June 28, 1966 J. A. D. P. LHERAULT ETAL 3,258,058

RADIANT GAS BURNERS

Filed May 10, 1961 4 Sheets-Sheet 1

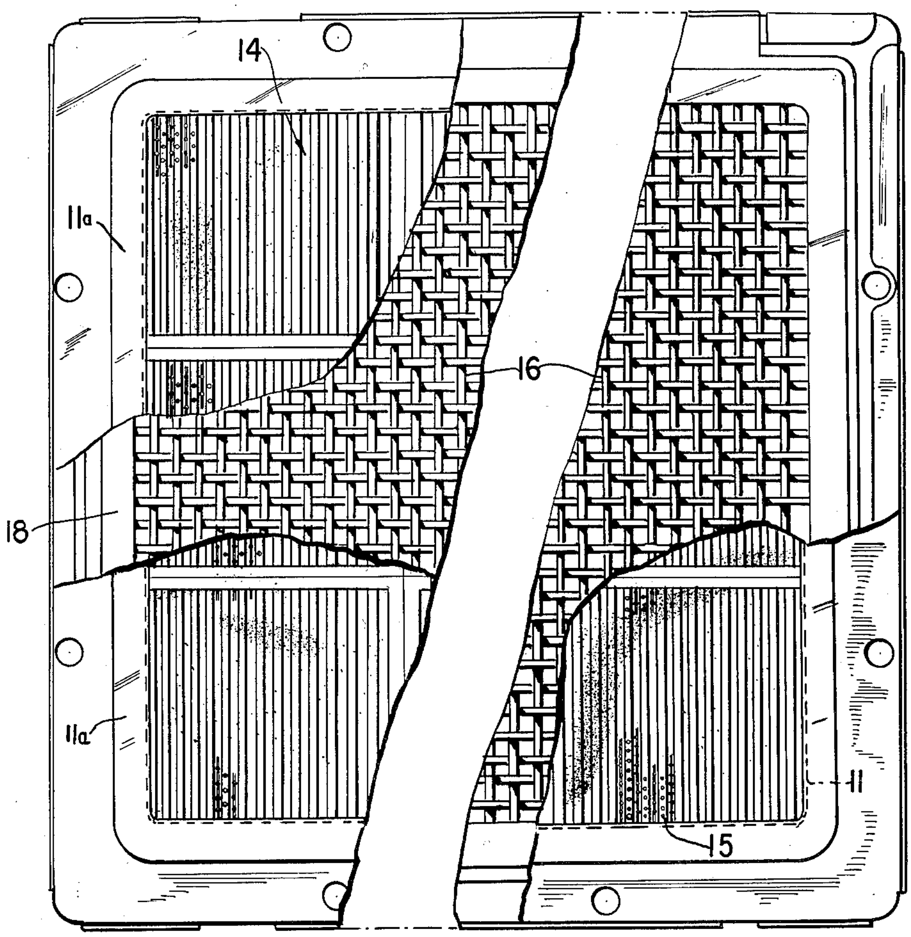

Fig. 1

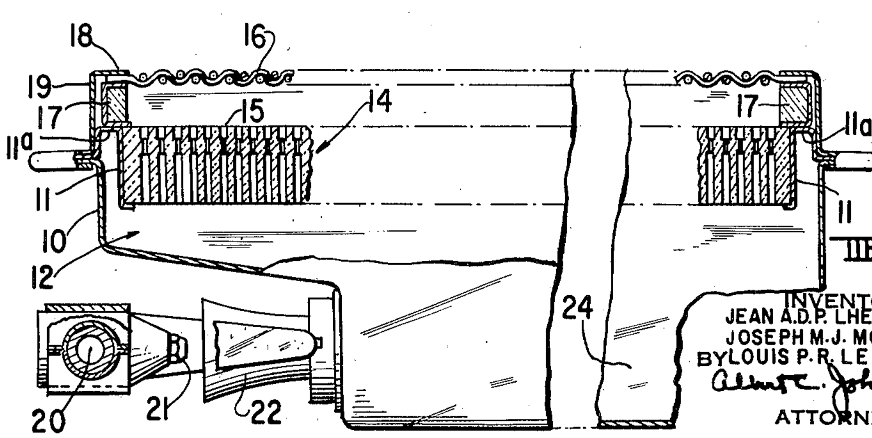

Fig. 2

INVENTORS
JEAN A.D.P. LHERAULT
JOSEPH M.J. MORGAND
BY LOUIS P.R. LEPAGE
Albert C. Johnston
ATTORNEY

RADIANT GAS BURNERS

Filed May 10, 1961 4 Sheets-Sheet 2

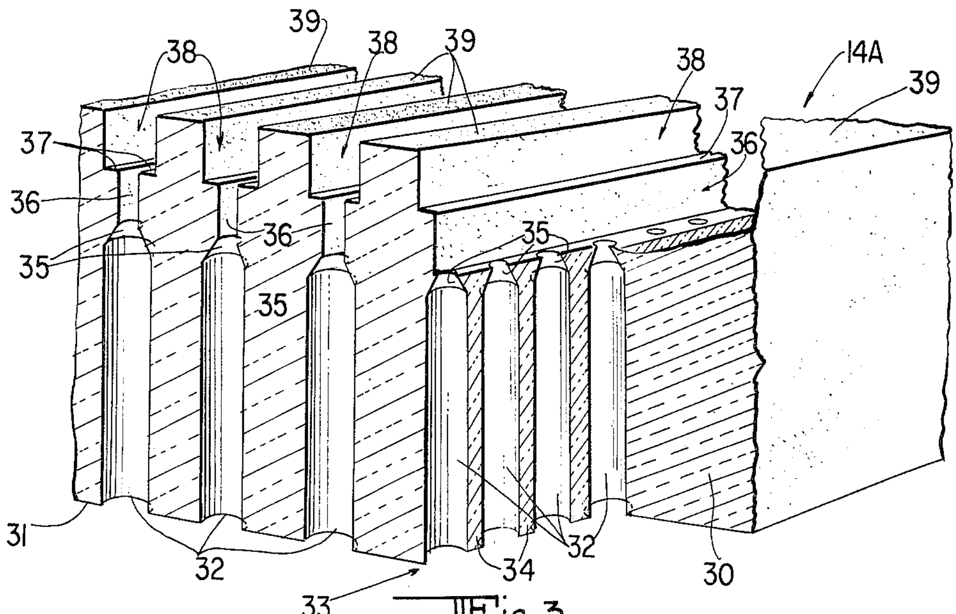

Fig. 3

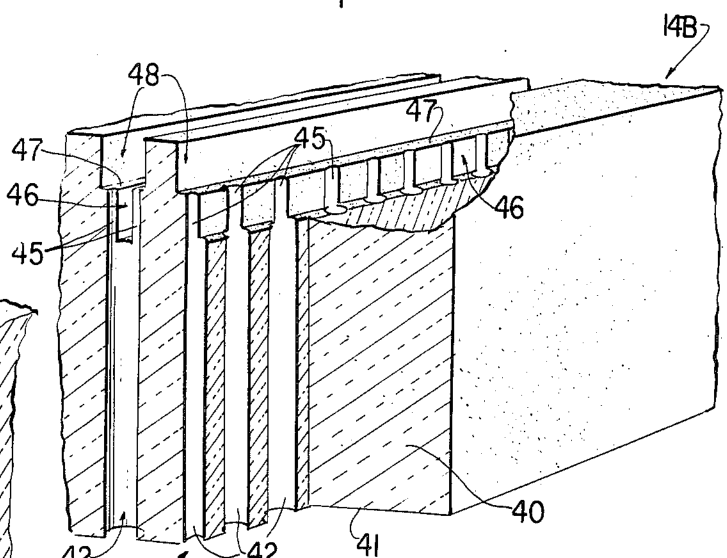

Fig. 4

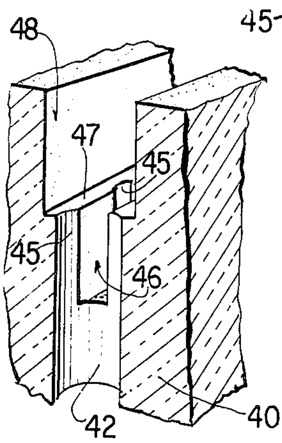

Fig. 4A

INVENTORS
JEAN A.D.P. LHERAULT
JOSEPH M.J. MORGAND
BY LOUIS P.R. LEPAGE
Albert C. Johnston
ATTORNEY

June 28, 1966 J. A. D. P. LHERAULT ETAL 3,258,058

RADIANT GAS BURNERS

Filed May 10, 1961 4 Sheets-Sheet 3

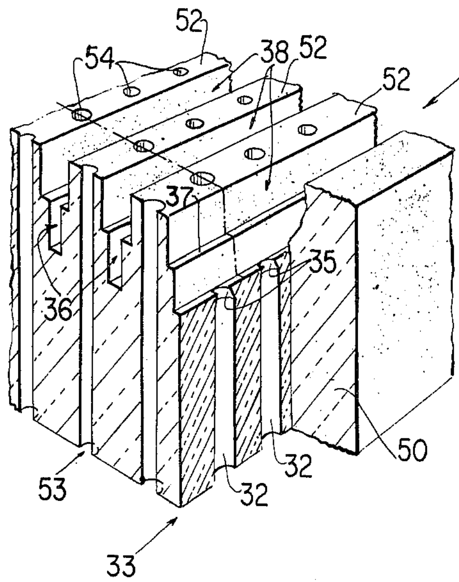

Fig. 5

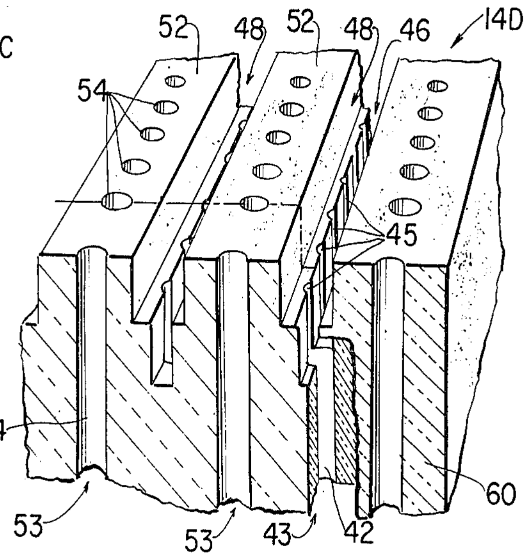

Fig. 6

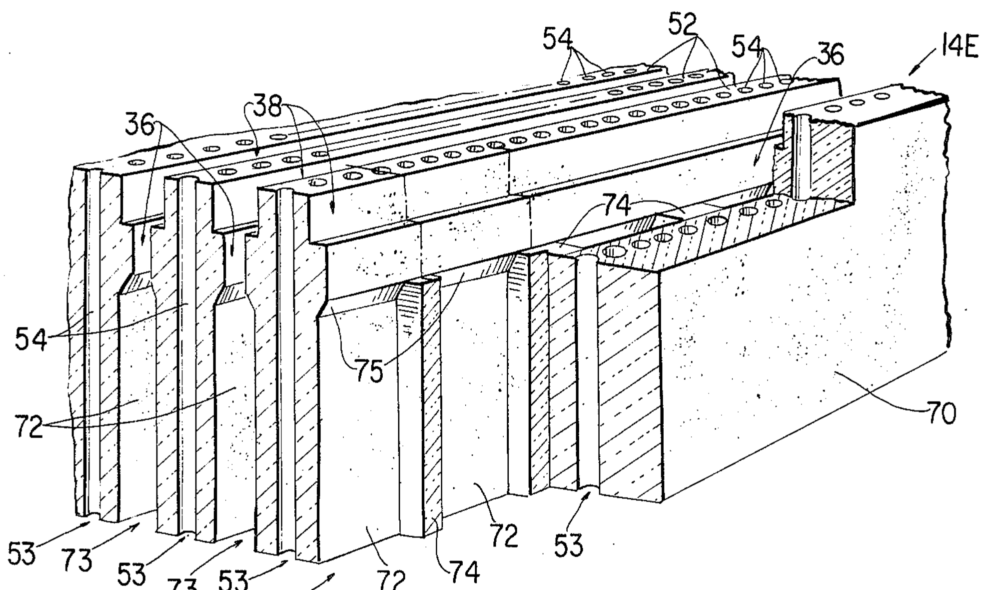

Fig. 7

INVENTORS
JEAN A.D.P. LHERAULT
JOSEPH M.J. MORGAND
BY LOUIS P.R. LEPAGE
Albert C. Johnston
ATTORNEY

RADIANT GAS BURNERS

Filed May 10, 1961 4 Sheets-Sheet 4

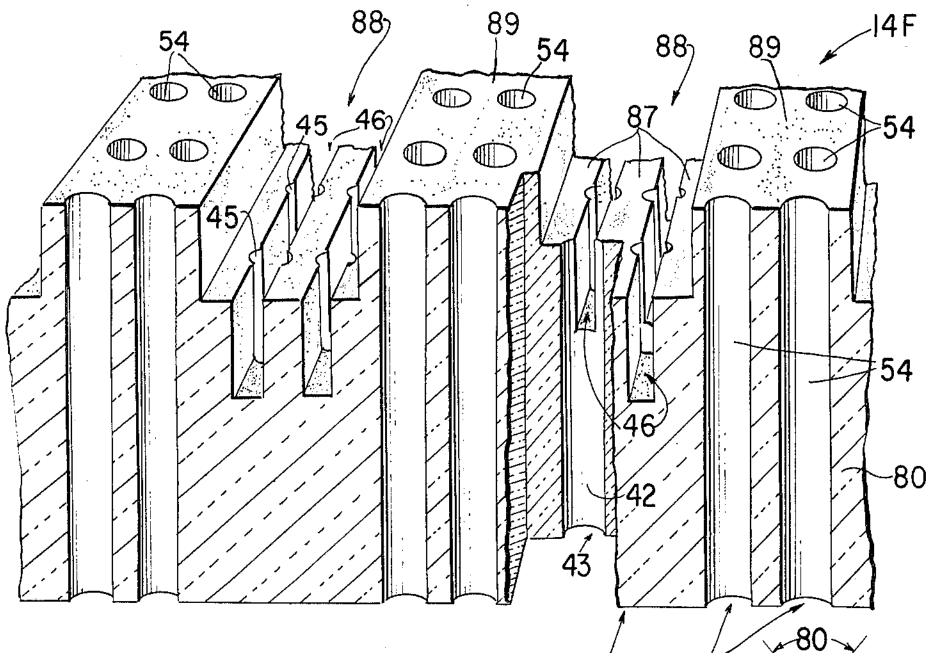

Fig. 8

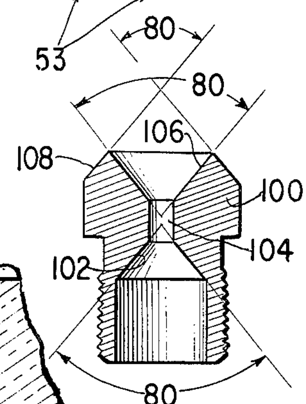

Fig. 10

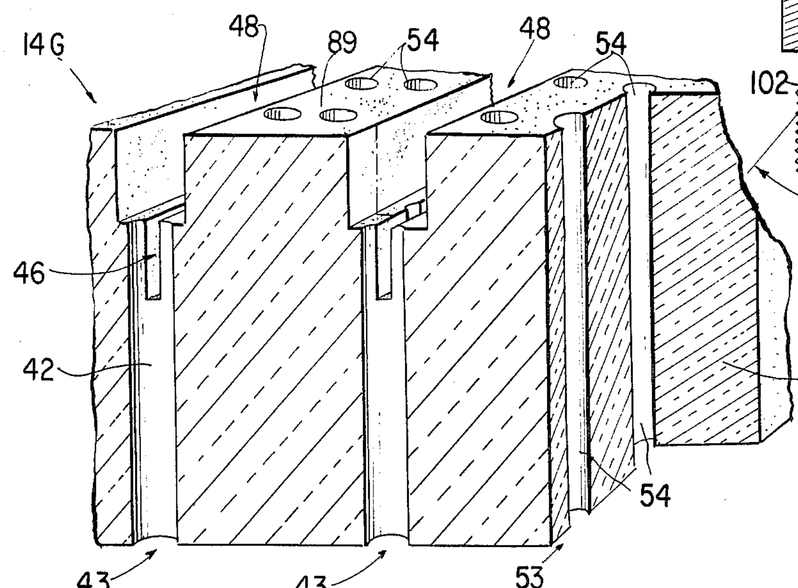

Fig. 9

INVENTORS
JEAN A.D.P. LHERAULT
JOSEPH M.J. MORGAND
BY LOUIS P.R. LEPAGE
Robert C. Johnston
ATTORNEY

United States Patent Office

3,258,058

Patented June 28, 1966

3,258,058

RADIANT GAS BURNERS

Jean A. D. P. L'Herault, Paris, Joseph M. J. Morgand, Versailles, and Louis P. R. Lepage, Bagneaux, France, assignors to Antargaz Societe Anonyme de Distribution de Gaz Liquides de Petrole, Paris, France, a corporation of France

Filed May 10, 1961, Ser. No. 109,224
Claims priority, application France, Sept. 27, 1960, 839,813
15 Claims. (Cl. 158—116)

The present invention relates to new and useful improvements in radiant gas burners or heaters by which the energy value of fuel gas is converted largely into radiant heat. It relates more particularly to new construction of heat-radiating refractory plates for use as the active elements of such burners or heaters.

It has long been known that infra-red and other radiation can be generated from fuel gases such as natural gas, manufactured gas, or bottled gas such as propane or butane, by the distribution of a combustible mixture of the fuel gas and air through a multitude of narrow tubular passages extending transversely through plates of heat insulating refractory material, for example, baked perforated ceramic plates of low thermal conductivity, and burning the resulting minute streams of the gas mixture as they issue from the passages to render the outer surface of the plates incandescent.

The heat radiating capacity or performance of gas burners operating in that manner is well known to be dependent upon (1) the energy input or fuel consumption of the burners, which is limited by the pressure head required for the flow of the gas mixture through the burner plate or plates, and (2) the amount of the energy input converted into radiation, which depends upon the area of, and the temperature attained by the radiating surface. The values of these factors are in turn closely related to the form of construction of the plates used as the active elements of the burners.

In the use of such burners of known construction the performance is very considerably limited by the magnitude of the pressure head required for the flow of the gas mixture through the plates. This factor becomes especially important, for example, when it is necessary, as often is the case in order to meet safety regulations, that the mixture issuing from the plates be assured of burning so completely that the burned gases will contain no appreciable amount of carbon monoxide.

In such cases, a relatively large proportion of air must be mixed with the fuel gas, hence a relatively large volume of the mixture must be passed into the burner and through the plates for a given fuel consumption. If the volume is increased, however, an increase of head pressure is required in order to keep the mixture flowing through the plates, and this may not be feasible due to the fact that the fuel gas is usually supplied under a restricted feed pressure. Accordingly, when a large proportion of air must be used in the mixture to assure complete combustion, the fuel supply rate ordinarily must be so limited that the burner will not operate with a high radiation output.

It is obvious that this important limitation would be alleviated by reducing the loss of pressure attending the flow of the gas mixture through the passages of the burner plates, i.e., by a reduction of the pressure head required in order to keep the fuel throughout at desired high values even when the fuel gas is mixed with enough air to assure complete combustion.

The possibilities of achieving such reduction are, however, limited by definite physical factors in the use of known expedients. It is generally sought to increase the total open section or delivery area of the gas passages

to the maximum extent and in a uniform manner, such as by forming the plates with the maximum number of passages each of the maximum cross section suitable for the fuel to be used and the working temperature to be attained. The cross section of the passages, however, cannot exceed a value above which there would be danger of flame backfiring through the passages to the rear of the plate. The number of the passages, in turn, is limited by the fact that a certain amount of the refractory material forming the plate must be left between the passages in order to have distinct passages and, fundamentally, in order to preserve required mechanical strength in the plate.

It is, therefore, an object of the present invention to provide new heat-radiant refractory plates for radiant gas burners, which possess the required mechanical strength and yet operate with considerably reduced losses of pressure, or pressure head requirements, thus enabling valuable improvements to be realized in the performance and the use of such burners.

Another important object of the invention is to provide new constructions of the burner plates by which, for a given fuel gas and a given size of burner, both the energy input or fuel consumption and the conversion of the energy input into radiation may be caused to approach or substantially to reach the maximum values attainable under practical service and safety conditions.

The present invention is based in one important aspect upon observation of certain physical phenomena which occur in the workings of perforated refractory plates of the constructions commonly used in radiant gas burners. It has been found that although the resistance to the flow of a gas mixture through the cylindrical passages of such plates increases in proportion to the length of the passages when the plate is cold, this relationship no longer holds true when the mixture is burning. When the mixture is burning at the outer side of the plate, its temperature increases greatly as it travels through the passages. As its temperature increases, so also does its speed; but at the same time its viscosity increases too. It has been found that the relative increase of the viscosity is substantially greater than that of the speed—so much so, in fact, that the pressure loss or increased resistance to flow in the last increment of the travel of the mixture in the passages, up to the point where it catches fire, is many times greater than it is in the first increment of such travel.

According to the invention, advantage is taken of the described phenomena by the provision of foraminous plates composed of heat-insulating refractor material, in which gas passages having flow-relieving outlet portions leading to the outer or flame surfaces of the plates are provided for the delivery of the combustible gas mixture through the plates. These passages comprise inlets and outlets differing in their forms and their flow limiting quantities.

The inlets are provided in the form of individual ducts of any desired shape suitable for the efficient distribution of the relatively cool gas mixture into the plate and for the strength requirements of the plate. They extend into the plate transversely from its inner surface and are mutually surrounded and spaced apart through the body of the plate by interconnected walls of the refractory plate material which give the plate the required mechanical strength.

The outlets are provided in the form of slots which extend into and along the outer side of the plate so that each slot connects the outer ends of a plurality of the inlets with the outer or flame surface of the plate and provides increased passage freedom for the gas mixture as it flows through the zone of the greatest increases of its temperature and its viscosity. The slots, however, are made narrower than the inlets and with a width so restricted that the velocity of the gas mixture flowing through them will be kept sufficiently high to prevent back-firing from occurring through them.

It has been found that in this way the pressure head required under working conditions for the flow of a given fuel-air mixture through a plate of given size can be very materially reduced, so that burners using plates made according to the invention will operate with a greater energy input, hence a greater radiation output, than prior radiant gas burners; and so that they will perform with a high radiating efficiency even when supplied with gas mixtures containing air in proportions sufficient to assure the complete combustion of the fuel content. The invention thus enables the safe elimination of all provisions for a supplemental air supply at the outer side of the plates in order to prevent the delivery of carbon monoxide in the burned gases.

It has been found that, all other things being equal, the loss of pressure occurring in an outlet slot having a given gas delivery area and a width restricted so that it will not permit back-firing is substantially smaller than that occurring in a plurality of tubular ducts, whatever their shape, which provide the same delivery area and are also restricted in width so that they will not permit back-firing. It has also been found that the loss of pressure occurring in such a slot may be further reduced by a construction in which the slot cuts across or is intersected by a plurality or row of tubular ducts so that the orifices, in effect, widen the slot at spaced locations by extending transversely through the slot to the outlet edge thereof.

Although the limiting width at which back-firing will occur is considerably greater in the case of a tubular duct such as one of circular section than it is in the case of a slot—being, for example, depending upon the composition of the gas mixture, from 1.0 to 3.2 mm. in the former case and from 0.5 to 1.6 mm. in the latter—it has been found that nearly the same limiting dimensions are still valid for a construction in which slots intersect and are traversed by rows of tubular ducts, such as end portions of cylindrical gas passages extending through the plate. The slot-traversing ducts in such a construction may therefore be formed with the width provided for ducts not interconnected by a slot, without giving rise to a hazard of back-firing.

Radiant burner plates embodying the foregoing principles to give improved performance qualities may be provided in various forms of construction, and various types or compositions of heat-insulating refractory materials may be used successfully for the manufacture of the plates.

In some embodiments, the inlets of the gas passages are provided by tubular ducts, each separated from the others by intervening refractory material, which have a larger cross section near the inner surface of the plate than at their junctions with the slots. The size and shape of the inlets and the total passage area for the distribution of the gas mixture into the plate are limited in such embodiments only by the mechanical strength requirements of the plate, and may be chosen as desired to meet those requirements and give the desired passage freedom for the gas inflow.

In particularly advantageous embodiments of the invention, the inlets are provided by a multitude of individual tubular ducts of circular cross section and of any desired diameter or progression of diameters consistent with the strength requirements; and rows of these ducts are connected at their outer ends with continuous outlet slots of the character described.

In embodiments further reducing the pressure drop in the plate, the inlet ducts are made or joined with cylindrical end portions intersected by and traversing the outlet slots to the outer edges of the slots; these end portions being limited in width, for example, to a diameter not larger than 1.0 to 2.5 mm., depending upon the composition of the gas mixture, so that they will not allow the flame to back-fire through them.

According to another important feature of the invention, it has been found that the radiation output of gas burners of the type described can be further enhanced by forming the burner plates with outer surfaces comprising flame channels recessed in the outer side of the plate to the outlets of gas passages in the plate. The flame channels are made wider than the passage outlets and so wide that the gas streams entering them will expand abruptly and become ignited within the channels.

The flame channels are formed along outlet slots with lengths substantially coextensive with those of the slots. Their cross section preferably is substantially rectangular, and in preferred embodiments their depth is as great as or greater than their width but not in excess of about 2.5 mm. Their width in such embodiments is usually in the range of about 1.2 to 1.8 mm.

The flames formed within the flame channels burn in contact with the side walls of the channels and close to the contiguous unrecessed portions of the plate surface, thus rendering the surface highly incandescent and increasing the ignition rate of the burner and keeping the heat absorption of the plate surface at high efficiency even when there are fluctuations in the velocity of the gas streams entering the channels. The flame channels thus enhance the radiation output of the burner, both by causing the temperature of the radiating surface to become higher than would be the case in their absence and by increasing the effective radiating area of that surface.

When such flame channels are provided along the outlet slots of the plate, the number of flame channels that may be formed in the plate is limited by the fact that if the plate is provided with the greatest practicable number of gas passages terminating in outlet slots, the space available at its outer side is usually not sufficient to enable the formation of a separate flame channel for every outlet slot. Too little room, if any, then remains for the provision of walls to lie between, and border the flame channels.

This limitation, however, can be dealt with satisfactorily by forming dividing walls of increased thickness between the adjacent flame channels and forming in those walls passages delivering the gas mixture at the face of those walls rather than into flame channels. When it is desired to keep the dividing walls in a unitary form for increased strength, the passages formed in them may be rows of individual passages, such as rows of cylindrical ducts not larger than about 1.0 mm. to 3.2 mm. in diameter, depending upon the composition of the gas mixture, which ducts extend through the entire thickness of the plate and are arranged in alternation with those of the gas passages which deliver into flame channels.

The radiant burner plates provided according to this invention may be composed of any of a wide variety of heat-insulating refractory materials, the composition of which may be selected so as to give the plates valuable combinations of properties with respect to their mechanical strength and thermal conductivity and their durability and efficiency in service.

In general, the lower the thermal conductivity of the refractory material, the less the thickness of the plates may be for a given operating temperature without allowing the inner surface of the plate to reach a temperature that would ignite the gas mixture or result in excessive losses of heat by conduction or convection.

On the other hand, we have found that the mechanical strength of a ceramic material is generally smaller the lower is the thermal conductivity of the material, which is generally a function of the degree of internal porosity in the material, and that the gas or energy throughput and radiation capacity of the plate are not materially diminished by an increase of plate thickness. Accordingly, plates having extraordinary qualities of strength and serviceability, together with extraordinarily high radiation outputs, can be provided according to the invention by making the plates with a thickness considerably greater than is necessary to prevent excessive heating of the inner surface and by making the plates of a molded, relatively dense, baked ceramic or other heat-insulating refractory material having less internal porosity and correspondingly a greater thermal conductivity and much greater strength and durability than would be suitable for a ceramic plate of the minimum thickness effective to prevent excessive heating at the inner surface.

Radiant gas burners made with plates of the constructions set forth herein perform with substantially greater radiating efficiencies than do those made with plates of the types currently used in the art.

Their radiating efficiencies are still further increased when there is arranged at a certain distance, such as 6 to 12 mm., in front of the radiating surface a perforated or woven screen of a suitable heat-resistanct metal or other refractory material, the openings of which do not permit a flame of the gas mixture to be trapped and held on the screen. The screen, as well as the outer surface of the burner plate or plates, then becomes heated to incandescence by the gas flames and the burned gases, and the screen by back-radiation then increases the temperature and the radiating intensity of the plate surface while adding its forward radiation to the radiation passing from that surface through its openings.

A screen arrangement of this nature gives excellent results when the screen is placed relatively close to the plate and the openings of the screen occupy a proportion between 25 and 60% of its total surface area. A burner so constituted and using a plate or plates constructed in accordance with the present invention can operate safely without any supply of secondary air at the face of the plate. By virtue of the reduced pressure drop through such a plate, all the air required for the completely hygienic combustion of the fuel can be supplied by the mixer into the mixing chamber of the burner and thence through the plate, while the fuel input is still maintained at a rate giving a very high burner efficiency. The elimination of secondary air adds to the radiation output, since secondary air reduces the working temperature of the plate, of the flame gases and of the screen.

Other objects, features and advantages of the present invention and preferred ways of practicing it will be evident from the accompanying drawings and the following detailed description of illustrative embodiments of the invention.

In the drawings:

FIG. 1 is a fragmentary plan view of face of a radiant burner embodying the invention, portions of the outer grid or screen being broken away;

FIG. 2 is a fragmentary schematic cross-section through such a burner;

FIG. 3 is an enlarged fragmentary isometric view, partly in section, of one form of a burner plate constructed according to the invention;

FIG. 4 is a similar view of another form of such plate;

FIG. 4A is an enlarged view of a portion of the structure of FIG. 4;

FIG. 5 is an enlarged fragmentary isometric view, partly in section, of a third form of such plate;

FIG. 6 is a similar view of a fourth form thereof;

FIG. 7 is a similar view of a fifth form thereof;

FIG. 8 is a similar view of a sixth form thereof;

FIG. 9 is a similar view of a seventh form thereof; and

FIG. 10 is an enlarged axial cross-sectional view of a fuel gas injector especially suitable for use as an element of a Venturi-type mixer for the formation of gas mixtures of extraordinarily high air content at the gas intake of a burner embodying the invention.

The general arrangement of a radiant gas burner mak-

ing use of the invention is indicated in FIGS. 1 and 2 of the drawings. As there shown, a housing **10** forms a gas distributing chamber **12** which is bounded at its forward side by a perforated ceramic plate structure **14** supported by flanges **11** secured to the side walls of the housing. The plate structure **14** preferably is composed of a plurality of individual perforated ceramic plates, or plate sections, secured together in edge-to-edge relation so as to provide a complete burner plate of the desired size, having, for example, a total exposed area of about 2.7 square decimeters.

A woven wire screen **16**, preferably made of a heat-resistant metal such as a nickel-chromium alloy, is spaced at a distance of, for example, 9 mm. forwardly from the face **15** of the ceramic plate structure. The margins of this screen are laid on the outer surface of a rectangular refractory spacer **17** which is positioned on forward portions **11***a* of the flanges **11**, and they are held in place by flanges **18** formed on a forward extension **19** of the housing structure.

The gas mixture to be burned is supplied, for example, by the injection of a suitable fuel gas from a gas supply pipe **20** through an injector **21** into the mouth of a Venturi-type mixer **22** leading into a mixing chamber **24** at the backward side of the housing. Air in the required proportion is drawn into the tube mouth by the jet of fuel gas entering tube **22** from the injector **21**. The resulting combustible gas mixture flows from chamber **24** into chamber **12** and thence in a multitude of minute streams through the passages in the plate structure **14**, to be burned at the outer side **15** of that structure inside the combustion space bordered by the screen **16** and the spacer **17**.

One effective form of construction of the plate structure provided according to the invention is seen on an enlarged scale at **14A** in FIG. 3. The plate **14A** is formed as a perforated body **30** of a suitable heat-insulating refractory material, having a thickness of, for example, about 14 mm. and composed, for example, of a relatively dense baked ceramic material, such as a ball clay composition baked to a specific gravity of, for example, about 1.5, and having a thermal conductivity of, for example, between .55 and .65 kilocal./hr./m./° C., which gives the passage-defining walls a relatively high intrinsic mechanical strength.

Extending transversely into the plate body **30** from the inner surface **31** thereof are large numbers of individual gas distributing inlets **32** which are formed as tubular ducts or passages of circular cross-section arranged in parallel rows. One of the rows is shown partially in section at **33**. The inlets are mutually surrounded and spaced apart in the body **30** by interconnected walls of the ceramic material, such as indicated at **34**, which give the plate the required mechanical strength. These inlets have any desired diameter suitable to promote full flow of the gas mixture while preserving the required plate strength, for example, one of about 1.2 mm. They extend through the body of the plate for a distance of, for example, 10 mm. They are tapered to a reduced diameter at their outer ends, as indicated at **35**, where the tubular ducts **32** of each row **33** deliver and taper into a common slot **36** formed to a depth of about 2 mm. in and along the outer side of the plate body. Each of the slots **36** has a width limited so as to give the greatest passage freedom for the gas mixture consistent with the assured prevention of backfiring through the slot in the use of the plate with the gas mixture to be supplied into the burner. For the use of a gas composition giving an energy input of about 3,000 B.t.u. per hour per dm.^{2} of plate area, containing about 130–135% of the amount of air required theoretically for complete combustion of the fuel content and entering under a pressure holding a water-column 4 inches high in the cases of manufactured gas and natural gas and 11 inches high in the case of propane or butane, the width of each slot desirably is, for example, 0.5 mm. in the case of manufactured gas, 0.7 mm. in the case of propane and 0.9 mm. in the case of natural gas or butane.

Each slot **36** interconnects the outer ends of the tubular ducts of the related row with portions **37** of the outer surface of the plate. These outer surface portions in the plate **14A** are the bottoms of rectangular flame channels **38** which are considerably wider than the slots **36**, having, for example, a width of about 1.35 mm. so that the gas streams will be ignited in them, and which are recessed in the outer side of the body **30** to a depth of about 2 mm. from the facial portions **39** of its outer surface.

In the operation of a burner having its foraminous plate structure **14** formed of plates of the construction shown in FIG. 3, the gas mixture passes first through the tubular ducts **32**, being slightly heated by their walls, and then passes from the ends of those inlets of each row **33** into and through one of the slots **36** at rapidly increasing temperatures. The mixture flows from each slot **36** in a state of high turbulence into a flame channel **38**, where it expands abruptly and catches fire before reaching the outer surface of the plate. Thus a flame is maintained within each of the channels **38** as well as on contiguous portions of the outer face **39**, so that not only these facial portions but also the bottoms **37** and the side walls of the flame channels become incandescent and serve as sources of high-intensity radiation from the burner.

The form of burner plate shown in FIG. 4 and FIG. 4A is similar in many respects to that of FIG. 3, but it is distinctly superior to the latter in its operating capacity. In this plate **14B**, the plate body **40** is again provided with gas passages comprising cylindrical inlets **42** similar to the inlets **32** in FIG. 3, and slots **46** connect the outer ends of the inlets of respective rows **43** with each other and with the bottoms **47** of flame channels **48**, as in the plate **14A** of FIG. 3. The cylindrical inlets **42** in this form are, however, not tapered to a reduced diameter for delivery into the slots. Instead, they have end portions or extensions **45** of the same diameter as their inlet portions, which end portions intersect and extend across the slots **46** to the outlet edges of the slots at the bottoms of the flame channels.

In effect, the cylindrical passages **42** extend for the full distance of, for example, 12 mm. from the backward plate surface **41** to the bottoms of the flame channels **48**, and the slots **46** are cut through and across the outer ends of the cylindrical passages so as to interconnect and laterally enlarge those end portions and thus relieve the gas pressure and flow resistance that otherwise would develop in them in the high temperature zone contiguous to the outer or flame surface of the plate.

In the case of a plate such as plate **14B** made for use, for example, with a gas flow giving an energy input of about 3,000 B.t.u. per hour per dm.^{2} of plate area, under the illustrative conditions specified in reference to FIG. 3, the respective dimensions of the passage **42**, slots **46** and flame channels **48** desirably are, for example about, 0.9 mm., 0.46 mm. and 1.35 mm. in the use of manufactured gas; about 1.25 mm., 0.8 mm. and 1.35 mm. in the use of propane; and about 1.35 mm., 0.8 mm. and 1.35 mm. in the use of natural gas.

In the form of plate construction shown at **14C** in FIG. 5, the body **50** of the plate is formed with parallel rows **33** of tubular inlets **32** having tapered outer ends **35** connected through slots **36** with the bottoms **37** of flame channels **38**, as in the plate **14A** of FIG. 3; but the flame channels of these rows of inlets coacting with slots and flame channels are spaced apart by intervening wall portions **52** of the plate material and these wall portions, although not wide enough to accommodate flame channels, are made sufficiently wide to accommodate rows **53** of cylindrical passages **54** extending through the entire thickness of the plate. The passages **54** are formed with a diameter not greater than about 1.0 to 2.5 mm., depending upon the composition of the gas mixture to be burned; for example, they have desirably a diameter of about 0.9 mm. in the case of manufactured gas, about 1.25 mm. in in case of propane, and about 1.35 mm. in the case of natural gas or butane. They are arranged in the rows **53** in offset relation to the passages **32** of the rows **33** as indicated in FIG. 5. In this way, the plate may be provided with a very large number of gas passages and yet assured of possessing good mechanical strength in the dividing wall portions **52** as well as in other portions of the plate body.

FIG. 6 shows a plate construction **14D** in which the body of the plate is formed with rows **43** of cylindrical passages **42** traversing and cut through by slots **46** which deliver into the bottoms of flame channels **48**, as in the form of FIGS. 4 and 4A. The flame channels of these rows are separated by walls **52** which accommodate rows **53** of cylindrical passages **54** extending through the entire thickness of the plate, as in the embodiment of FIG. 5. This construction has a greater gas flow and radiating capacity than that of FIG. 5, by reason of the greater flow capacity of the slots **46** traversed by the outer end portions **45** of the cylindrical inlet passages **42**.

The structure of FIGURE 6 is capable of being used for example, with an energy input of about 4,000 B.t.u. per hour per dm.^{2}, supplied in a gas mixture entering the burner under a pressure holding a water column about 4 inches high in the cases of manufactured gas and natural gas, and 11 inches high in the cases of propane and butane, and containing about 130–135% of the amount of air required theoretically for complete combustion of the fuel content of the mixture, where the respective dimensions of the passages **42**, slots **46**, flame channels **48** and passages **54** are as follows: 0.9 mm., 0.46 mm., 1.35 mm. and 0.9 mm. in the case of manufactured gas; 1.25 mm., 0.8 mm., 1.35 mm. and 1.25 mm. in the case of propane; and 1.35 mm., 0.8 mm., 1.35 mm. and 1.35 mm. in the cases of natural gas and butane.

FIG. 7 shows at **14E** another form of the plate construction, in which the body **70** is formed with gas passages arranged substantially as in the construction of FIG. 5; but instead of having rows of inlets of circular cross section delivering into the flow-controlling slots **36**, the inlets delivering into the slots are formed as tubular passages **72** of rectangular cross section. These passages are elongated in the direction of the respective slots, and they form rows **73** in which the individual passages **72** are separated by walls **74** of the thickness and strength required to keep the plate structure intact under service conditions. The outer end portions of the passages **72** are tapered to reduced widths, as indicated at **75**, where they deliver into the inlet edges of the slots **36**. Since the slots are formed with a width limited so as to prevent back-firing, the inlet passages **72** may have a considerably greater width.

FIG. 8 and FIG. 9 show further forms of the new plate construction, in each of which all of the gas passages formed in the plate body comprise cylindrical inlets which extend from the inner surface to the outer or flame surface of the plate. Some of the rows of these passages have their outer end portions cut through by slots, similar to the slots **46** of FIG. 4, and deliver from the outer edges of the slots into flame channels recessed in the outer side of the plate.

In the plate **14F** of FIG. 8, adjacent rows **43** of the cylindrical passages **42** have their outer end portions **45** extending through slots **46** to recessed outer surface portions **87** of the plate body **80**, where the slots **46** deliver the gas mixture into relatively wide flame channels **88** each receiving the flow from two rows of passages. Between each two of these widened flame channels there are two rows **53** of cylindrical passages **54** which traverse the entire thickness of the plate.

In the plate **14G** of FIG. 9, the flame channels **48** are similar to those of FIGURE 4, each of them receiving the gas mixture from a single slot 46 interconnecting and cutting through the end portions of the cylindrical passages 42 of a single row 43. The narrower flame channels in this construction are separated by outer wall portions 89 of the body 90, to the face of each of which the gas mixture is delivered from two rows of cylindrical passages 54 traversing the entire thickness of the plate as in the construction of FIG. 8.

As has been indicated hereinabove, the greater passage freedom provided by the burner plates of the present invention enables burners provided with these plates to be operated at high radiating efficiencies with gas mixtures containing all the air required for the completely hygenic combustion of the fuel gas contained in the mixtures. In order to supply a fuel gas delivered under a standard pressure into the burners in admixture with the desired excess of air, the fuel injector used, as at 21 in FIG. 2 of the drawings, should be one which will spread the jet of fuel gas without reducing its speed so that the gas will entrain and deliver into the burner the desired very large proportion of air without thereby reducing the pressure maintained inside the burner for the flow of the resulting mixture through the perforated plate structure.

For this purpose, use can be made of a Venturi injector of known type; for example, one of the type known as a diaphragm injector may be used. It has been found advantageous, however, to use an injector of the construction shown in FIG. 10. The injector has a body 100 which is machined internally to form a calibrated cylindrical neck 104 of suitable diameter to accommodate the desired gas flow, to which the fuel gas flows through a convergent conical passage 102 having, for example, a cone angle of 80°, and from which the gas flows through an outer divergent conical passage 106. The outer passage 106 diverges to a width greater than its length, having, for example, a cone angle of 80°, and interconnects with an outer convergent conical surface 108 having a similar cone angle. The cylindrical neck 104 is made with a length such that the cone angles of the passages 102 and 104 nearly meet at their apices but do not overlap within the neck. The flow from the divergent passage entrains the required amount of air as it enters the wide mouth of the mixer tube 22 disposed near the end of the injector.

It will be evident that new features of the present invention may be embodied in various forms of apparatus other than those particularly described hereinabove and that the invention is not restricted to these illustrative embodiments except as may be required by a fair construction of the appended claims.

What is claimed is:

1. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture and slots narrower than said inlets and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent back-firing through the plate, each of said slots being sufficiently narrow to keep said mixture flowing through it at a velocity confining the flame thereof to said outer side.

2. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture and slots narrower than said inlets and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets, said slots each being of a width effective when said streams are burning to confine the flames to the outer side of the plate and yet to afford passage freedom for said mixture in the passage zone of its greatest viscosity increase.

3. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture and slots narrower than said inlets and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent back-firing through the plate, said slots each being of not more than 0.5 to 1.6 mm. in width, depending upon the composition of the gas mixture, and being sufficiently narrow to keep said mixture flowing through the slot at a velocity confining the flame thereof to said outer side.

4. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising rows of tubular ducts extending into the plate for distribution of said mixture and slots narrower than said ducts and formed inward from the outer side of said plate and each interconnecting the ducts of one of said rows so as to afford passage freedom for said mixture yet prevent back-firing through the plate, said slots intersecting and being traversed to their outlet edges by end portions of said ducts not larger than 1.0 to 2.5 mm. in width, depending upon the composition of the gas mixture, each of said slots being sufficiently narrow to keep said mixture flowing through it at a velocity confining the flame thereof to said outer side.

5. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat-insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising rows of tubular ducts extending from said inner surface into the body of the plate for distribution of said mixture and slots narrower than said ducts and formed inward from the outer side of said plate and each interconnecting the outer ends of the ducts of one of said rows so as to afford passage freedom for said mixture yet prevent back-firing through the plate, said ducts being mutually surrounded and spaced apart in said body by interconnected walls of said material giving the plate the required mechanical strength, each of said slots being sufficiently narrow to keep said mixture flowing through it at a velocity confining the flame thereof to said outer side.

6. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passes extending transversely through it for conducting

from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat-insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture, and slots narrower than said inlets and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said outer surface comprising flame channels wider than the outlets of said slots, each recessed in said outer side to the outlet edge of at least one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots, each of said slots being sufficiently narrow to keep said mixture flowing through it at a velocity confining the flame thereof to said outer side.

7. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture and slots narrower than said inlets and formed inward from the outer side of said plate and each intersecting outer end portions of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said slots each being of not more than 0.5 to 1.6 mm. in width, depending upon the composition of the gas mixture, said outer surface comprising flame channels wider than and substantially coextensive in length with said slots, each recessed in said outer side to the outlet edge of at least one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots, said slots intersecting and being traversed by rows of end portions of said inlets the diameter of which exceeds the width of said slots but does not exceed 1.0 mm. to 2.5 mm., depending upon the composition of the gas mixture.

8. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising rows of individual tubular ducts extending from said inner surface into the body of said plate for distribution of said mixture and slots narrows than said ducts and formed inward from the outer side of said plate and each interconnecting the outer ends of the ducts of one of said rows so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said outer surface comprising flame channels wider than and substantially coextensive in length with said slots, each recessed in said outer side to the outlet edge of at least one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots, said ducts being mutually surrounded and spaced apart in said body by interconnected walls of said material giving the plate the required mechanical strength, each of said slots being sufficiently narrow to keep said mixture flowing through it at a velocity confining the flame thereof to said outer side.

9. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multiude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising rows of individual cylindrical ducts extending from said inner surface into the body of said plate for distribution of said mixture and slots narrower than said ducts and formed inward from the outer side of said plate and each interconnecting the outer ends of the ducts of one of said rows so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said slots each being of not more than 0.5 to 1.6 mm. in width, depending upon the composition of the gas mixture, said outer surface comprising flame channels wider than and substantially coextensive in length with said slots and each recessed in said outer side to the outlet edge of at least one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots, each of said slots intersecting and being traversed to its outlet edge by end portions of the ducts connected with it, said end portions being not larger than 1.0 to 2.5 mm. in diameter, depending upon the composition of the gas mixture, said ducts being mutually surrounded and spaced apart in said body by interconnected walls of said material giving the plate the required mechanical strength.

10. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the body of said plate for distribution of said mixture and slots narrower than said inlets and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said slots each being of not more than 0.5 to 1.6 mm. in width, depending upon the composition of the gas mixture, and flame channels wider than said slots, each recessed in said outer side to the outlet edge of at least one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots, said inlets being rows of tubular channels elongated in the same direction as said slots and mutually surrounded and spaced apart in said body by interconnected walls of said material giving the plate the required mechanical strength.

11. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture and slots narrower than said inlets and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said mixture yet prevent backfiring through the plate, said width, depending upon the composition of the gas mixture, said outer surface comprising flame channels of substantially rectangular cross section and wider than and substantially coextensive in length with said slots, each recessed in said outer side to the outlet edge of at least

one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots.

12. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture and slots narrower than said inlets and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said slots each being of 0.6 to 1.3 mm. in width, depending upon the composition of the gas mixture, said outer surface comprising channels wider than and substantially coextensive in length with said slots, each recessed in said outer side to the outlet edge of one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots, said channels each having a width of 1.2 to 1.8 mm. and a depth exceeding its width.

13. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture and slots narrower than said inlets and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said slots each being of 0.6 to 1.3 mm. in width, depending upon the composition of the gas mixture, said outer surface comprising flame channels wider than and substantially coextensive in length with said slots, each recessed in said outer side to the outlet edge of at least one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots; said passages also comprising rows of individual cylindrical ducts not larger than 1.0 to 2.5 mm. in diameter, depending upon said composition, extending through the entire thickness of said plate in portions thereof lying between said channels.

14. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture and slots narrower than said inlet and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said slots each being of 0.6 to 1.3 mm. in width, depending upon the composition of the gas mixture, said outer surface comprising flame channels wider than and substantially coextensive in length with said slots, each recessed in said outer side to the outlet edge of one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots, said inlets comprisng rows of cylindrical ducts not larger than 1.0 to 2.5 mm. in diameter, depending upon said composition, extending through the body of said plate and through intersections with said slots to the bottoms of said flame channels, said ducts being mutually surrounded and spaced apart in said body by interconnected walls of said material giving the plate the required mechanical strength, said flame channels each being substantially rectangular in cross section and having a width of 1.2 to 1.8 mm. and a depth greater than its width but not exceeding about 2.5 mm.

15. A radiant gas burner comprising a plate of heat-insulating refractory material formed with a multitude of passages extending transversely through it for conducting from its inner side streams of a combustible gas mixture to be burned at its outer side, said plate being sufficiently thick and heat insulating that its inner surface remains below a temperature that would ignite said mixture while its outer surface is kept incandescent by the burning of said streams, said passages comprising inlets extending from said inner surface into the plate for distribution of said mixture and slots narrower than said inlets and formed inward from the outer side of said plate and each interconnecting the outer ends of a plurality of said inlets so as to afford passage freedom for said mixture yet prevent backfiring through the plate, said slots each being of 0.6 to 1.3 mm. in width, depending upon the composition of the gas mixture, said outer surface comprising flame channels wider than and substantially coextensive in length with said slots, each recessed in said outer side to the outlet edge of one of said slots, for the expansion and ignition within said channels of the streams entering them from said slots, said inlets comprising rows of cylindrical ducts not larger than 1.0 to 2.5 mm. in diameter, depending upon said composition, extending through the body of said plate and through intersections with said slots to the bottoms of said flame channels said flame channels being substantially rectangular in cross section and having a width of 1.2 to 1.8 mm. and a depth greater than their width but not exceeding about 2.5 mm., said passages also comprising rows of individual cylindrical ducts not larger than 1.0 to 2.5 mm. in diameter, depending upon said composition, extending through the entire thickness of said plate and arranged in alternation with those of said passages which deliver into said channels, said ducts being mutually surrounded and spaced apart in said body by interconnected walls of said material giving the plate the required mechanical strength.

References Cited by the Examiner

UNITED STATES PATENTS

1,313,196	8/1919	Lucke	158—99
2,742,437	4/1956	Houdry.	
2,775,294	12/1956	Schwank	158—116
3,179,155	4/1965	Partiot	158—116

FOREIGN PATENTS

558,007	6/1957	Belgium.
485,086	5/1928	Germany.
601,249	1/1960	Italy.

FREDERICK L. MATTESON, Jr., *Primary Examiner.*

JAMES W. WESTHAVER, *Examiner.*

D. G. BLACKHURST, H. B. RAMEY, *Assistant Examiners.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

'atent No. 3,258,058 June 28, 1966

Jean A. D. P. L'Herault et al.

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 10, line 75, "passes" should read -- passages --. :olumn 11, line 57, "narrows" should read -- narrower --. :olumn 12, line 70, cancel "said mixture yet prevent backfiring hrough the plate, said" and insert -- said slots each being f not more than 0.5 to 1.6 mm. in --.

Signed and sealed this 3rd day of March 1970.

;EAL)

ttest:

dward M. Fletcher, Jr.

ttesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents