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REVERSE FLOW JET BURNER WITH GAS VORTEX FLAME HOLDERS

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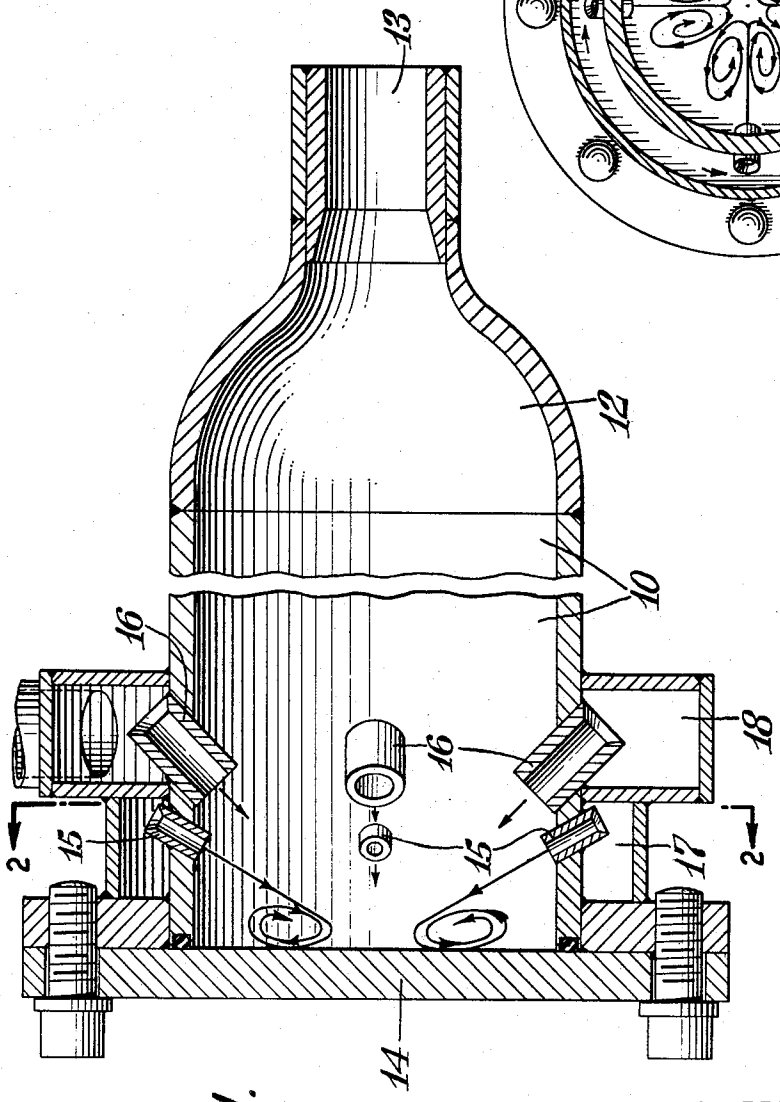


Fig. 1.

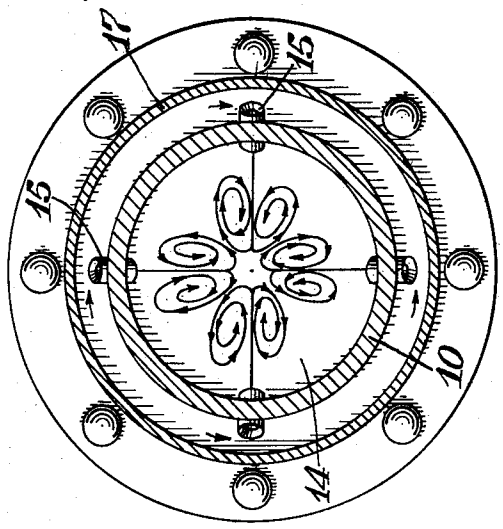


Fig. 2.

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REVERSE FLOW JET BURNER WITH GAS VORTEX FLAME HOLDERS

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This invention relates to reverse flow jet burners with vortex flame holders for holding the flames within the combustion chamber when the flame velocity exceeds the rate of flame propagation.

The majority of conventional jet burner designs used today, whether for combustion, chemical reaction, or propulsion applications, have a relatively narrow operating range, as to both flows and ratio of fuel to oxidant, over which uniformly smooth, stable burning will take place in the combustion chamber. A burner having a narrow fuel to oxidant ratio range over which stable combustion takes place will usually have a very rough burning range at both the upper and lower ratio limits. On the other hand, a burner having a wide ratio range will burn smoothly over the entire range, blowing out only when the flammability limits of the combustion elements have been exceeded.

The efficiency of operation of a jet burner depends upon obtaining such uniformly smooth, stable burning or combustion. Noisy, turbulent burning of a flame can take place in the open atmosphere if mixing of the combustion elements is not thorough or turbulent flow of these elements takes place in the mixed stream leading to the flame port. Take the same flame and confine it within a chamber and the roughness of burning will be more pronounced because of the vibrations set up within the chamber. These vibrations, caused by ragged, uneven combustion, can build up and seriously affect the individual flows of the combustion elements to the combustion chamber. If the vibration build-up is great enough, burning within the combustion chamber will no longer be possible. Even if this extreme condition is not reached, the result of uneven combustion is a loss of energy in the form of decreased forward thrust, a lower combustion temperature, and the liberation of far less than the maximum available B.t.u.'s. In addition, the unstable burning gives rise to excessive noise of a type which is extremely objectionable.

Theoretically, a properly desinged jet burner should be operable with uniformly smooth, stable burning over the full range permitted by the flammability limits of the particular fuel and oxidant mixture being used. For example, the flammability limits of methane in air are approximately five parts of air to one part of methane as the lower limit and approximately 15 parts of air to one part of methane as the upper limit. However, the upper limit may be extended because of the effect of gas temperature on the upper flammability limit. A gas temperature of 1500 deg. F. will increase the upper limit from 15 to 1 to approximately 30 to 1. Thus, a theoretically properly designed burner should be operable with all air-methane ratios between 5 to 1 and at least 15 to 1. Such, however, is not the case with the majority of the conventional jet burners in use today.

Basically, there are three conditions which must be present in a jet burner to achieve the required uniformly smooth, stable combustion over the full range permitted by the flammability limits of the fuel and oxidant. These conditions are: complete and intimate mixing of the fuel and oxidant; means to hold the flames within the combustion chamber when the flame velocity exceeds the rate of flame propagation; and proper proportioning of the combustion chamber to the mixer capacity. We have

found that the total feed orifice area for both combustion elements should not be greater than approximately $\frac{1}{25}$ of the burner chamber cross-sectional area for maximum flame stability. Also, diameter and length should be great enough to permit proper combustion over the flow range.

Various means have been employed in conventional jet burner designs to achieve complete mixing of the fuel and oxidant. It is generally agreed that the more turbulent these elements are at the point of mixing, the more thorough will that mixing be. For example, introducing the fuel and oxidant from opposite sides of the combustion chamber such that the two elements impinge within the burner chamber results in improved mixing.

Another method that has been used consists of introducing the two combustion elements at the rear of the burner such that they impinge against the underside of a plate, the diameter of which is less than that of the combustion chamber, and are thus deflected or caused to change flow direction to cause more intimate mixing. The mixed elements then pass into the combustion chamber through the annulus formed between the outer edge of the deflecting plate and the cylindrical wall of the chamber.

A third method, such as that disclosed in Patent No. 2,606,421, comprises introducing the combustion elements in a reverse direction toward a closed or inner end portion or target of the combustion chamber. Radial outward spreading of the combustion elements after striking the target is retarded by such means as a plurality of concentric ridges normal to the target surface.

All of these methods, by increasing the turbulence of the combustion elements at the point of mixing, will result in more thorough and intimate mixing of the elements. However, with jet burners incorporating any of these means of improving mixing, the ratio range over which stable burning takes place is still narrow. Even assuming that such burners are designed with the proper proportioning of the combustion chamber to the mixer capacity (total feed orifice area not greater than $\frac{1}{25}$ of the burner chamber cross-section area), unless some means is provided to hold the flames within the combustion chamber when the flame velocity exceeds the rate of flame propagation, the ratio range over which stable burning takes place will remain narrow.

The combustion of a fuel as it takes place in the combustion chamber of a jet burner is not unlike the conventional burning of a fuel in the open atmosphere. If the velocity of the mixed stream is higher than the rate of flame propagation for the mixture, the flame will blow away from the end of the tip of an open burner; or in the case of the jet combustion chamber, the flame will travel down the burner chamber and out through the burner outlet orifice or exhaust port. The rate of flame propagation in both cases is governed to a large extent by the ratio of the two combustion elements and the thoroughness of the mixing.

Various mechanical type flame holders in the form of plates, formed shapes, rings, or rods located in strategic positions in the combustion chamber have been tried in jet burners. The primary object of any such flame holder is to create a disturbance in the mixed gas stream, for example when the fuel and oxidant are gases, such as to slow up a portion of the mixed gas stream, or create turbulence eddies which slow up a portion of the stream, so that the velocity of this portion of the stream is below the rate of flame propagation. This slower moving gas stream results in a portion of flame having a lower flame velocity than the rest. Thees flames of lower velocity serve to hold the higher velocity flames in the burner and stabilize the flame at high rates of gas flow. This same

principle applies whether the combustion elements are solids, liquids or gases.

There are a number of important disadvantages to the use of mechanical type flame holders. Since they are of necessity located in the combustion chamber, they are subject to the high temperature of the burning combustion elements in the chamber either directly or by radiation. Therefore, even when made of heat resistant material, they may be subject to erosion and even destruction due to the extreme temperatures encountered. Such erosion may well interfere with the effectiveness of the flame holder to retain the flames in the combustion chamber. In addition since the pattern of the disturbance (creation of the slower moving eddies which are moving toward the chamber outlet at a rate below the rate of flame propagation), as well as the magnitude of the disturbance, is proportional to the rate of flow of the combustion elements, the range of flow over which a particular mechanical type flame holder is effective is limited. Also, this range of flow over which the holder is effective is somewhat unpredictable because of the changing pattern of the disturbance the holder creates as the flow is increased or decreased. In other words, a particular mechanical type flame holder that works very effectively for one given set of flow ratio conditions, may well lose its effectiveness entirely with a relatively slight change in flow ratio. There is too the added disadvantage that mechanical type flame holders add to the cost of manufacture of the jet burner, especially where holders of special shape are used, such as disclosed in the F. W. Bailey Patent No. 2,920,445.

Thus, it may be seen that the mechanical type flame holders are not a satisfactory solution to the problem of preventing flame blowout in a jet burner.

The main object of the present invention is to provide the three conditions outlined above as being necessary to achieve uinformly stable combustion over the full fuel to oxidant ratio range permitted by the flammability limits of the fuel and oxidant without the need of mechanical type flame holders.

According to the present invention, the full advantages to be gained from reversing the direction of flow of the combustion elements to provide turbulent mixing thereof are achieved by introducing the combustion elements in a reverse direction in streams having their longitudinal axes directed toward the center of the closed back end of the combustion chamber to impinge thereon at the same localized area at the center thereof. While the invention is applicable to the combustion of elements in the solid, liquid or gaseous form, for convenience the description will be restricted to the combustion of gaseous elements.

In the drawings:

FIGURE 1 is an axial cross section through the burner according to, and for carrying out the method of, the present invention; and

FIGURE 2 is a radial cross secion taken along the line 2—2 of FIGURE 1.

As shown in the FIGURE 1, the jet burner of the invention comprises essentially a combustion chamber **10**, reducing bell **12**, containing the outlet orifice or exhaust port **13**, attached to the front end of combustion chamber **10**, the combustion chamber back plate **14**, fuel gas (such as methane metering orifices **15**, combustion supporting gas (such as air) metering orifices **16**, fuel gas header **17**, and combustion supporting gas header **18**. The fuel gas enters the combustion chamber **10** through four metering orifices **15** located at 90 deg. intervals around the circumference of the cylindrical combustion chamber **10**, equidistant axially from the back plate **14**.

The angle of entry of the metering orifices **15** relative to the axis of the combustion chamber **10** is such as to cause the incoming streams of methane to impinge against the back plate **14** at a localized area in the center of this plate. The combustion supporting gas enters the combustion chamber **10** from the four metering ports **16** located axially in line with, but downstream of, the fuel gas metering ports **15**. The angle of entry of the gas metering ports **16** is such as to direct the longitudinal axes of the four gas streams at the same point on the back plate **14** as the fuel gas streams. Thus, the eight gas streams have their longitudinal axes directed at a point directly in the center of the back plate **14** with the gas of greater mass (air) being located forwardly or downstream of the gas of lesser mass (methane).

The combination of these three factors: reverse flow introduction of the fuel and combustion suporting gases, both gases impinging against the back plate at a single localized area, and gas with the greatest mass introduced downstream of the gas with lesser mass, results not only in the complete and intimate mixing of the two gases, due to the extreme turbulence created, necessary for complete combustion of the fuel gas, but also in the creation of distinct gas ring vortices with surrounding slower moving gas eddies which form the novel gas-type flame holders of the invention.

Very effective gas-type flame holders are provided in the jet burner of the invention through the creation of a plurality of areas of ring vortex type of flow of the combustion elements at the point of mixing, that is, when the combustion elements impinge the center point of the rear plate of the combustion chamber. By ring vortex type of flow is meant a vortiginous type of flow wherein rotation is about a circular axis having a substantially fixed position.

In such areas of ring vortex flow, the required eddies of slower moving gases and hence, low velocity flames, are created to hold the high velocity flames in the combustion chamber of the burner. As shown in FIGURE 2, a plurality of such ring vortices are created, evenly distributed radially around the center point of the rear plate of the combustion chamber of the jet burner such that the low velocity holding flames thus created are also evenly distributed radially around the central axis of the burner chamber.

It is believed that these gas ring vortices are created in the following manner. As the entering streams of gas impinge against the back plate of the combustion chamber at a single localized area, the fact that the air has the greater mass and is located on the downstream side of the methane streams, causes the impinging gases to curl under and then out radially from the center point of the back plate as the gases expand. The normal tendency of the expanding gases to then fan out along the combustion chamber back plate is converted into a substantially unidirectional flow outward toward the combustion chamber wall because of the activity of the adjacent incoming gas streams.

That is, the expanding gases from adjacent streams are prevented from moving except in the one direction toward the cylinder wall, since movement in any other direction is blocked by the very presence of the adjacent expanding gas which is tending to move in an opposite direction. However, the aspirating effect of the adjacent incoming gas streams tend to cause these expanding gases to change direction back toward the center of the chamber and a ring vortex is set up. The interaction between the expanding gases and the incoming streams and the interaction between adjacent vortices ensure the continued maintenance of the ring vortices. That is, once the individual ring vortices are set up, the expansion of the gas on burning tends to cause the vortex to fly apart, but this it cannot do because of a similar tendency on the part of the gas in the adjacent vortices in an opposite direction.

This is more clearly shown in FIGURE 2. The result is a plurality of gas type flame holders at the base of the combustion chamber which are extremely effective in preventing flame blowout and at the same time stabilize the flame at high rates of gas flow. Since the gas streams entering the burner in the manner described above are the principal means whereby the ring vortices

are formed and maintained, increasing the velocity of the gas entering the burner combustion chamber simply increases the strength of the ring vortices so that the flames are not blown out of the burner even at unusually high velocities.

While the burner illustrated in the drawings has four pairs of metering orifices for entry of the fuel gas and combustion supporting gas, and hence eight ring vortices are created, more or less could be used, depending upon the size of the combustion chamber, so long as sufficient space between the entering gas streams is maintained for the formation of the ring vortices. Also, the distance forward of the rear plate of the combustion chamber at which the gas metering orifices are situated should be great enough so that space is provided for the formation of the ring vortices but not so great that the interaction between the ring vortices and the incoming gas streams is lost.

The low pressure jet burner design shown in FIGURE 1 incorporating the novel features of the invention, has been found in laboratory tests to operate with uniformly smooth, stable burning over the full range of flammability limits of air-methane mixtures, 5 to 21.7 parts of air to 1 part of methane, and over a wide range of flow rates up to the full rated flow of the burner, 45,000 c.f.h. The methane metering orifices are 0.196 inch diameter and the air ports 0.688 inch diameter.

Four pairs of metering orifices 15 and 16 for the entry of the methane and air respectively, located at 90 deg. intervals around the cylindrical combustion chamber 1, provide the required space between entering gas streams for the formation of the ring vortices. Similarly, an angle of 45 deg. to the axis of the combustion chamber for entry of the air stream, an an angle of 60 deg. to this axis for the entry of the methane, with the metering orifices located relative to the rear plate 14 such that the entering gas streams impinge the rear plate at a common point in the center of the plate, provided the required space for the formation of the ring vortices while maintaining the necessary interaction between the ring vortices and the incoming gas streams.

The results of laboratory tests indicated that if the total gas-feed metering orifice area is much greater than approximately $\frac{1}{25}$ of the burner chamber cross-section area, the burner stability falls off regardless of the rate of gas flow to the burner or the size of the burner outlet port. In the burner shown in FIGURE 1, this ratio of total gas feed orifice area to burner chamber cross-sectional area is approximately 1 to 30.

The illustrated jet burner is of the low pressure type, since gas inlet pressures of between 20 and 25 p.s.i. of each gas will provide the full rated flow of 45,000 c.f.h. The gas metering ports are sized such as to permit the use of balanced air and methane pressures and give a 5 p.s.i. pressure differential across the orifice. In this way, the effects of upstream gas flow conditions are minimized and maximum flow and stability are obtained.

Though not shown on the burner drawing, cooling of the burner could be accomplished by means of a water jacket surrounding the burner. For those applications where preheating the combustion supporting gas would be advantageous, an annular chamber surrounding the burner having a spiral channel could be used to supply the combustion supporting gas to the header such that at least this gas would pass in heat exchange contact with the burner chamber outer wall to cool the burner.

Two reverse-flow, ring vortex type burners, identical to that shown in FIGURE 1 except for diameter and capacity, were used in the laboratory development of the burner of the invention. Burner No. 1 had approximately a 2 inch diameter chamber and $\frac{1}{24}$ the capacity of the full size burner. Burner No. 2 had approximately a 3 inch diameter chamber and $\frac{1}{12}$ the capacity of the full-size burner. Besides demonstrating the combustion and flow stability attainable with this burner design, the purpose of these tests was two-fold: (1) to establish the importance of the L star ratio (ratio of chamber volume to flame outlet port area) in the reverse-flow, ring vortex type burner, and (2) to determine the capacity limit with stable burning of the $\frac{1}{12}$ and $\frac{1}{24}$ capacity burners.

The series of tests to determine the importance of the L star ratio was run using the $\frac{1}{12}$ capacity burner, having a combustion chamber diameter of 3.068 inches and a cylindrical chamber length of 8 inches plus the length of the reducing bell on the discharge end. The L star ratio of the burner, which had an 0.0622 inch diameter outlet port, was 240. Combustion in this burner proved exceptionally stable and smooth over very wide gas ratio limits, 5 to 21.7 parts of air to one part of methane. No oxygen enrichment of the air was required for stable operation.

The entire reducing bell was then cut from the front end of the burner. Thus, the full diameter of the combustion chamber became the outlet port. This modification reduced the L star ratio to eight. Combustion was in every way as stable as that in the previous tests, and as smooth over the same extreme range of gas ratio. The combustion flame could readily be seen by looking into the wide open end of the burner. Clearly visible were the four distinct mixing zones and the intervening areas of relatively dark color, where it is believed the vortex eddies that act as flame holders are formed. The flame pattern was perfectly symmetrical and consistent. There was no indication of roughness or flame cycling, and the flame was fully contained within the combustion chamber.

The combustion chamber was reduced in length from 8 inches to 4 inches for the next test, the end remaining wide open to the full diameter of the chamber. Burning remained very stable although the gas ratio range over which combustion occurred narrowed slightly, being 7 to 17.5 parts of air to 1 part of methane. Some of the combustion flame burned out the end of the chamber, indicating insufficient chamber length. The L star ratio was three.

The reducing bell end was again installed on the open end of the burner. Various lengths of chamber in combination with different outlet port diameters were tried and resulted in the same smooth stable operation.

It would appear from the test results that the L star ratio has little or no effect upon the combustion within the burners if the burner length is sufficient to fully contain the combustion flame. L star ratios ranging from 8 to 240 had no appreciable effect on either burner stability or gas ratio range of burning.

Tests to determine the capacity of both the $\frac{1}{12}$ and $\frac{1}{24}$ capacity burners consisted of establishing the maximum flows of each gas that could be supplied to the burner and still retain stable burning over a reasonably wide gas ratio range. Both the gas and air metering ports feeding the burner were enlarged in steps and equal gas pressures were maintained at the burner for a ratio of approximately ten parts of air to one part of methane. In some instances, it became necessary to increase the size of the burner outlet port in order to hold the combustion chamber pressure low enough to permit operation of the burner at 20 p.s.i. of each gas at the inlet to the burner.

With the $\frac{1}{24}$ capacity burner, stable burning over a wide ratio range was obtained up to a total gas flow of approximately 2,500 cu. ft. per hour. The $\frac{1}{12}$ capacity burner had a total gas flow limit of approximately 7500 cu. ft. per hour. In no case was oxygen used except for starting pilot combustion within the burner. Burning was very smooth and free from rumble or roughness. These test results clearly indicated that the gas capacity of the burner is more a function of the ratio of gas-feed orifice area to cross-sectional area of the chamber than of other variables such as outlet-port area or gas inlet pressure to the burner. As stated above, if the total gas-feed orifice area is much greater than approximately $\frac{1}{25}$ of the burn-

er chamber cross-sectional area, the burning stability will fall off regardless of the rate of gas flow to the burner or the size of the burner outlet port.

A rough check of the temperature of the gas issuing from the outlet port of the burner during the above tests indicated a temperature of approximately 2200 deg. F., several hundred degrees higher than reported temperatures for other burners.

The burner outlet port velocity in feet per second, based on Q/A at an assumed gas temperature of 2000 deg. F. and at atmospheric pressure, proved to be practically a direct function of the burner chamber pressure, indicating steady, uniform combustion. This velocity was not affected to any great extent by the burner size.

Tests were also conducted on the 1/12 capacity burner with the rear plate replaced by caps that located the rear face of the burner chamber 1 inch and 3 inches behind the point of impingement of the gas streams. Thus, the chamber length was extended 1 inch and 3 inches, respectively, so that the entering gas streams would converge in space rather than at the face of the rear chamber plate. These tests indicated a marked reduction of flame stability. The combustion was very rough and the gas ratio range very narrow. There was every indication that the ring vortices or flame holding eddies were broken up and ineffective.

A high-pressure burner of the same basic design as above has undergone preliminary laboratory tests. These tests have indicated that a considerably higher thrust can be attained when using the higher chamber pressures. An additional advantage to this type burner is that it can be made physically much smaller than the low pressure type for the same capacity. The low-pressure burner has a combustion chamber diameter of 8 inches as compared to 4 inches required for the same capacity in the high pressure burner.

Advantages of the burner of the invention are:

(1) Reverse-flow gas-vortex type mixing of the air and methane (natural gas) provides complete and thorough mixing of the two gases.

(2) The gas eddies, formed around the gas ring vortices resulting from the turbulent mixing, act as gas-type flame holders, and thus add appreciably to the combustion stability.

(3) Proper proportioning of the gas-feed port area to the combustion chamber cross-sectional area, ratio of 1 to 25 or less, in conjunction with the reverse-flow mixing, eliminates rough burning or rumble.

(4) The conventional mixer is eliminated which leaves the entire combustion chamber area, as well as the rear plate, available as possible locations for injection of a third element.

(5) The L star ratio (ratio of chamber volume to flame outlet port area) has extremely wide latitude. L star ratios from 8 to 240 were tried with equally satisfactory results.

(6) The need for oxygen enrichment of the air for light-up or during the burning cycle is eliminated.

(7) Burner performance is not affected by gas feedline geometry.

(8) The more thorough mixing of the air and methane, afforded by the reverse-flow principle, results in higher chamber temperatures (approximately 2200 deg. F.) than attainable with conventional burners. This provides greater thermal expansion of the gases and therefore increased thrust.

What is claimed is:

1. In a jet burner, a cylindrical combustion chamber having a flat back plate attached thereto perpendicular to the axis thereof, a reducing bell attached to the front end of said chamber and containing an exhaust port, said chamber having fuel gas metering ports spaced about ninety degrees apart around the circumference thereof and having axes inclined rearwardly at an angle to the axis of said cylinder to intersect each other at the center of said flat back plate, said chamber having combustion supporting gas metering ports located axially in line with, but spaced farther away from said flat back plate than said fuel gas metering ports and having axes inclined rearwardly at a lesser angle to the axis of said cylinder than said fuel gas metering port to also intersect each other at the center of said flat back plate.

2. In a jet burner as claimed in claim 1, the combination therewith of a fuel gas header adjacent said back plate surrounding said cylinder and said fuel gas metering ports, and a combustion supporting gas header surrounding said cylinder and said combustion supporting gas metering ports adjacent said fuel gas header.

3. Apparatus for forming flame holding vortices in the combustion of fuel gas, which comprises

(*a*) a jet burner having a cylindrical combustion chamber,

(*b*) a perpendicular flat back plate, and

(*c*) an open front end through which products of combustion flow forwardly,

(*d*) means forming cylindrical rearwardly directed metering fuel gas orifices in said burner uniformly spaced about 90° apart around the circumference of said combustion chamber at an angle to the axis of said combustion chamber such as to cause the incoming streams of fuel gas to impinge upon said perpendicular flat back plate at a target at the center thereof,

(*e*) means forming rearwardly directed combustion supporting gas metering ports in said burner located axially in line with but downstream of the fuel gas metering orifices but at a more acute angle of entry than the fuel gas such that the streams of combustion supporting gas impinge upon the same target at the center of said perpendicular flat back plate, with the greater mass of combustion supporting gas located downstream of the lesser mass of fuel gas, thereby causing extreme turbulence of the two gases and creating distinct gas ring vortices with surrounding slower moving gas eddies which form gas type flame holders to hold the flames within said combustion chamber when the flame velocity exceeds the rate of flame propagation.

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