Wednesday, 22nd July 1959 a meeting of the Sydney Section was held at Science House, Sydney. The Chair was taken by the Local Vice-President, Captain G. I. D. Hutcheson, R.A.N., and there were thirty-four members and guests present.

A paper on "Computing in Industry and Commerce" was read by Professor D. M. Myers, B.Sc., D.Sc.Eng., and in the discussion that followed Captain Bell, Captain Parker, and Messrs. A. E. Anderson, D. S. Carment, G. B. Williams and K. A. Smith took part.

A vote of thanks to the author was proposed by Mr. W. G. C. Butcher and carried by acclamation.

### Student Section

*Lloyd's Register of Shipping Award: Essays*

The following awards have been announced in connexion with the essays written by students who took part in the Lloyd's Register of Shipping Award visit to London on 19th and 20th March 1959:

F. B. Longstaff (Student)—25 guineas
W. B. Parsons (Student)—10 guineas

Messrs. Longstaff and Parsons, together with the following Students, have also been awarded book prizes: G. J. Buchanan, C. B. Legge, K. T. Maunders and G. V. Miles.

### Honorary Life Members

Since the first list of Honorary Life Members was published in the TRANSACTIONS in August 1956, the following members have been distinguished similarly by the Council in recognition of at least fifty years' membership of the Institute:

| | *Membership Number* |
|---|---|
| S. D. Casebourne | 2060 |
| J. E. Charnock | 2247 |
| R. K. Craig, C.B.E. | 2146 |
| H. M. W. Daw | 1658 |
| E. J. Doig | 1914 |
| W. C. Jones | 2131 |
| J. W. Lawson | 2097 |
| A. MacPhee | 1469 |
| L. S. Polychroniadis | 2137 |
| E. Pull | 2116 |
| Sir John R. Richmond, K.B.E., LL.D. | 1890 |
| W. Smith | 1869 |
| E. L. Taphouse | 2140 |
| T. S. Wallis | 1779 |

### Election of Members

*Elected on 14th September 1959*

MEMBERS

Edward William Burgis
Geert Den Bakker
Harold Dowle
John Benjamin Gibson
Walker Henry Marsden
John Garvie O'Flaherty
William Rennie
Frits Timmerman
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John Dixon
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TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER
Frederick Hicks
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TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER
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