

Feb. 7, 1967

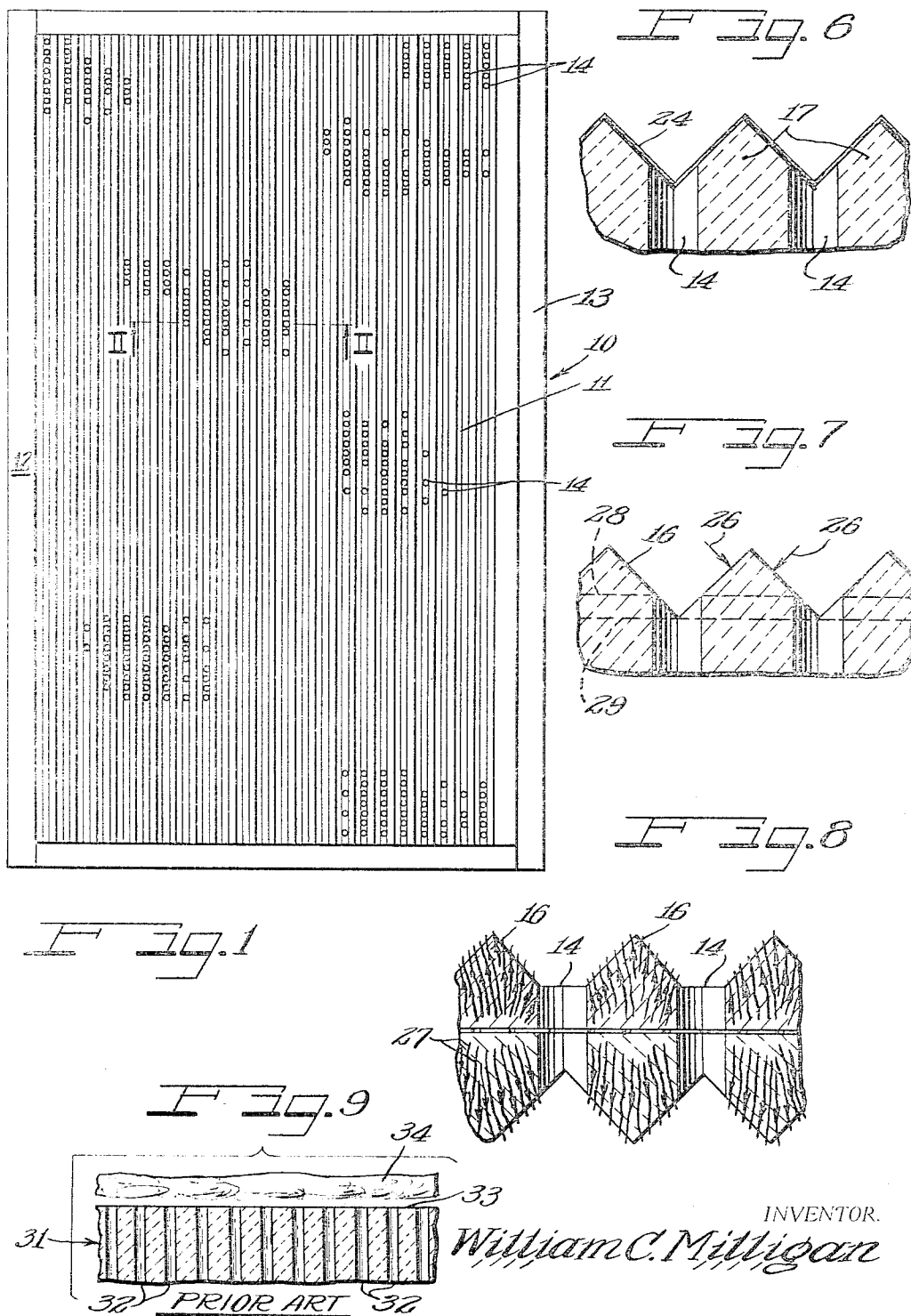
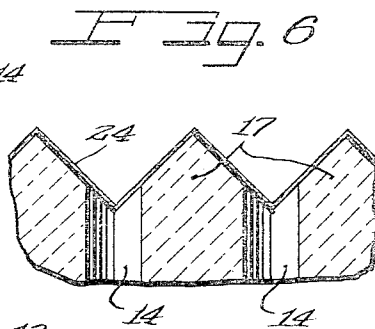
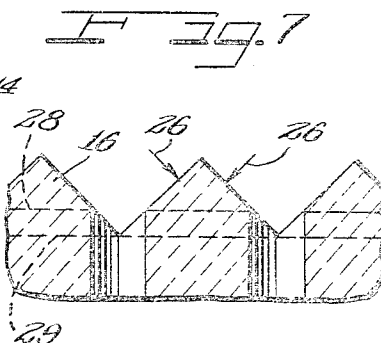
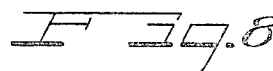
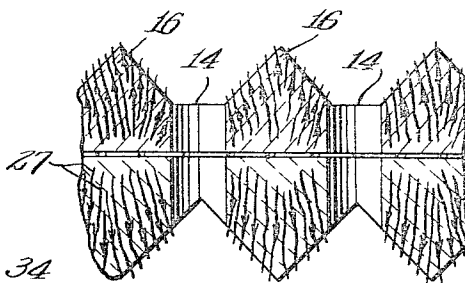
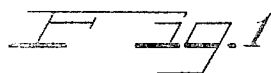
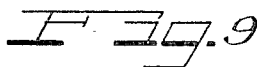
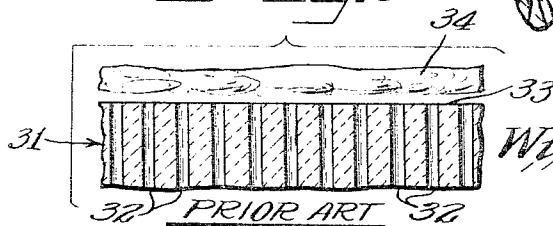
W. C. MILLIGAN

3,302,689

CATALYTICALLY ACTIVE RADIANT TILE

Filed Feb. 11, 1965

2 Sheets-Sheet 1



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3,302,689

CATALYTICALLY ACTIVE RADIANT TILE

Filed Feb. 11, 1965

2 Sheets-Sheet 2

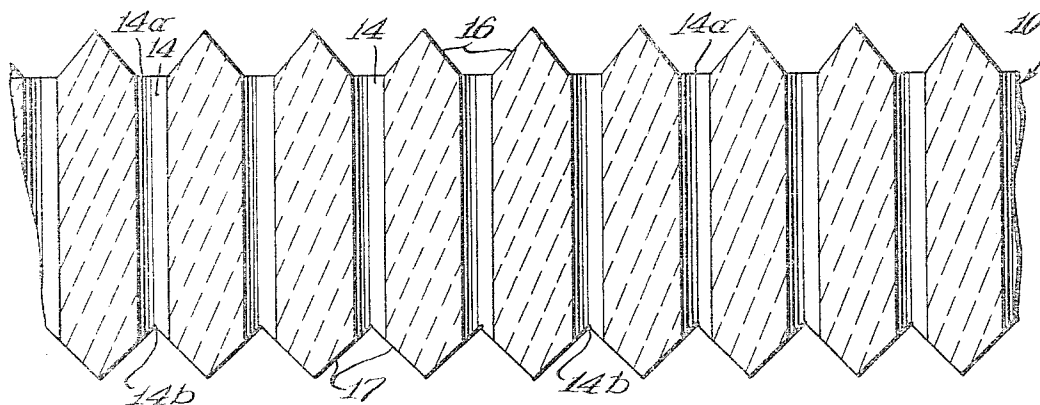


Fig. 2

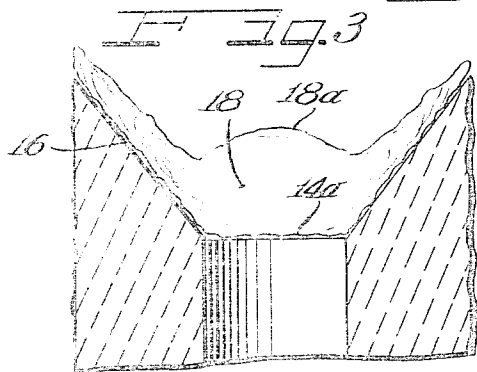


Fig. 3

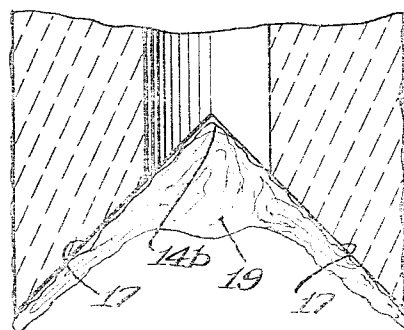


Fig. 4

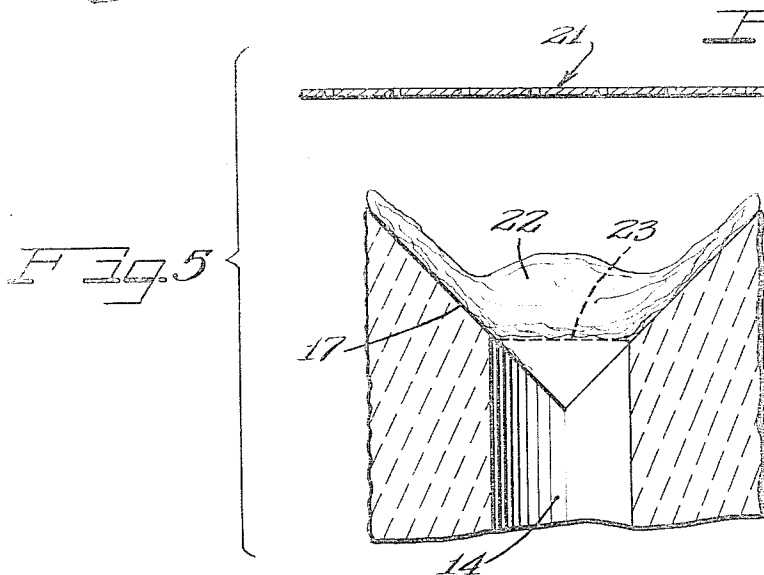


Fig. 5

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3,302,689
CATALYTICALLY ACTIVE RADIANT TILE
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Filed Feb. 11, 1965, Ser. No. 431,858
14 Claims. (Cl. 158—116)

This application is a continuation-in-part of my co-pending Ser. No. 404,147, filed Oct. 15, 1964 which in turn was a continuation-in-part of Ser. No. 127,419, filed June 6, 1961 now abandoned, and a continuation-in-part of my copending Ser. No. 246,761, filed Dec. 24, 1962, now abandoned.

The present invention relates to efficient infrared radiating units for combustion type heaters.

The most serious drawback to ordinary combustion type heaters has been a lack of efficient infrared radiation output from the combustion of the gaseous fuel. Although the combustion of fuel gases can attain a fairly high temperature, the density of the gases and their radiation efficiency are both extremely low. The hot gases generated, therefore, are suitable only for heating other objects primarily during the combustion process. The radiation released during the combustion process is so low, and normally lost so rapidly as to be of little benefit to the combustion flame. Therefore, the radiation losses from the flame were so high as to put a ceiling on the temperature obtainable during the combustion process, the ceiling being substantially lower than the peak temperatures theoretically obtainable from the mixture.

Metals, ceramic materials, and other solid objects which can withstand high temperatures can be used very effectively and efficiently as radiators of infrared energy. However, it is difficult to heat these dense materials to obtain efficient radiation due to the limitations of heat transfer from hot gases to the dense objects through the boundary layer resistance present in all combustion process environments. This relatively stagnant area of the boundary layer can only transfer heat effectively over a substantially large area which will allow the gradual transfer of heat present in the combustion gases. Normally, the only way that heat transfer can be attained at a fairly rapid rate under these conditions is with the use of flame velocities having a substantial Reynolds number in order to attain severe turbulence at the boundary layer surfaces and therefore transfer more heat. Although in theory this would seem to be a solution to the problem, it introduces other difficulties in that a substantial loss of efficiency occurs when this practice is attempted.

The most desirable characteristic for an infrared heating system would include a compact, high temperature area with the ability to radiate infrared radiation with high efficiency and at reasonable rates of fuel-air consumption. These requirements exist because of space and cost considerations required to make the device practical, and the fact that the higher the surface temperature of the radiating material, the higher the radiation output for a given size. The radiation efficiency properties of any good radiant energy material should have a radiation density gain of 400% to 500% or so for equal incremental increases in temperature.

As an example, a black body heated to 1600° F. will radiate 30,300 B.t.u. per square foot per hour. The same black body material at 2000° F. will radiate 60,200

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B.t.u. per square foot per hour. If the same material is raised another 400° to 2400° F., the total B.t.u. per square foot per hour is 112,500. The transfer of such substantial amounts of heat energy to the radiating surface is a formidable problem, particularly in small areas.

In addition to the fundamental problem of transferring substantial quantities of infrared energy despite the presence of the boundary layer, other and almost equally difficult problems affect the overall picture. One of these is flash-back from the heated surface back through the fuel-air supply system. The extremely high surface temperatures required to radiate large quantities of infrared energy also place very severe load heat transfer problems on the heating element. In order to prevent flash-back, the thermal and infrared radiation transfer rates must be exceptionally low or the flash-back tendencies will seriously impair the operation of the device.

Furthermore, any device of this type should be compatible with relatively compact gas chamber supply systems. The heated mass should not normally be in excess of 1 inch in thickness and is preferably $\frac{3}{4}$ inch thick or less to minimize gas flow back pressure problems from low gas pressure supply mains presently in use. Furthermore, the device should have a long life and high operating temperatures, and should provide a very efficient conversion of fuel-air mixtures into radiated heat. Finally, any such device must be reasonably simple and easy to fabricate and to service during its normal operational life.

One of the objects of the invention is to provide an improved heating tile which can be employed with existing fuel-air combustion systems and provide a substantially higher degree of infrared radiation than has heretofore been achieved with such tile.

Another object of the invention is to provide a device which will withstand very high surface temperatures so that it can radiate large quantities of infrared energy, while effectively preventing flash-back into the fuel supply system.

Another object of the invention is to provide a ceramic heating tile which is reasonably easy to fabricate and to service.

These and other objects of the invention are attained by correlation of the geometry and dimensions of the improved heating tile of the present invention. Before proceeding to a discussion of the specific parameters involved, it would be well to discuss some of the fundamental phenomenon which occur in a combustion process, particularly at the interface between the burner tile and the flame, in order to understand the reactions involved more completely. For that purpose, reference is invited to the attached sheets of drawings in which:

FIGURE 1 is a plan view of an improved tile embodying the improvements of the present invention;

FIGURE 2 is a greatly enlarged cross-sectional view taken substantially along the line II—II of FIGURE 1;

FIGURE 3 is a still more highly magnified view of the tile construction, illustrating somewhat schematically the configuration of the flame in the areas of the tile where combustion occurs;

FIGURE 4 is a view similar to FIGURE 3, but illustrating the condition existing at the bottom face of the tile, with the flames being directed downwardly;

FIGURE 5 is a view illustrating the inclusion of a radiating grid to improve the combustion characteristics of the flame;

FIGURE 6 is a greatly enlarged view of the combustion area, showing the existence of the boundary layer rather schematically;

FIGURE 7 is a view similar to FIGURE 6 but illustrating some of the limiting conditions which may exist in systems of this type;

FIGURE 8 is a greatly enlarged view of an improved tile according to the present invention showing the manner in which the gas-air flow is supplemented by flow through the tile itself; and

FIGURE 9 is a fragmentary view of conventional prior art tile structures.

As shown in the drawings:

In FIGURE 1, reference numeral 10 indicates generally a single ceramic tile embodying the principles of the present invention and including a radiating face 11, the tile 10 having recessed lateral edges 12 and 13 for receiving them in a suitable fixture. The tile 13 is provided with spaced rows of gas ports 14, the configuration of which can best be seen in the greatly enlarged view of FIGURE 2.

As seen in that figure, the upper surface of the tile 10 is formed with ridges 16 which are triangular in cross-section, and bottom ridges 17 of similar configuration. The ports 14, and the valleys between the top ridges 16 are generally flat as indicated at numeral 14a, while at the base of the tile 10, the ports 14 have V-shaped portions 14b.

The tile 10 is composed of a porous catalytic ceramic material and the method for manufacture of such tile is described in a copending application of the present applicant.

In FIGURE 3, reference numeral 18 has been applied to a combustion flame extending between adjacent ridges 16 and above the relatively flat outlet end 14a of a gas-air port 14. The showing of FIGURE 3 is intended to indicate the actual area of contact between the flame and the sides of the ridges when the flame is operated at an optimum rate of fuel-air mixture issuing at a proper velocity from the gas port 14. The combination of the flattened area of the port outlet with the adjacent ridges has the property of forcing the flame to be virtually in contact with the bottom and sides of the ridges, with a minimum of lost contact area in the center where a small hump 18a may be observed. The upward flow of the flames follows the contour of the ridges due to the aerodynamics involved in gaseous flow over tapered surfaces. As a result, an efficient contacting and turbulent mixing area is provided directly at the surfaces, where the heat transfer from the flame 18 to the secondary object must occur for the purpose of most effective heat transfer.

In FIGURE 4, a flame 19 is shown depending from the V-shaped portion 14b of the port 14. In this instance, a much narrower flat area, or no flat area at all, is used between the ridges 17 because in this upside down position of the flame, there is sufficient back pressure from the hot exhaust gases just outside the flame area to force the bottom portion of the flame farther down the sides of the ridges without as much assistance from the flat area. If the flames are forced down too far into the port area, it will be observed that the outer surfaces of the ridges will not be as hot as the area immediately surrounding the ports and adjacent the port area. This phenomenon causes a substantial loss in output radiation since the overheated area will have much less surface area than the underheated area of the ridges. Since the tile 10 is composed of a catalytic material, the overheated area may result from excessive activation of the catalysts and the excessive temperature input in this narrow, confined region from the increased mass, density and turbulence of the hot gases adjacent to the narrow region and due to the increased supply of combustion fuel to the catalytic surfaces in the same region.

In FIGURE 5, a radiating grid element 21 is shown positioned in spaced relation to a flame 22. The positioning of the grid 21 in this manner tends to extend the flame over the entire surface area. If the grid 21 is removed, with no change in the fuel-air input rate, the bottom of the flame position will shift to the dotted line area indicated at reference numeral 23, just above the ports 14, due to the removal of back pressure effects from the grid which tend to force uniform heating down to the bottom of the V-shaped portion. This shifting leaves a visibly lower temperature area of material in the ported section which is at a lower temperature than the remaining portions of the ridges above the dotted line 23.

The explanation for these rather unique shifts in flame position and heating reactions depend on a number of interrelated, complex factors. First, there is a change in flame combustion characteristics when a hot flame is directed at an adjacent object. The heat must be transferred through the boundary layer which exists between the outer wall of any flame and a nearby object being heated, regardless of the nature and type of the flame and regardless of the nature and type of the material which is being heated by the flame. In essence, the flame has a much higher temperature than the object being heated, even in the case of a highly porous, low thermal conductivity ceramic element. A very sharp temperature gradient exists between the outer wall of the flame and the outer wall of the object being heated. This sets up a condition which interferes with normal flame combustion characteristics due not only to the physical interference presented by the nearby objects within the wall of the flame, but also from the excessive cooling effect presented by the object being heated. This situation therefore has a very strong tendency to reduce the temperature of the nearby gases close to the combustion flame to sub-normal temperatures for the flame to exist vigorously or at all within a very narrow or thin film area, even if the flame is directed toward the object to be heated. Combustion gases require a certain minimum temperature within the hot gas area to sustain the reaction of a flame from molecule to molecule throughout the combustion mixture. In any region, however thin, if the combustion molecules are not maintained at this minimum temperature level, a flame cannot exist within the confines of the narrow gap or layer if there is not sufficient temperature to sustain the combustion effect throughout the mass.

The boundary layer interferes with the rapid supply of heated gases to an object to be heated and also the rapid removal of the cooled gases which have transferred some portion of their total heat content to the heated object. Thus the effective conductance of heat is prevented by the boundary layer characteristics. This boundary layer is caused by the frictional effect of any surface area over which the moving gas comes in contact. This semi-stagnant or slow moving gas, although only a few thousandths of an inch in thickness, exists even over a highly polished surface. Consequently, the frictional effect of the surface area in contact with the outermost portion of the moving gas flowing over its surface sets up a condition whereby a thin layer of gas between the main body of the moving gas and the surface area is sufficient to cause formation of this boundary layer.

The Bunsen type of flame, with which the present invention is concerned, is only stable within certain flow limits, termed the stability limits. The flame is held from striking back by the gas flow. The flame front always adjusts itself so that at any point of the flame front, the component of the gas flow normal to the flame front is equal to the normal burning velocity at that point. Roughly, the burning velocity is nearly constant over most of the

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flame front but falls sharply to a much lower value near the cooler ridge of the burner surface, due to quenching effects at this surface. These effects may be due either to heat loss to the wall or to the removal of active centers by diffusion to the walls. These effects therefore act as a serious barrier in conjunction with the low thermal conductivity of the hot gases in the boundary layer to the efficient transfer of heat from the combustion flames to an object to be heated. This problem is further complicated by the rapid radiation of electromagnetic energy from the objects being heated and on through to some other nearby object which absorbs the radiated energy. The flame then must re-supply the radiated energy, which becomes quite difficult since a larger proportion of heat delivered through the boundary layer is almost immediately radiated away from the same surface at a very high rate. This radiated energy which must pass through the surrounding wall of flame, however, does help maintain the flame existing in the valley at a much higher temperature than would exist otherwise since it reduces the loss of radiant energy existing in the flame at any instant to a much lower degree than would otherwise be possible. Since the loss of radiant energy from the flame has an appreciable effect on the flame temperature, the steady and intense re-radiation of the heated walls in the flame area back through the flames serves to keep the flame temperatures higher than would normally be possible when the radiant energy is promptly lost as in an open flame with no opportunity for additional radiant energy to be passed back through the flame. The heated walls, according to the present invention, are constructed at an angle which promotes the transfer of radiant energy from one wall to the other and back again for a substantial number of times before the radiant energy is permanently lost by being radiated completely away from the heating element. The gas boundary layer barrier cannot retard or affect the emission of the radiant energy from its heated surface or its subsequent absorption through another boundary layer to another adjacent wall. Consequently, radiant energy transfer between walls or from the walls to a heated object is not seriously interfered with by the boundary layer since its resistance to transmission of radiant energy is relatively low. The very thin boundary layer appearing on the walls of the tiles has been indicated at reference numeral 24 in FIGURE 6.

A second effect which enters into the problem is that of the back pressure effects from the heated surface against the entrance of the flames to the heated surface. This effect can be readily observed in flames when ceramic cones are placed up against the side of the flame in such a way that the cones can be heated. It can then be observed that the hotter the cone tip, the larger will be the dimple effect against the flame front by the heated tip. This heated tip is a point of excessive pressure from superheated gases being forced against the wall of flame. This effect obviously interferes with the combustion gases being able to reach the heated cones effectively and there is also apparently a lesser distribution of combustion materials in this dimpled area due to excessive heat dissipation.

It is therefore evident that the hotter a surface becomes, the more difficult it is to transfer heat energy through the boundary layer to the objects being heated. Any high temperatures existing on the surface of the heated objects and any increase in temperature of the flames themselves also proportionately expand the molecules in the boundary layer and reduce their concentration. This proportionally reduces the ability of the hot gas molecules to transfer heat. The hotter the object becomes, the more difficult it is to transfer the required amount of heat to make up for the increased amount of radiation resulting from the increased temperature, in proportion to the reduction in heat transfer of molecules across the boundary layer to the radiating surface.

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From the foregoing, it will become more apparent as to why a supplementary re-radiator grid placed above the flames helps to increase the temperature of the radiating surfaces both by back radiation received from the radiating grid and from the back pressure effect on the flame itself forcing the combustion flame closer to the hot surfaces to be heated in spite of the combination of circumstances referred to previously.

Without a grid, the same effect is utilized in the present invention in a manner that can be observed when the flame 18 is operating as shown in FIGURE 3, free to burn in a vertical plane. When the combustion mixture is first ignited, it will be observed that the flames will be operating near the top of the peaks or ridges 16 only, with a considerable distance between the bottom of the flame and the bottom of the valley represented by 14a. As the tips of the ridges grow hotter, the back pressure effect of the ridges gradually forces the flame to seat down lower. The increase in wall temperature reduces the heat loss to the flame from excessive quenching at the outer walls of the flame. This effect continues on down until the flame is fully seated in the flat area 14a in the valley between the ridges. The flat areas between the adjacent ports 14a also serve as a reduced pressure area to help pull the flame down to proper seating relationship along the bottom of the ridge.

The same action proceeds much faster if a grid is properly positioned above the flames. If the ridges have a sharp V at the bottom as shown in FIGURE 5, the bottom part of the flame does not go below the area indicated at the dotted line 23 unless a re-radiator grid 21 is placed above the flames, as previously described. Without the grid 21, the creeping heat effects from the ridge down to the base will occur as in FIGURE 3, but without the assistance of a flat area at the bottom of the ridges, the flame cannot fully seat itself or heat up all of the bottom part of the ridge. Thus, the V-shaped orifice will be used only when the flame is inverted, or with the use of a re-radiating grid.

In a porous ceramic material being heated by a combustion flame, peak temperatures will be obtained on the surface only with extremely porous materials which exhibit a low thermal loss toward the rear of the ceramic element. It has been observed that with the difficulties of supplying sufficient heat across the boundary layer to keep up with the rate at which radiant energy is being radiated from the heated surface, a very shallow depth of heating occurs, measuring only a few thousandths of an inch. However, by using the proper geometry of orientation of surfaces according to the present invention, this surface heating effect will only be observed at relatively low rates of fuel-air input, and even in these conditions, the catalytic effect will cause a higher temperature to exist at the surfaces than normally. Accordingly, it is desirable to use a material having a pore volume area of at least 100 square meters per gram, and up to 900 square meters per gram, the upper limit being defined by structural requirements.

The catalytic materials contained in the ceramic elements of the tiles are activated and controlled by infrared radiation, so that an exothermic heating effect is obtained from the catalyst which nullifies to a substantial degree the limitations of the boundary layer problem. A gain in heat transfer occurs from the catalytic action because its heat transfer properties are not limited by the boundary layer effect, since the heat is transferred at the instant of contact when the actual exothermic reaction occurs. At that instant, it is most effective to transfer heat to the secondary object, in this case, the ceramic catalytic pores. With the use of the extremely porous masses of the present invention, an unusually large surface area is presented in a compact mass to obtain exothermic heat reactions during the direct contact between the catalyst and the reactant gases. In the present instance, a catalytic reaction is necessary to force an exothermic reaction between the react-

ant gas molecules and the radiating materials. Since the heat transfer is primarily during the contact time between the catalyst and the reactive molecules, a more efficient heat transfer takes place during the exothermic reaction to the catalytic material. Consequently, the heat transfer properties are substantially different than those existing from a flame through a boundary layer and the object to be heated.

With the use of very porous material of the type contemplated herein, it will be found that reactant gases can penetrate substantially deeper than the outer catalytic surfaces. With sufficient radiant energy existing at the outer surfaces, part of the outer radiant energy is directed inwardly as shown by the arrows 26 in FIGURE 7.

The existence of the boundary layer is substantially altered when a catalytic effect of any significant magnitude occurs on the catalytic surfaces. The sudden heating and resulting expansion of the reactant gases at and below the outer surface of the catalytic material in the ridges causes proportional changes in expansion and substantial velocity changes in the reactant gases which cause such high turbulence that the boundary layer is significantly altered. The rate at which reactant gases can reach the catalytic area is increased because of the increase in turbulence. An important reduction in quenching is obtained due to higher temperatures existing in the former boundary layer. Furthermore, a significant amount of ionization is provided during the catalytic reaction to bring the outer wall of the flame front in actual contact with the catalytic surfaces. In addition, the ability to rapidly heat the radiating surfaces in actual contact provides a highly effective means of eliminating the barrier effects of the boundary layer.

The pore volume area required for the catalytic reactions also reduces the low heat transfer properties of the boundary layer by increased turbulence, and provides a superior scavenging area for the removal of hot gases which have given up as much heat as possible to the ridges. In addition, the high porosity increases the scavenging action to remove the exhaust products of the catalytic reaction and supply fresh fuel-air mixtures for subsequent exothermic catalytic reactions outside and inside the ridges.

As the temperature and the resultant radiation energy increase, some definite optimum point is reached which limits the amount of heat energy that is possible to transfer under these conditions, even though this level is substantially higher than possible with any previous system. An additional means must then be provided to take full advantage of the catalytic capabilities of the system since the input rate of the fuel-air mixture to the ridges will reach a point where the flame starts to lift off. This is not a particularly serious limitation in the device of the present invention as illustrated in FIGURE 8. The tile is of such porous construction as to provide internal communicating channels through which the fuel-air mixture flows, as indicated by the arrows referred to at reference numeral 27. This diffusion of fuel-air mixtures through the ceramic mass in addition to that provided through the regular gas ports 14 has several important advantages. For one, when velocity conditions begin to limit the amount of heat or reactant materials obtained on the heated surfaces, the additional internal supply of gases diffusing from inside the pores again effectively adds to the total reactant gas supply in the combustion flames over the surfaces of the ridges. This permits the heating to progress farther and farther inside the ridges in proportion to the fuel-air mixture input rate and permits progressively hotter surface temperatures inside and on top of the ridges. This effectively increases the supply of reactant gases to the catalytic materials which cannot be consumed in the flames above the ridges. The increased temperature of the ridges and the slower moving gas supply also provide a means of preventing the lifting of the flames due to high velocity gas mixtures. This is due

to the progressively higher temperatures of the ridges, which in turn prevent the flames trapped between the ridges from developing excessively cooled areas underneath the flame, and reduces the problem of fuel-air velocity exceeding the flame propagation rate, and a consequent lift off of the flame. The high temperatures at the ridge surfaces then re-ignite any reactant mixtures that exceed their normal velocity of propagation throughout the burning area. This effect is observed over a wide range of gas velocities because the increased reactant gas velocity which would normally cause lift off of the flame, increases the amount of reactant materials for the catalytic combustion at and below the surface of the porous ridges. As indicated in FIGURE 7, the mass heating of the ridges 16 without a grid will occur down to the level indicated by the dashed line 28 unless the flame burns in a downward position, when it will shift to the position indicated by the dashed line 29. In this manner, the entire thickness of the ridge is heated at the higher levels of gas input, and therefore more effectively supplies radiant energy to the outer surfaces.

While temperatures of almost 3000° F. have been obtained in this type of device using a re-radiating grid and natural gas as a fuel, no flash-back problems have been created by such extremely high temperatures so close to the gas ports. This is apparently due to the cooling effect of the fuel-air mixtures in the numerous gas ports, the radiation angles indicated by the arrows 26 in FIGURE 7, and also due to the diffusion of gases between the gas ports and up to the ridged area, as shown at numeral 27 in FIGURE 8.

One of the discoveries incident to the development of the present invention was that relatively common materials can be activated to substantial degrees of catalytic activities by being bombarded with intense infrared radiant energy. More specifically, it has been discovered that catalytic activity of common metallic oxides can be stimulated sufficiently to exceed even the noble metal catalysts which have been employed in the past. The noble metals have the further disadvantage that they are extremely expensive.

In contrast, the materials preferred for use in the present invention consist of common clays, ordinary metallic oxides, and the like which are capable of withstanding very high temperatures without loss of catalytic activities. Also, high temperature materials such as aluminas, zirconia, and the like can be used at higher temperatures than even the noble metals. These materials have the characteristic that the catalytic activity rate increases in direct proportion to the infrared radiation present in the vicinity of the catalytic surfaces.

Since infrared radiation heats up an object by internal vibrations of the atomic structure at a high frequency, this condition apparently raises the catalytic activity also. The activity rate is directly proportional to the intensity of the infrared radiation. The lowest catalytic activity of common materials is from radiation propagated from surfaces heated to about 1200° F. and rises to achieve a maximum activity up to and including the fusion point of the particular material. Although a broad band of infrared frequencies are involved, those affecting the catalytic activity of common materials to a noticeable degree are those varying in peak wave length from 3.16 microns to less than 1 micron. Actually, at temperatures as low as 1200° F., they may include infrared frequencies having wave lengths of about 20 microns. These lower frequency radiations are apparently not as effective for the stimulation of common materials as the frequencies having peak wave length intensities from 3.16 microns to less than 1 micron. However, it has also been discovered that the catalytic activity of the noble metals can be substantially increased at peak wave lengths of approximately 5 microns to 3.16 microns when used in combination with porous carriers or support media made from common clays.

The common metallic oxides or powdered metals or clays used in accordance with the present invention continue to operate at peak temperatures for long periods of time without deterioration and without any danger of poisoning which occurs in the use of noble metal catalysts.

Metals such as chromium, nickel and the like are particularly suitable for use in conjunction with the porous clays since they have high radiation emissivity and high catalytic activity. Such metals may be present as powders in amounts up to about 20% by volume.

The showing of FIGURE 9 represents a conventional type of ceramic heating system which utilizes a flame out of actual contact with the surface area, unless an outer radiating grid is utilized. Even when such a grid is utilized, however, very serious temperature and efficiency limits are encountered with this type of device. Specifically, the device consists of a tile 31 having a plurality of gas ports 32 extending therethrough and terminating in a planar surface 33 above which the flame 34 exists in spaced relation. Since this type of heating element usually employs a large number of ported areas, in order to prevent flash-back and obtain a combined cooling action, a serious loss of radiation results, particularly in those devices using from 200 to almost 300 holes per square inch. Furthermore, hot gases cannot contact the material to an effective degree. As an example, if the burner is operated in the position shown in FIGURE 9, the tile temperature attained with natural gas at the optimum fuel-air mixture and flow rate will be less than 1400° F., and generally a little over 1300° F. If operated in the other direction, that is with the flame burning in a downward position, enough back pressure is thereby created to force the flames a little closer to the tile 31 and the temperature will then rise to about 1450° to 1500° F., depending upon the flow rates, the fuel-air mixture, and the type of fuel.

In contrast, the ceramic tiles of the present invention have achieved temperatures of 2100 to 2200° F. without the use of external grids. With the presence of radiating grids, temperatures of approximately 2800° F. have been achieved without any problem of flashback, and a very uniform surface temperature has been achieved over the entire radiating surface.

To cite specific examples, I have found that the total cross-sectional areas of the fuel-air orifices should comprise about 4% to 19.8% of the total radiating area, including the ridge surfaces, of the burner, and preferably should be in the range from about 8 to 16%. Each orifice can have an average diameter between about 0.010 to 0.110 inch, and the preferred sizes fall between 0.040 and 0.080 inch. The specific sizes to be used depend upon the thermal conductivity of the catalytic material, the type of fuel, and the fuel-air ratio, and the length of fuel-air ports. The length of the fuel-air ports is varied over a considerable range from about ¼ inch to several inches. Air aspirator systems usually require from about ½ to ¾ inch in order to prevent excessive back pressure on the movement of fuel-air mixtures through the ports. Premixed positive pressure types of fuel-air supplies can use much longer ported channels if necessary.

The shortest distance separating two or more adjacent orifices is between about 0.010 and 0.400 inch, and preferably ranges from about 0.030 to 0.060 inch.

The total width of the ridges should be in excess of 1% of the total width of the area between any two adjacent rows of ported sections. The total ridged width may be extended to in excess of 10 times the total width of the area between two adjacent rows of port sections, in some cases. Generally, the ridge width will vary from 50 to 200% in excess of the total width between the two adjacent rows of ported sections.

The foregoing examples have been found to be practical limitations, but should not be construed as limiting the scope of the present invention.

It should be evident that various other modifications

can be made to the described embodiments without departing from the scope of the present invention.

I claim as my invention:

1. A catalytically active radiant heater tile comprising a highly porous refractory plate having an input surface and an opposed combustion surface, said refractory plate containing a combustion catalyst dispersed therein and having a pore volume area of at least 100 square meters per gram, said plate having regularly spaced passageways of substantially equal diameter in parallel rows permitting a uniform flow of combustion gases from said input surface to said combustion surface, a plurality of continuous ridged surfaces extending beyond the plane of said passageways at said combustion surface, the bases of said ridges terminating at said rows and having their peaks between adjoining rows, said plate being sufficiently porous to provide for significant diffusion of combustion gases through its pores in addition to the gases passing through said passageways, thereby heating the interiors of said ridges and raising the radiant energy output from said ridges.

2. The tile of claim 1 in which said ridged surfaces are on both sides of said plate.

3. The tile of claim 1 which includes up to 20% by volume of a metal selected from the group consisting of chromium and nickel.

4. The tile of claim 1 in which the passageways have an average diameter in the range from about 0.010 to 0.110 inch.

5. The tile of claim 1 in which the passageways have an average diameter in the range from about 0.040 to 0.080 inch.

6. The tile of claim 3 in which the length of each of the passageways is at least ¼ inch.

7. The tile of claim 1 in which the width of the ridges is from 50 to 200% in excess of the distance between adjacent rows of passageways.

8. The tile of claim 1 in which the distance separating adjoining passageways in a row is at least 0.010 inch.

9. The tile of claim 1 in which the distance separating adjacent passageways in a row ranges from about 0.030 to 0.060 inch.

10. The tile of claim 1 in which the total cross-sectional areas of said passageways comprises from 4 to about 19.8% of the total radiating area of said tile.

11. The tile of claim 1 which contains metallic elements which are catalytically activated by the frequencies of electromagnetic energy present in the combustion system.

12. The tile of claim 1 which contains a material which is an efficient infrared emitter as well as a combustion catalyst.

13. A catalytically active radiant heater tile comprising a highly porous refractory plate having a pore volume area of at least 100 square meters per gram, said plate having regularly spaced passageways of substantially equal diameter in parallel rows permitting a uniform flow of combustion gases therethrough, a plurality of continuous ridged surfaces extending beyond the plane of said passageways, the bases of said ridges being spaced apart thereby leaving substantially flat areas in which said passageways are located, the total radiating surface and the flat area combining to cause the combustion flames to extend into close proximity to said passageways, said plate being sufficiently porous to provide for significant diffusion of combustion gases through its pores in addition to the gases passing through said passageways.

14. A catalytically active radiant heater tile comprising a highly porous refractory plate having a pore volume area of at least 100 square meters per gram, said plate having regularly spaced passageways of substantially equal diameter in parallel rows permitting a uniform flow of combustion gases therethrough, a plurality of continuous ridged surfaces extending beyond the plane of said passageways, the bases of the ridges inter-

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secting to provide V-shaped grooves in which said passageways are located, said plate being sufficiently porous to provide for significant diffusion of combustion gases through its pores in addition to the gases passing through said passageways.

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