

Oct. 27, 1931.

C. E. HAWKE

1,828,839

FURNACE AND METHOD OF OPERATING THE SAME

Filed Jan. 5, 1928

2 Sheets-Sheet 1

Fig. 1

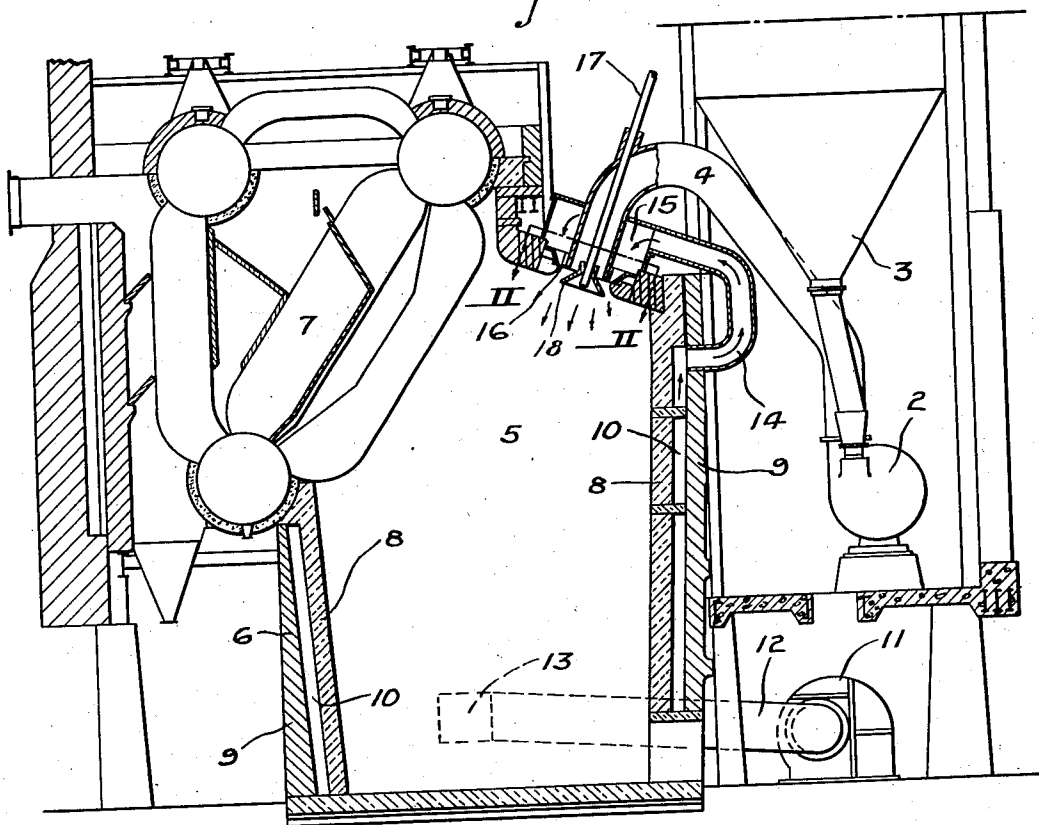


Fig. 2

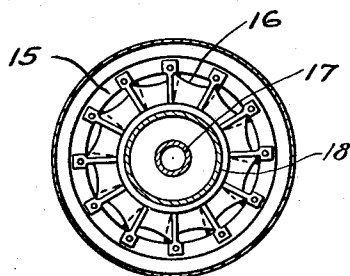
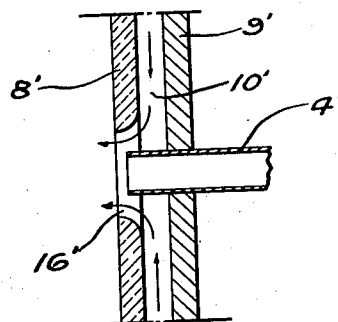


Fig. 3

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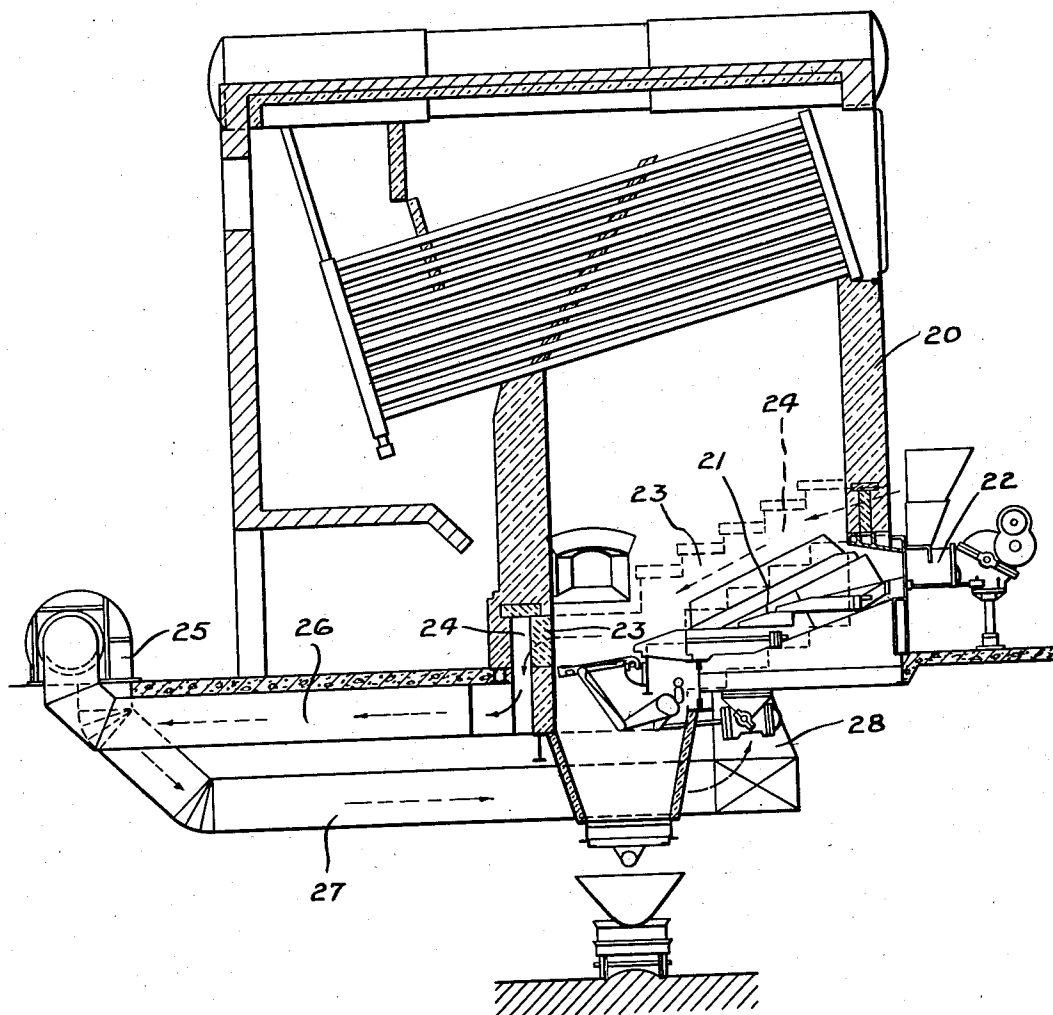
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FURNACE AND METHOD OF OPERATING THE SAME

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2 Sheets-Sheet 2

Fig. 4



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UNITED STATES PATENT OFFICE

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FURNACE AND METHOD OF OPERATING THE SAME

Continuation of application filed May 2, 1923, Serial No. 636,146. This application filed January 5, 1928. Serial No. 244,734, and in Canada June 15, 1926.

This invention relates to furnaces and more particularly to the construction of furnace linings, and constitutes a continuation of my application Serial No. 636,146 filed May 2, 1923.

There is an increasing tendency to operate furnaces at extremely high rates of combustion. In line with this general practice boiler furnaces are quite generally operated at from 300 to 500% of their rating. Whereas in old type furnaces the rate of combustion ranged generally between 15,000 to possibly 30,000 B. t. u./cu. ft./hr., the rate of combustion according to present practice is frequently materially above these values.

One serious difficulty that arises with the increased rates of combustion is the rapidity with which the brickwork of the furnace is destroyed. At these temperatures the slag or fused ash flows over the refractory walls, reacts with them, and erodes them. In the burning of injected fuels, especially powdered coal, the destructive action at high rates of combustion is particularly severe.

If high rates of combustion are to be secured and the efficient burning of fuel is to be obtained, there should be a minimum excess of air supplied to the combustion chamber over that required theoretically for complete combustion of the fuel, as the excess of air decreases the furnace temperature and retards combustion. It is also desirable that the air be preheated, as the rate of reaction between the air and fuel increases very rapidly with the increase in the temperature of the air.

Heretofore furnace walls have generally been made of a fire clay refractory, which refractory is a relatively good heat insulator. To decrease the destructive influences within the furnace, the flame temperature is depressed by the introduction of an excessive amount of air, which of course means a lower rate of combustion and a greater amount of heat carried out of the furnace in

the form of a larger volume of flue gases.

According to the present invention I provide a furnace and a method of operating the same according to which the slag or molten ash is congealed as a thin protective film on the exposed face of the refractory. This congealed film of slag of course does not erode the refractory because there is no washing action against the exposed face of the refractory. Moreover, it prevents the hot furnace gases, fuel particles and catalytic materials from coming directly into contact with the exposed face of the refractory, tending to seal the pores of the refractory and exclude those materials which accelerate the disintegration of the refractory. In order to effect this result it is necessary to maintain the exposed face of the refractory at a temperature below the flame temperature of the furnace and sufficiently below the flame temperature to cause the skin or slag immediately adjacent the furnace wall to substantially congeal.

In order to do this I use a refractory which is a relatively good conductor of heat in place of a refractory which is a relatively good heat insulator. By reason of the high thermal conductivity of the refractory employed, the heat can be carried away from the exposed face of the wall at a high rate. The amount of heat which can be carried away increases with the increase in the temperature drop between the exposed face and the unexposed face of the wall or furnace lining.

According to my invention, a cooling fluid, preferably air, is circulated back of the exposed face of the wall and the rate of air circulation is varied as the rate of combustion in the furnace is varied. As the rate of combustion in the furnace is increased, the amount of heat that has to be removed through the refractory to form the protective layer of slag increases, and the amount of air is therefore increased.

In order to obtain the method of operation

which I have outlined, a heat insulating refractory such as fire clay cannot be used because the heat will not go through it fast enough. Thus a fire clay wall which is sufficiently thick to have mechanical stability is such a good insulator of heat that it cannot be used for the practice of my method. No matter how fast or how much air is circulated against the unexposed surface of a fire clay wall, the heat cannot be removed fast enough to cause the formation of the protective layer of ash on the exposed face of the refractory.

Therefore my invention contemplates the use of a fairly good conductor of heat for the lining of the furnace chamber rather than the use of a highly insulating material. In order to conserve the heat which is carried through the wall, the invention contemplates that the air used for cooling the wall shall be returned to the furnace chamber for supporting combustion therein. The air is thus preheated, and as stated above, the preheating of the air increases the rate of combustion.

On the other hand, the slag or ash which accumulates on the inside of the furnace is a relatively poor conductor of heat. The protective film which forms on the surface of the refractory retards the conduction of heat to the refractory so that outside the protecting film the slag or molten ash flows freely over the protecting film. The protecting film thus automatically maintains itself relatively thin, but is always sufficiently thick to afford protection to the refractory wall itself against the washing of the molten slag.

As an example of a refractory that may be employed, the invention contemplates the use of silicon carbide refractories of high thermal conductivity. The thermal conductivity of silicon carbide is many times that of fire clay, whereas the former is considered a heat conductor, and the latter is considered a heat insulator.

My invention may be readily understood by reference to the accompanying drawings which illustrate embodiments of my invention and in which

Figure 1 represents diagrammatically a cross-section through a boiler provided with a powdered coal burning furnace and constructed in accordance with the present invention;

Figure 2 is a detail sectional view in the plane of line II-II of Figure 1;

Figure 3 is a detail view showing a slight modification of the burner and air intake; and

Figure 4 is a section through a mechanically-stoked boiler furnace embodying my invention.

It will be understood that the constructions shown in the accompanying drawings are merely illustrative of the invention, and that the invention is not confined to the particular type or design of apparatus illustrated, being

applicable to combustion chambers in furnaces of various types and designs.

The arrangement shown in Figure 1 is a typical powdered coal burning installation applied to a boiler furnace. In this figure, 2 is the pulverizer fan for feeding powdered coal from a hopper 3 through a feeder pipe 4 into the combustion space 5 of the furnace, designated generally as 6. The boilers are indicated generally as 7. The wall of the furnace has an inner or lining portion 8 and an outer wall portion 9, and in the wall between the inner portion 8 and the outer portion 9 is an air circulating space or passage 10. The inner wall or lining is formed of a refractory material having a high co-efficient of thermal conductivity as compared with fire clay, as for instance, a good grade of silicon carbide refractory. Air is supplied to the space 10 by a fan 11 which forces the air through a pipe 12 into an opening at 13 communicating with the space 10. The air which is forced through the space 10 is discharged into a pipe 14 that communicates with a chamber 15 surrounding the turbulent burner 16 at the end of the pipe 4, the arrangement being such that the air which is forced through the space 10 between the silicon carbide walls and the outer shell of the furnace may be discharged with the fuel into the combustion chamber. The position of the deflecting cone 18 of the burner may be adjusted by moving the adjusting member 17, thus controlling the shape and position of the flame. Air may, if desired, be introduced through member 17.

In the modification shown in Figure 3 the outer shell of the furnace is designated 9' and the inner wall of silicon carbide is designated 8'. Between the two wall portions is a space 10' and there are one or more openings 16' from which air may flow from the space 10' into the combustion chamber. With this arrangement the air which circulates between the inner silicon carbide wall and the outer shell of the furnace is drawn directly into the combustion space without the use of pipes. The opening 16' may be adjacent or remote from a fuel feeding pipe, such as 4'.

In the operation of the furnace, the fuel is burned in the usual manner. In order to secure most favorable conditions of combustion and prevent chilling of the flame, the temperature of the inner walls 8 should be maintained at 400° C. or above. This condition must be maintained over a considerable area of combustion space. At the same time the walls must not be allowed to become too hot. The effect of heat plus the ash is to destroy the walls by softening and erosion. With the present invention air is forced through the space 10 at a rate sufficient to afford the most desirable operating conditions for the inner face of the combustion chamber. When the furnace is operating under a heavy load the air is circulated

through the cooling space at a higher velocity than when the furnace is operating under a light load. Due to the good heat conducting properties possessed by silicon carbide, the heat can be conducted away from the exposed surface of the walls to the extent necessary to maintain the temperature of the exposed face below the congealing point of the ash and slag so that ash and slag coming into contact with these walls will be cooled enough to prevent softening and erosion of the walls by the slag. At the same time the temperature of the walls may be kept sufficiently high to prevent the flame from being chilled by contact therewith, so that efficient conditions of combustion are maintained. Variation in the wall temperature may be controlled by varying the volume or velocity of air or other cooling medium circulating therethrough. This may be done, for instance, by suitably varying the speed of the fan which circulates air through the cooling passages.

Generally speaking, the cooling of a silicon carbide wall $4\frac{1}{2}$ inches thick or less is much more nearly proportional to the velocity of the cooling air over the surfaces than it is with fire clay or other poorly conducting refractory walls of similar thickness. Where all of the air used in combustion is pulled or forced through furnace walls so that it is preheated, a method of regulation is secured. As the temperature of the furnace goes up, the rate of combustion is increased. This means that an increased amount of air must be supplied to the combustion chamber so that there is an increased flow of air through the space 10 and the walls are cooled at a higher rate by reason of the greater volume of air flowing through the walls. The system is, under these conditions, nearly self regulating.

The following figures secured on actual walls of fire clay and of silicon carbide with the furnace in each case held at 1300°C . clearly demonstrate the practicability of temperature control with a silicon carbide wall or a wall composed of other suitable refractories, and the lack of such possibility of control with fire clay even though the test wall of fire clay was only half the thickness required for commercial installations and hence was more amenable to control. The figures hereinafter given are for silicon carbide and clay walls having a thickness of $4\frac{1}{2}$ inches, whereas a clay wall in order to be commercially practical must have a thickness of nine inches or greater.

Cooling air velocity

Across wall—feet per sec.	10	20	30	40	50	60
Temp. hot face of wall—						
SiC	1207	1170	1140	1112	1097	1090
Clay	1268	1267	1265	1263	1259	1252
Rise in temp. of cooling air—						
SiC	187	120	80	57	46	39
Clay	57	37	23	15	11	10

The degree to which the wall is cooled is

evidently roughly dependent upon the rate at which the heat passes through it. Measurements made with air flowing at the rate of forty feet per second as an example show the following:

	SiC	Clay	Ratio SiC Clay
B. t. u./sq. ft./hr. through wall	32,100	5,100	6.3
Difference in $^{\circ}\text{C}$. between furnace temp. and that of hot face of wall	188	37	5.1

This means that the cooling of the clay wall might be as effective as the cooling of the silicon carbide wall if its thickness were reduced to such a point that the rate of heat transmission became equal to that of the silicon carbide. From the foregoing figures it is apparent that the fire clay wall could only be $1/6.3$ times as thick. While the foregoing test data indicates that silicon carbide has a thermal conductivity 6.3 times that of fire clay, this figure will vary according to the density of the silicon carbide wall, the amount of bonding material, and according to the way in which the brick is made. A silicon carbide brick of high density has been found to possess a thermal conductivity nine times that of fire clay. Assuming a thermal conductivity of nine as compared with fire clay, walls of equal thickness formed of different refractories would possess the following properties:

	SiC	Fused Al_2O_3	Mag- nesite	Clay
Thickness	Same.	Same.	Same.	Same.
Thermal conductivity	9	2.5	2.5	1
Transverse str. at 1350°C	1,500	200	140	200
Crushing str. at 1350°C	1,000	200	50	50
Resistance to fused ash	10	1	0.4	1
Resistance to abrasion	3	2	0.01	1
Resistance to spalling	1	$\frac{1}{2}$	0.3	1
Fusion point	$2,240^{\circ}\text{C}$. (Decomposes)	$1,900^{\circ}\text{C}$.	$1,900^{\circ}\text{C}$.	$1,750^{\circ}\text{C}$.

According to this, walls of the different refractories having equal thermal conductivities would necessarily have different thickness. For walls having equal thermal conductivities the properties are as follows:

	SiC	Fused Al_2O_3	Mag- nesite	Clay
Thickness	9	2.5	2.5	1
Thermal conductivity	Same.	Same.	Same.	Same.
Transverse str. at 1350°C	121,500	1,250	875	200
Crushing str. at 1350°C	9,000	500	150	50
Resistance to fused ash	90	2.5	1	1
Resistance to abrasion	27	5	0.03	1
Resistance to spalling	9	1.25	0.75	1
Fusion point	$2,240^{\circ}\text{C}$. (Decomposes)	$1,900^{\circ}\text{C}$.	$1,900^{\circ}\text{C}$.	$1,750^{\circ}\text{C}$.

From the foregoing it becomes apparent that silicon carbide possesses a high mechanical strength and resistance to shock as compared with other refractories. Its superior ability to permit control of the temperature

of the face of the wall has also been shown. Not only this, but silicon carbide radiates a much greater amount of heat than fire clay. The combination of these factors permits a silicon carbide wall to be used satisfactorily, the wall being mechanically sound and the controlled cooling keeping the temperature of the wall below the point at which the slag will erode it and yet above that at which the flame is extinguished. The greatly increased preheating of the air with silicon carbide is also of great advantage where the air which has been preheated is used in supporting combustion for the reason that each approximately 100° C. rise in temperature of the air substantially doubles the rate of reaction of the air and the fuel.

It will therefore be seen that a ventilated or cooled silicon carbide wall wherein there is forced circulation of the cooling fluid to secure a controlled temperature condition at the exposed surface of the wall is peculiarly suited for the burning of injected fuels at a high rate per cubic foot of combustion space per hour. Attempts have previously been made to avoid the necessity of cooling the walls by keeping them out of contact with the flame. This entails the necessity for very large furnaces in order to keep the walls sufficiently remote from the flame and is not satisfactory because the remoteness of the walls fails to cause a turbulence in the combustion space which has been found extremely beneficial to the improvement of combustion. With my invention the furnace volume may be kept at relatively small values without the walls being destroyed by flame or slag impingement, but rather being protected by a layer of congealed slag; nor is the use of large percentages of excess air essential as would otherwise be the case, the above protection permitting operation with 20% excess air or less.

It will therefore be seen that in the burning of injected fuels, particularly powdered coal, the use of a refractory provided with my controlled means for cooling the refractory gives rise to conditions which are most favorable to sustained operation at a high rating over long periods of time and most favorable to efficient combustion. As a specific example, a furnace operated at a temperature in excess of 1400° C. may be cooled, according to the present invention, to a point where the temperature of the exposed face of the lining is decreased more than 100° C. below this furnace temperature. This would be entirely impractical with a fire clay wall.

Although peculiarly suited to the burning of injected fuels my invention is not confined to furnaces for the burning of fuels of this class. The control of the temperature at the inner face of the furnace wall which is possible with the practice of the present inven-

tion makes it also highly satisfactory in the burning of other fuels.

In Figure 4 there is shown an application of the present invention to a mechanically-stoked furnace for the burning of solid fuel. In this view 20 designates the furnace generally, 21 the tuyère blocks and 22 the mechanical stoker. The walls of the furnace are formed generally of fire clay, but the portions at the sides and rear of the fuel bed are of silicon carbide. The silicon carbide walls are designated 23 and in back of these walls is a ventilating space 24. Air is circulated through the space 24 back of the silicon carbide walls 23 in the direction of the arrows by means of a positive draft venting device 25 which draws the air from the space 24 through the pipe 26. The preheated air is discharged from the positive draft venting device 25 into a pipe 27 leading to the wind box 28 below the grate bars. This preheated air is thus used in burning fuel in the furnace to increase the rate of combustion. The rate of cooling can be controlled by controlling the volume or velocity of the air circulated through the space 24 to a temperature where the slag and ash which comes into immediate contact with the walls of the furnace will be congealed so that a protective coating of slag and ash is formed on the surface of the silicon carbide refractory. By conducting the heat away from the walls at the proper rate, the temperature of the slag and ash in immediate contact with the walls can be kept just below the melting point. On the other hand the heat will not be conducted away from the wall at such a rate as to materially cool this portion of the fuel bed.

It is therefore evident that the present invention may be applied to furnaces of various types where control of the temperature of the refractory face or furnace lining is necessary or desirable.

By reason of the high mechanical strength of silicon carbide at elevated temperatures, I have found that for most installations the thickness of the ventilated wall need not exceed 4½ inches whereas a fire clay wall for practical purposes in commercial installations must be nine inches thick or greater in any height up to thirty feet. By reducing the thickness of the refractory wall better temperature control is possible.

While I am aware that silicon carbide refractories have been extensively used, and the high heat conducting properties of silicon carbide are known, it has not heretofore been proposed to make any practical use of silicon carbide refractories in furnaces in combination with a means whereby an accurate control of temperature conditions at the face of the refractory can be secured. A refractory, to be practical in the carrying out of my invention, should have a thermal conductivity in excess of 0.006 cal/cm²/°C./sec.

Fire clay is rated at .004—silica ordinarily rated at .005+ or —, fused alumina between .008 and .010; fused magnesium oxide between .009 and .011, and silicon carbide is rated between .038 and .020. It will thus be seen that silicon carbide particularly is many times more thermally conductive than fire clay.

While I have illustrated and described certain specific embodiments of my invention, it will be understood that this is merely by way of illustration and that the invention may be applied to various types of furnaces and combustion units, various changes and modifications being contemplated under the scope of the following claims:

I claim:

1. In a furnace, a refractory wall subject to slag erosion formed of a silicon carbide refractory, said wall having a closed air circulating passage back of the exposed face thereof, and means providing a forced flow of air through said passage by means of which the rate of air circulation may be varied to vary the cooling of the wall and protect it from slag erosion.

2. In a furnace, a wall subject to slag erosion having an inner lining portion formed of a heat-conducting non-metallic refractory substance the thermal conductivity of which is many times that of a fire clay wall of equal thickness and an outer portion, said wall having a closed air circulating passage therein between the inner and outer portions thereof, and means for inducing a forced circulation of air through the passage to cool the exposed face of the wall and heat the air.

3. In a furnace, a wall subject to slag erosion formed of a heat-conducting non-metallic refractory substance the thermal conductivity of which is many times that of a fire clay wall of equal thickness, said wall having a closed air circulating passage therein back of the exposed face thereof, means for inducing a forced circulation of air through the passage to cool the exposed face of the wall and heat the air, and means for conducting the air so heated into the furnace for supporting combustion therein.

4. In a furnace, a wall subject to exposure to molten slag, said wall comprising in combination an inner lining portion of non-metallic refractory which has a thermal conductivity in excess of .006 cal/cm³/sec./°C. and an outer portion spaced from said inner lining to provide an air passage between the two, and means for variably circulating cooling air through the passage in contact with the unexposed surface of said inner lining portion.

5. In a furnace, a wall exposed to slag erosion, said wall comprising an inner lining portion of a non-metallic refractory less than nine inches thick with a thermal conductivity in excess of .006 cal/cm³/sec./°C. and an

outer wall portion spaced from said inner lining portion to provide an air passage therebetween, and means for forcing a variable current of cooling air through the passage in contact with the unexposed surface of the inner lining in order that the rate of cooling of the lining adjacent to the combustion chamber may be varied in accordance with the rate of combustion in the furnace.

6. In a furnace, a combustion chamber having a wall subject to slag erosion, said wall comprising an inner lining portion composed principally of a silicon carbide refractory which has a thermal conductivity in excess of .006 cal/cm³/sec./°C. and an outer portion spaced from said inner lining to provide an air passage therebetween, and means for forcing a variable volume of air through said passage, the air coming into contact with the unexposed surface of said inner lining.

7. In a furnace, a combustion chamber having a wall subject to slag erosion, said wall comprising an inner lining portion composed principally of a silicon carbide refractory which has a thermal conductivity in excess of .006 cal/cm³/sec./°C. and an outer portion spaced from said inner lining to provide a closed air passage between the two, means for forcing a variable volume of air through the passage, the air coming into contact with the unexposed surface of said inner lining, and means for conducting the air so heated into the combustion chamber.

8. In the operation of a furnace having a combustion chamber with a lining of a non-metallic refractory material composed principally of silicon carbide to retard oxidation of the silicon carbide by the furnace gases and prevent slag erosion thereof, the method which comprises the steps of removing heat from the refractory lining at a rate sufficient to maintain the temperature of the exposed face of the lining below the temperature at which the slag in the furnace is fluid, whereby a thin protecting film of slag is formed over the exposed face of the lining, by means of a current of air circulated against an unexposed face of the lining, and varying the flow of air to compensate for variations in furnace temperature or variations in the melting point of the slag.

9. In the operation of a combustion chamber having a non-metallic lining formed of a refractory whose thermal conductivity is in excess of .006 cal/cm³/sec./°C., the steps which comprise the removal of heat from an unexposed surface of said lining by the forced circulation of a current of air against said unexposed surface and at a rate sufficient to maintain said lining below the flame temperature in the furnace to congeal a thin protective layer of ash over the exposed surface thereof, but at a rate insufficient to cool the exposed face of the lining below the kindling temperature of the injected fuel,

and varying the amount of air circulated directly with the rate of combustion of the fuel, whereby the removal of heat varies directly with the rate of combustion of the
5 fuel.

10. In the operation of a combustion chamber having a non-metallic lining formed of a refractory whose thermal conductivity is in excess of .006 cal/cm²/sec./°C., the steps
10 which comprise the removal of heat from an unexposed surface of said lining by the forced circulation of a current of air against said unexposed surface and at a rate sufficient to maintain said lining below the flame
15 temperature in the furnace to congeal a thin protective layer of ash over the exposed surface of said lining, but at a rate insufficient to cool the exposed face of the lining below the kindling temperature of the injected
20 fuel, varying the amount of air circulated directly with the rate of combustion of the fuel, whereby the removal of heat varies directly with the rate of combustion of the
25 fuel, and utilizing the air so circulated in the combustion chamber for burning the fuel.

In testimony whereof I have hereunto set my hand.

CLARENCE E. HAWKE.