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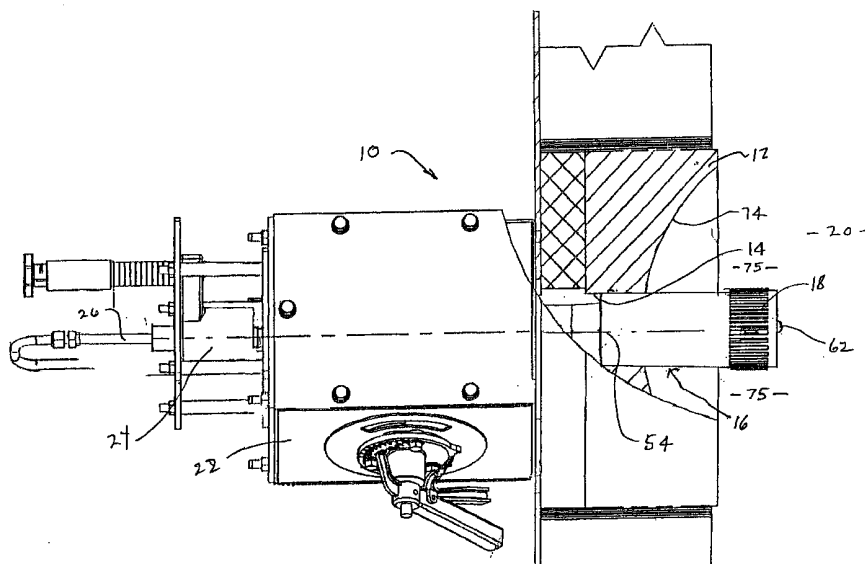
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ning of each regular issue of the PCT Gazette.

(54) Title: LOW NO<sub>x</sub> RADIANT WALL BURNER



(57) **Abstract:** A low NO<sub>x</sub> burner nozzle assembly for a radiant wall burner includes an elongated hollow burner tube and a discharge nozzle. The burner tube defines a conduit for supplying a mixture of fuel and air to a radiant combustion area. The discharge nozzle is mounted on the tube at the downstream end of the conduit and adapted for directing the mixture of fuel and air in an essentially radial direction. The discharge nozzle includes a plurality of flow directing members arranged in an array to define therebetween a plurality of passageways which extend in a generally radial direction and having different respective flow areas. The discharge nozzle also has an end cap to prevent axial flow of the primary air/fuel mixture. The end cap has an axially extending hole therein, and the nozzle assembly includes a staged fuel burner nozzle arranged so as to protrude axially through such hole.

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**TITLE OF THE INVENTION**LOW NO<sub>x</sub> RADIANT WALL BURNER**BACKGROUND OF THE INVENTION****Field of the Invention**

5                   The present invention relates to the field of radiant wall burners. In particular the invention relates to radiant wall burners wherein a number of technologies are combined in a single burner arrangement so as to achieve low NO<sub>x</sub> and low noise.

**The State of the Prior Art**

                  Reduction and/or abatement of NO<sub>x</sub> in radiant burners has always been a  
10   desirable aim. Some NO<sub>x</sub> abatement has been achieved in the past by staging a portion of the gaseous fuel. Low pressure staged gas may be introduced into the combustion zone either from low pressure gas tips arranged around the periphery of the burner or from a center gas tip which protrudes through the center of the end cap of the radiant burner nozzle. These arrangements have not always been successful because, for NO<sub>x</sub>  
15   abatement purposes, the staged fuel should not be introduced into areas of the combustion zone where the oxygen concentration is greater than about 4% by volume.

**SUMMARY OF THE INVENTION**

                  Various problems encountered in prior art burners are addressed by the concepts and principles of the present invention. In particular, the invention addresses  
20   the ever present need for NO<sub>x</sub> abatement. In accordance with one aspect of the invention, it has been found that when gas is burned in a staged manner it may sometimes be responsible only for about 6 ppm (vol) of the total NO<sub>x</sub> emissions of an individual burner. Accordingly it has been thought to be desirable to adapt the concept of fuel staging to radiant wall burners. Several different configurations have been tried, some more  
25   successful than others, but none with complete satisfaction. In some configurations, staged fuel has been delivered through a plurality of tubes at very low pressure around the circumference of the burner. In such a case the staged fuel is introduced in proximity to a combusting mixture which is still quite rich in oxygen. This excess oxygen leads to higher flame temperatures and higher NO<sub>x</sub> content in flue gases.

30                   In other configurations, staged gas has been introduced into the combustion zone from the axially distal end of the premix discharge nozzle. This

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configuration, where the staged fuel is injected coaxially at the center line of the premix burner assembly, has been somewhat more successful in achieving lower NO<sub>x</sub> emissions than the first configuration discussed above, at least in part due to the fact that the introduction point is located in spaced relationship to the face of the tile as well as away  
5 from the oxygen rich stream leaving the premix discharge nozzle. The down side of this particular methodology is that the momentum of the staged gas jet can and often does pull the primary oxygen rich premixed stream into the jet as an entrained flow thereby increasing the availability of excess oxygen as well as the production of NO<sub>x</sub>. This problem is exacerbated in applications requiring a multiplicity of individual burners in  
10 an array because of the interactions between burners.

In accordance with an important aspect of the invention, a low NO<sub>x</sub> burner nozzle assembly is provided for a radiant wall burner. The assembly includes an elongated hollow burner tube and a discharge nozzle. The burner tube has a central, longitudinally extending axis and defines a conduit extending along the axis for  
15 supplying a mixture of fuel and air to a radiant combustion area of a combustion zone that extends radially and surrounds the nozzle assembly. This mixture may desirably be fuel lean. The discharge nozzle is mounted on the tube at a downstream end of the conduit adjacent the combustion zone, and the same is adapted for receiving the mixture of fuel and air from the conduit and directing the same into the radiant combustion area  
20 in an essentially radial direction relative to the axis of the tube. The discharge nozzle may include a plurality of flow directing members arranged in an array which extends circumferentially around the discharge nozzle and the members may desirably be arranged to define therebetween a plurality of passageways which extend in a generally radial direction relative to the axis. The discharge nozzle may also include an end cap  
25 that is mounted on the members in a position to close the conduit and prevent flow of the mixture in a direction along the axis. Thus, the mixture is caused to flow through the passageways in a generally radial direction.

Preferably, the flow directing members may be arranged so that some of the passageways therebetween have a larger flow area than others. Desirably, the  
30 members may be in the form of plates which are essentially rectangular in shape. Ideally, the passageways may also extend in an axial direction. In a much preferred form of the invention, the end cap may have a lateral edge which is located at a first radial distance

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from the axis, and the members may each have an outer edge located at a second radial distance from the axis. The second radial distance ideally may be greater than the first radial distance such that passageways defined by the members extend radially outward beyond the lateral edge of the end cap.

5                   In accordance with another preferred form of the invention, the nozzle may include an internal baffle positioned and arranged to redirect at least a portion of the mixture flowing through the conduit and cause the same to flow through the passageways in a generally radial direction.

10                   In yet another preferred form of the invention, the end cap may have an axially extending hole therein, and the nozzle assembly may include a centrally located staged fuel burner nozzle made up, for example, of a length of tubing which extends along the axis of the conduit. The assembly may also include a staged burner nozzle tip at a downstream end of the length of tubing. In accordance with this aspect of the invention, the staged fuel burner nozzle may desirably be arranged so as to protrude  
15 axially through the hole. Importantly, the tip ideally may have a fuel delivery orifice therein for delivering fuel to the combustion zone in spaced relationship to the radiant combustion area.

                  In one desirable form of the invention, the delivery orifice may be disposed so as to introduce fuel gas into zone 20 at an upward and outward angle relative  
20 to a plane that is perpendicular to the axis. Preferably, the angle may be at least about 30°, and for some purposes in accordance with the invention, the delivery orifice may be disposed to introduce fuel gas in a direction along the axis.

                  Even more desirably, the staged fuel burner nozzle may be positioned such that a downstream portion of the length of tubing protrudes beyond the end cap so that  
25 the tip is positioned in axially spaced relationship relative to the end cap. Ideally, in this particularly desirable form of the invention, the low NO<sub>x</sub> burner nozzle may include an elongated protective sheath disposed in surrounding relationship to the protruding portion of the length of tubing and the tip. Such sheath may desirably include an opening disposed in alignment with the orifice. The sheath may also be provided with one or  
30 more vent openings configured to permit gases between the sheath and the length of tubing to escape into the combustion zone. In accordance with the foregoing aspects of the invention, the staged burner nozzle may be of significant value, regardless of the form

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of the discharge nozzle. Thus, the staged burner tip of the invention may be used with any sort of radial discharge nozzle that operates to spread a combustible mixture of fuel and air radially across the face of a radiant tile.

In accordance with yet another aspect of the invention, the burner tube  
5 may comprise a venturi tube having a throat that is in communication with an air supply and a source of fuel gas under pressure. The venturi tube may desirably be arranged such that the flow of fuel gas through the throat induces a flow of air from the air source whereby the mixture of fuel and air is created in the throat and caused to flow toward the discharge nozzle.

10 The invention also provides a low NO<sub>x</sub> radiant wall burner comprising a burner tile having a central opening surrounded by a radiant tile face and an elongated low NO<sub>x</sub> burner nozzle assembly as described above that extends through such opening. The face of the burner tile may be either dished or flat.

In addition, the invention provides a method for operating a burner  
15 comprising providing a mixture of fuel and air at a centrally located point adjacent a face of a burner tile, separating the mixture into a plurality of separate streams and causing such streams to flow radially outwardly from the centrally located point across the face of the tile, and causing the velocity of some of the streams to be greater than the velocity of others of the streams.

20 The invention further provides a method for operating a burner which includes the steps of providing a mixture of fuel and air at a centrally located point adjacent a face of a burner tile, separating the mixture into a plurality of separate streams and causing the streams to flow radially outwardly from the point across the face of the tile, causing the streams to combust to form flames, each having an outer peripheral  
25 terminus spaced radially from the point, and providing secondary air to the flame at a location adjacent the termini.

In yet another form, the invention provides a method for operating a burner that comprises providing a mixture of fuel and air, causing the mixture to flow along a path to a centrally located point adjacent a face of a burner tile, separating the  
30 mixture into a plurality of separate streams and causing the streams to flow radially outwardly from the path across the face of the tile, causing the streams to combust to form flames in an area of a combustion zone adjacent the face, and providing staged fuel

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to the zone at a location spaced from the area. In accordance with this form of the invention, the oxygen content of the gases at the location where the staged fuel is introduced is desirably not more than about 4% by volume.

The invention also provides a low NO<sub>x</sub> burner assembly which includes  
5 an elongated hollow burner tube providing a longitudinally extending conduit for supplying a mixture of fuel and air to a combustion zone. The burner tube has an outer wall surrounding the conduit, a longitudinally extending central axis and a pair of spaced ends. The assembly also includes a discharge nozzle at one of the ends of the burner tube, an inlet for a mixture of fuel and air at the other end of the burner tube, and at least  
10 one port extending through the wall at a location between the discharge nozzle and the inlet to communicate the conduit with an external area located outside the burner tube. Desirably the port may have a center axis which is essentially perpendicular to the central axis of the tube. Alternatively, the port may have a center axis which is at an angle relative to the central axis of the tube. Ideally the assembly may include a plurality of  
15 ports extending through the wall of the tube at respective locations between the discharge nozzle and the inlet. In one preferred form of the invention, the ports may be arranged in one or more rows which extend around the outer wall of the tube.

In another form of the invention, the ports described above may be utilized in combination with a discharge nozzle that includes a plurality of flow directing  
20 members as described, which are arranged to define therebetween a plurality of passageways which extend in generally radial directions relative to said axis, and an end cap mounted on said members in a location to redirect at least a portion of the mixture flowing from the end of the conduit and cause the same to flow through said passageways in a generally radial direction. In accordance with the invention, the members may be  
25 arranged so that some of the passageways have a larger flow area than others of the passageways.

The nozzle assembly having at least one port extending through the wall of the burner tube may be used as a component of a low NO<sub>x</sub> radiant wall burner that includes a burner tile having a central opening. In such a case, the nozzle assembly may  
30 extend through the central opening of the tile. Desirably, the discharge nozzle may include a plurality of flow directing members which are arranged to define therebetween a plurality of passageways which extend in generally radial directions relative to the axis

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of the burner tube, and an end cap mounted on said members in a location to redirect at least a portion of the mixture flowing from the end of the conduit and cause the same to flow through said passageways in a generally radial direction so that when ignited, the redirected mixture of fuel and air provides a generally laterally extending flame having  
5 an outer peripheral extremity at a location in said zone spaced radially from said axis.

The invention further provides a method for operating a burner which includes the steps of causing a mixture of fuel and air to flow toward a centrally located point adjacent a face of a burner tile, causing additional air to flow toward a location adjacent said face which is spaced laterally from said point, and separating a portion of  
10 said mixture and intermixing the same with said additional air to create an ultra lean admixture capable of flameless oxidation before the additional air reaches said location. More particularly, the method may include the steps of causing a mixture of fuel and air to flow toward a centrally located point adjacent a face of a burner tile, separating a first portion of said mixture into a plurality of separate streams and causing said streams to  
15 flow radially outwardly from said point across the face of said tile, causing said streams to combust to form flames, each having an outer peripheral terminus spaced radially from said point, providing secondary air to said flame at a location adjacent said termini, adding a second portion of said mixture to said secondary air at a location upstream from said location to create an admixture capable of flameless oxidation at the face of said tile,  
20 and flamelessly oxidizing said admixture at said face to create relatively cool oxidation products. In accordance with the concepts and principles of the invention, oxidation products may be admixed with the combusting gases to thereby dilute and cool the same. In further accordance with the principles and concepts of the invention, a flow of recirculated flue gas may be provided to said flame at a location adjacent said termini.

25 Prior art burners of the premix type of design have not been able to utilize as many NO<sub>x</sub> abatement technologies in a single burner as are provided in the burner arrangements of the present invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**FIG. 1** is a side elevational view, partly in cross-section, of a low NO<sub>x</sub>  
30 radiant wall burner which embodies the concepts and principles of the invention;

**FIG. 2** is a side elevational view of the nozzle arrangement of the burner of **FIG. 1**;

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**FIG. 3** is a schematic plan view of a preferred embodiment of the discharge nozzle of the nozzle arrangement of **FIG. 2**;

**FIG. 4** is an enlarged elevational, cross-sectional view of the discharge nozzle of **FIG. 3**;

5           **FIG. 5** is an enlarged view, partly in cross-section, of the discharge nozzle of **FIG. 3**;

**FIG. 6** is an enlarged view, similar to **FIG. 5**, which is partly in cross section to illustrate an embodiment of an internal baffle;

**FIG. 7** is a schematic view of the nozzle arrangement of **FIG. 1**;

10           **FIGS. 8A and 8B** respectively are side elevational and plan views an embodiment of a central staged nozzle tip for the nozzle arrangement of **FIG. 2**;

**FIG. 9** is a side elevational view of an embodiment of a tile for use with the burner of **FIG. 1**;

**FIG. 10** is a plan view of the tile of **FIG. 9**;

15           **FIG. 11** is a schematic side elevational view of one embodiment of a nozzle arrangement that is useful in connection with the invention;

**FIG. 12** is a schematic side elevational view of an alternative embodiment of a nozzle arrangement that is useful in connection with the invention;

20           **FIG. 13** is a schematic side elevational view of another alternative embodiment of a nozzle arrangement that is useful in connection with the invention;

**FIG. 14** is a schematic side elevational view of yet another alternative embodiment of a nozzle arrangement that is useful in connection with the invention;

**FIG. 15** is a side elevational view of yet another burner arrangement which embodies the concepts and principles of the invention;

25           **FIG. 16** is an enlarged cross sectional view of the discharge nozzle of the burner of **FIG. 15**; and

**FIG. 17** is a schematic view illustrating the operation of the burner of **FIG. 15**, including a schematic showing of the flow paths of the several combustion and flameless oxidation streams.



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## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

A burner 10 which embodies the concepts and principles of the invention is illustrated in Fig. 1 where it can be seen that the same includes a burner tile 12 having a centrally disposed opening 14 and a burner nozzle assembly 16 including a burner discharge nozzle 18 which protrudes through opening 14 and extends into a combustion zone 20. The burner 10 may also include conventional components such as a muffler 22, an air door 24 and an inlet tube 26 facilitating connection to a source of fuel gas.

With reference to Fig. 2, it can be seen that the nozzle assembly 16 may include spud 28 whereby a supply of fuel gas is supplied to the nozzle assembly 16. Spud 28 is connected to a coupling 42 (See Fig. 7) whereby fuel gas is supplied to the discharge nozzle 18. The assembly 16 also includes an elongated, hollow burner tube 30 and a base 32. Tube 30 extends between base 32 and discharge nozzle 18 and provides a passageway for primary combustion air and accommodates the gas supply system (not shown) which interconnects spud 28 and coupling 42.

Discharge nozzle 18 preferably includes a fuel distribution section 36 and an end cap 38. With reference to Figs. 5, 6 and 7, it can be seen that the downstream portion 34 of tube 30 may preferably include a venturi tube 40 whereby fuel gas being ejected through an opening 44 in coupling 42 induces a flow of combustion air from the interior of tube 30. Preferably coupling 42 may be provided with a plurality of openings 44 as shown. The fuel gas ejected through the openings 44 mixes with the induced air to preferably form a combustible fuel lean fuel gas/air mixture which travels through portion 34 of tube 30 toward and into fuel distribution section 36.

Fuel distribution section 36 is illustrated in Figs. 3 and 4. Section 36 includes a plurality of fin-like flow directing members 46 and 48 which define therebetween a plurality of passageways 50 and 52 which extend in a generally radial direction relative to the central axis 54 of the nozzle assembly 16. The members 46 and 48 may be sized and arranged such that the passageways 50 defined between adjacent members 46 may be larger in cross-sectional flow area than the passageways 52 defined between adjacent members 48. In operation, the fuel/air mixture flows through portion 34 of tube 30 in a direction which is generally parallel to axis 54. As the air/fuel mixture approaches end cap 38, the air/gas mixture is redirected so that it flows radially outward

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through the passageways 50 and 52. It is to be noted in this regard that the respective outer extremities 46a and 48a of members 46 and 48 are preferably spaced further from axis 54 than the outer edge 38a of cap 38. This provides respective openings 50a and 52a (see Fig. 5) at the axially outer ends of passageways 50 and 52 which permit a portion of the air/fuel combustible mixture adjacent thereto to bend slightly and flow toward zone 20 rather than in a direction at right angles to axis 54.

With particular reference to Fig. 3, it can be seen that the members 46 and 48 may be arranged so as to provide respective groups 56 and 58 of passageways 50 and 52. As shown, each group 56 includes five passageways 50 and each group 58 includes five passageways 52. As can clearly be seen from Fig. 3, the passageways 50 are wider than the passageways 52 so that the cross sectional flow areas provided by passageways 50 are greater than the cross-sectional flow areas provided by passageways 52. As shown, the groups 56 and 58 are arranged around section 36 in alternating positions. It can also be seen that in the presently preferred embodiment, the section 36 includes four groups 56 and four groups 58. However, it is to be noted that the passageways may be arranged in a variety of equally acceptable arrangements, depending upon the design and operational characteristics desired. The sizes of the passageways 52 and 50 may be varied to facilitate increased velocity, particularly through passageways 52. Increased velocity through passageways 52 relative to the velocity through passageways 50 provides increased diffusion of recirculated flue gas

In one preferred embodiment of the invention, shown particularly in Figs. 11 and 12, a central secondary staged fuel nozzle 60 protrudes through a hole 64 provided in end cap 38. Nozzle 60 includes a length of gas supply tubing 86 that extends along axis 54 and through portion 34. A staged burner tip 62 is mounted at the downstream end 88 of the tubing 86. Tip 62 may be as is illustrated in Figs. 8A and 8B, where it can be seen that the same may be provided with delivery openings 66 for directing the flow of preferably raw fuel into zone 20 in spaced relationship relative to a radiant combustion area 75 in zone 20 adjacent face 74 (see Fig. 1). As shown in Figs. 8A and 8B, openings 66 may be disposed at an approximate angle of 45° from the plane of the tile face; however, the angle required for any given installation may vary depending upon the desired operational and performance characteristics of the burner. In this latter regard, the angle of openings 66 should desirably not be less than about 30°, as shown

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schematically in Fig. 11, to insure that premature mixing of the staged fuel with an oxygen rich mixture is avoided. Likewise, the number and spacing of the openings 66 is a function of the desired performance characteristics.

In another embodiment of the invention, nozzle 60 may be as shown in Figs. 12, 13 and 14, where the downstream portion 90 of tubing 86 protrudes beyond end cap 38 such that the tip 62 is positioned in spaced relationship relative to end cap 38. In this case, the assembly 16 may preferably include a cylindrical sheath 92 which is mounted on end cap 38 and extends along the entire length of protruding portion 90 in surrounding relationship to the latter. Appropriately positioned openings 94 may be provided in sheath 92 to permit the entirety of tip 62 to be protected from the heat of the combustion zone and yet allow egress of staged fuel from tip 62.

As shown in Fig. 12, the sheath 92 may also have an open end 96 which is adapted to vent the sheath 92 by permitting gases between the sheath 92 and the tubing 86 to escape into the combustion zone. Alternatively, the arrangement may be as shown in Figs. 13 and 14, where the end of the sheath 92 is closed by a flat (Fig. 13) or domed (Fig. 14) cap 98. In this case, appropriate vent holes 100 may be provided in the wall of the sheath 92. These vent holes 100 serve essentially the same purpose as the open end 96, but as shown, the same may preferably be disposed at a downwardly inclined angle of about  $10^\circ$  relative to a plane which is perpendicular to the longitudinal axis of the sheath 92. Desirably, nozzle 60 may also be provided with an orifice 68 as shown in Fig. 5 to control the amount of fuel which flows into the combustion zone via nozzle 60.

In accordance with the concepts and principles of the invention, the tip 62 desirably may be positioned far enough away from the premixed discharge nozzle 18 such that the flow patterns of the oxygen rich and radially moving combusting gases in the radiant combustion area 75 and the staged fuel injected via nozzle 60 are mechanically decoupled so as to avoid burning of the staged fuel in an oxygen rich environment. Thus, the staged gas jet leaving tip 62 is far enough from the premixed flow envelope such that the momentum of the jet is insufficient to cause the staged gas and the premixed gas/air mixture to intermingle, at least until the fuel from nozzle 60 has had an opportunity to become mixed with flue gas. This is extremely important, particularly when considered in conjunction with the ultralean concept of the primary air/fuel mixture where the large amount of excess air left over from the combustion in the

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radiant heating area 75 is significant enough to cause localized combustion to start at the tip of the staged riser, thus increasing NO<sub>x</sub> emissions. Desirably, for best results in NO<sub>x</sub> abatement, the staged fuel should be combusted in an atmosphere which contains no more than about 4% oxygen by volume.

5                   With reference to Figs. 9 and 10, for some important applications utilizing the concepts and principles of the invention, the opening 14 may desirably be larger in internal diameter than the outer diameter of tube portion 34 so that secondary combustion air may flow into zone 20 through the annular space between opening 14 and cylindrical section 34. In accordance with the invention this aspect of the invention, and as  
10 illustrated in Figs. 9 and 10, secondary air ducts 70 may be provided to facilitate and improve the flow of secondary air. One end 72 of duct 70 is in communication with zone 20 at the face 74 of tile 12. The other end 76 of duct 70 is in communication with opening 14. As can be seen from Fig. 10, end 72 is arcuate in shape so that the same projects a fan-shaped flow of air into zone 20. End 76 is also arcuate in shape and in  
15 general is in the shape of a slot which extends around the internal surface 78 of opening 14. In accordance with the invention, the face 74 of tile 12 may be dished or flat. Dishing may facilitate recirculation of flue gas inside the dish.

                  In the operation of a burner which incorporates the tile illustrated in Figs. 9 and 10, the fuel lean fuel/air mixture leaving passageways 50 and 52 travels radially,  
20 outwardly of axis 54 and generally across face 74 of tile 12 where it is burned in a radiant combustion area 75 adjacent face 74. The combustion products of the fuel/air mixture eventually intermix with raw fuel from nozzle 60. In many embodiments of the invention, the intermixture may be fuel rich, and after combustion, the same may provide a generally laterally extending flame having an outer peripheral extremity at the radial  
25 periphery of area 75, which periphery is spaced radially from the axis. Preferably, end 72 of duct 70 may be positioned so as to provide a fan a air to the flame at the outer peripheral extremity of the laterally extending flame.

                  An embodiment of the nozzle of the invention which includes an internal baffle 84 is shown in FIG. 6. Baffle 84 is generally in the shape of an inverted cone and  
30 the same is positioned for redirecting the flow of the air/fuel mixture traversing tube 40. The combustible mixture travels along tube 40 in a generally axial direction until it encounters baffle 84 which redirects the flow so that it moves in a generally radial

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direction. In FIG. 6 the baffle is shown in combination with a nozzle structure which includes a centrally located raw fuel nozzle 60. However, it will be recognized by one of ordinary skill that the internal baffle will be highly useful regardless of the presence or absence of the central nozzle.

## 5 EXAMPLE

A burner embodying the concepts and principles of the invention was operated as follows: the burner is fired at 0.63 MMBtuh; excess air is 10%; furnace temperature is 1800 °F; burner differential pressure is 0.25 inches of water; secondary and primary burner damper is fully opened; combustible gas is 50% natural gas and 50%  
10 hydrogen; burner is aligned with outer cupped tile edge and then pushed in 0.25 inch.  
**Measured results using a single burner: 2.5% O<sub>2</sub>; 0 ppm CO; and 8 to 10 ppm NO<sub>x</sub>.**  
**Measured results using an array of 13 burners: 2.5% O<sub>2</sub>; 0 ppm CO; and 15 to 19 ppm NO<sub>x</sub>.**

As a result of the experiment it was noted that with deeper staging of air  
15 through the tile, NO<sub>x</sub> emissions can be brought down by a significant percentage of the overall emissions.

The advantages provided by the invention described above include very low NO<sub>x</sub>, low noise, partial premix with a rich gas stream axially staged for low NO<sub>x</sub>, prompt NO<sub>x</sub> alleviation with fuel induced furnace gas recirculation, simplicity, short  
20 flame profile, high pressure utilization at turndown for jet stability, high stability, operation with either flat or cupped tile face, facilitation of the manipulation of L/D for defined combustion of premixed fuel and air, staged air tile further decreases NO<sub>x</sub> formations with staged air technology, staged gas is directed away from furnace wall for slowed combustion, and secondary air staging is integral part of tile such that no excess  
25 air is needed at the base of the premix tip.

The burner of the invention is of a premix design. The burner may also include a venturi that is preferably optimized sufficiently to deliver an extremely fuel lean premix of air and fuel to the main discharge nozzle of the burner. The discharge nozzle may be designed so that its slots have a significant L/D (width to depth ratio) to keep  
30 each individual premixed jet as a defined individual flame envelope. This allows for the natural recirculation patterns of the tile and furnace to inject furnace flue gas into each stream. This is one factor in the reduction of NO<sub>x</sub>.

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The discharge nozzle may be arranged in eight sections, four (4) that are high flow and four (4) that are of lower flow. Since the webbing between each section is proportional the recirculation of flue gases in the tighter restricted area is more pronounced. The variation of area assures stability in the larger flow areas while the smaller areas are subjected to a higher percentage of flue gas by diffusion due to the smaller mass.

As described above, a center riser 60 may be inserted through the burner tube 34, which preferably may be a venturi, so that the riser protrudes through the end plate 38 of the discharge nozzle 36. The secondary or staged nozzle 60 is fed pure gas fuel (unpremixed) at a pressure of about 10 psig. The gas is then expelled via a staged tip 62 designed to handle the high temperatures of the furnace and subsequently burned. This tip 62 desirably provides a L/D sufficient to ensure that the gas can be directed at an angle as required to oxidize the gas in a stable manner away from the heat of the furnace wall. This ensures that the combustion process is impeded, but not enough to induce appreciable amounts of CO.

The tip pressure is maintained by an integral orifice 68 located in the line from the main gas spud to the staged tip. The discharge nozzle 36 and the staged tip 62 interact together in flow patterns created by the open slots in the face of the discharge nozzle 36 to insure appropriate staging of the raw fuel and the subsequent recirculation of the CO and CO<sub>2</sub> formed to lower the NO<sub>x</sub> further in the primary premixed section of the flame.

Another aspect of the burner of the invention is its capability to utilize a truly staged air tile formation, whereby secondary air is mixed into the premixed portion of the flame at its peripheral tip. The NO<sub>x</sub> can be further impeded by the mixing mechanics of this secondary air tile as it stages the air out instead of allowing the secondary air to come into contact with the base of the premixed flame envelope.

In another preferred embodiment of the present invention, and as illustrated in Figs. 15, 16 and 17, the burner may be provided with one or more, preferably several, and ideally eight or more radially extending ports 100 in the wall of the centrally disposed tube 34 which provides a conduit for delivering the central air/fuel mixture to the burner tip. These ports 100 communicate with the space 102 surrounding the tube 34 whereby a portion of the air/fuel mixture flows through the ports 100 and

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becomes admixed with secondary air flowing along the outside of the tube 34 toward the combustion zone 20. The admixture thus formed may generally be too lean to support a conventional flame; however, low temperature oxidation thereof occurs at face 174 of the burner tile 104, whereby  $\text{NO}_x$  emissions are minimized.

5                   In accordance with a particularly preferred form of the invention described above, where the ports 100 are used in connection with a radiant burner having a cupped tile 104, the ports 100 provide for a prestaging of some of the premixed air and fuel resulting in decreased tip velocity through discharge nozzle 36, enhanced stability and minimization of  $\text{NO}_x$  emissions. The cupped tile 104 enables the placement of the ports  
10   100 at a location about 3 full inches upstream from the discharge nozzle 36 whereby, as shown in Fig. 17, the already lean air/fuel mixture 152 escaping from the central tube 34 through the ports 100 is able to become thoroughly admixed with secondary air flowing in the direction of the arrows 154 along the outside of tube 34 to present an ultra lean admixture well before the latter reaches the face 174 of the tile. This ultra lean admixture  
15   undergoes low temperature oxidation without conventional flame on the face of the tile. The products of this low temperature oxidation are then entrained into the main flame 150 created at the discharge nozzle 36 and provide a quenching, cooling effect to thereby reduce  $\text{NO}_x$  in the main flame. The overall effect provides in a reduction of  $\text{NO}_x$  emissions to a level well below 10 parts per million on a volumetric basis (ppmv). In  
20   accordance with the principles and concepts of the present invention,  $\text{NO}_x$  emissions below 5 ppmv can be achieved consistently.

                  The attributes of this form of the invention include: 1) low  $\text{NO}_x$  emissions with staged fuel; 2) flameless combustion coupled with rapid oxidation in the proximity of the tile; 3) low noise as a function of tip pressure and heat release; 4) staged gas jets  
25   entraining flue gas external to the burner; 5) prompt  $\text{NO}_x$  alleviation; 6) secondary air has less effect on  $\text{NO}_x$  emissions; 7) short flame profile; 8) high turndown ratios with added premix tip velocities; 9) high stability; 10) minimization of CO emissions; 11) very lean premixed zone; 12) oxidation against radiant tile with stoichiometry below LEL's (cold combustion); and 13) three separate fluid flow zones containing different stoichiometries  
30   of gas and air.

                  As shown in Fig. 16, the holes 100 for directing a portion of the primary air/fuel mixture into the flow of secondary air on the outside of the burner tube 34 to thus

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create an ultra lean mixture of air and fuel, desirably may be used in conjunction with a burner nozzle which includes flow directors such as the directors 46, 48, a central nozzle such as the nozzle 60, and an internal baffle such as the baffle 84.

Broadly, in accordance with the concepts and principles of the configuration illustrated in Figs. 15, 16 and 17, by prestaging a volume of an ultra lean premixed air and fuel gas in conjunction with a premixed burner and a fuel rich staged tip, ultra low NO<sub>x</sub> emissions may be achieved in conjunction with a tile designed to facilitate flameless combustion of the prestaged ultra lean admixture while maintaining separation of the latter from the main flame until a appropriate product mix is achieved to dilute and cool the main flame so as to lower emissions therein.

In the burner of Figs. 15, 16 and 17, once some fraction of the fuel, ranging from about 15% of the fuel to all of the fuel, is mixed with air, a small portion of the mixture is removed prior to the main discharge nozzle and redirected into a secondary air stream. In the case of a radiant wall burner, the premix is removed from the central tube 34, which may be in the form of a venturi, by means of ports (radially drilled holes) 100 positioned around the body of the burner prior to the tip. In another configuration the premix may be mixed with recirculated flue gas that is ported back through the tile using special ports. This creates a mixture that is below the flammability limits and incapable of sustaining combustion. This stream must pass then pass through the highly radiant tile section that is capable of accelerating the kinetics of the gas and causing a rapid oxidation of the fuel even though it is below its flammability limits. When substantial oxidation, if not complete oxidation, has taken place this stream is then remixed with the main premixed air and gas stream that is exiting the main burner tip and is just within its flammability limits. The main premix stream sustains and stabilizes the combustion. The oxidized stream has a quenching effect on the main flame, lowering its theoretical temperature by putting a heat load on the flame by means of extra mass.

In addition, a secondary staging of pure fuel gas is also being introduced from a secondary tip 60 downstream of the main burner premix discharge nozzle. The secondary fuel is introduced further into the furnace and uses the kinetic energy of its sonic jets to entrain and mix in substantial amounts of furnace flue gas before it is pulled back into the main flame by the momentum of the main flame and the force of recirculating furnace gases. This also has a quenching effect to the main flame and also



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serves to bring the flammability limits of the overall mixture into a range that is once again flammable. The stabilizing affect of the refractory helps to maintain a stable flame envelope during turndown and low oxygen regimes seen during operational excursions within the furnace.

5                   It is important to note that the premix prestaging technique described in connection with Figs. 15, 16 and 17 provides NO<sub>x</sub> reductions to approximately half of what was already an ultra-low NO<sub>x</sub> burner. It should be noted in this regard that the premix prestage concept facilitated by the holes 100 can be extended for use with essentially any burner shape and/or mounting pattern. In other words, the premix  
10                   prestaging technique can be extended to essentially any burner application. Thus, this concept may be used to make very low NO<sub>x</sub> round flame, upfired or sidefired burners, as well as rectangular flat flame burners and downfired burners. The concept may also be utilized in both, what are fundamentally diffusion flame burners as well as full fledged premixed type burners.

15                   The use of a lean primary air/fuel mixture augmented by a flameless combustion zone within the tile located in proximity to the main flame, plus a substantial staged portion of the gas in fuel rich form that is subsequently returned to the main flame by entrainment and momentum via a nozzle such as the nozzle 60 to provide reduction of theoretical temperature by additional mass, is a very important feature of the invention.

20                   Overall, the invention is adaptable so as to provide several families of burners ranging from radiant wall burners to horizontal, upfired, and even downfired burner designs with the capability of delivering NO<sub>x</sub> emissions much below current burner technologies.

                  In another configuration, in accordance with the concepts and principles  
25                   of the invention, the ported nozzle arrangement may be used in conjunction with a specially ported version of a tile that is adapted to recirculate flue gas which may then be used instead of secondary air to dilute the ported primary air/fuel mixture. Such an arrangement also may be used to provide and maintain a lean premix behind the tile assuring that combustion which would be detrimental to the burner tip does not take  
30                   place. The spin off to this is the loading of the flame that helps to lower the theoretical temperature of the flame much more than is typically seen in burner designs. The

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flameless combustion zone may be controlled and kept separate from the main flame until most of the initial oxidation is complete.

The concepts and principles of the present invention add a new twist to an already evolving technology. The creation of a flameless combustion zone (lean  
5 premixed) coupled with specific tile designs to control and stabilize the combustion process operate together to provide low NO<sub>x</sub> without the use of flue gas recirculation and/or other dilution methods for reducing flame temperature.

The burner of Figs. 15, 16 and 17 provides single digit NO<sub>x</sub> numbers in what may be considered "within the parts that are usually included in a conventional  
10 burner". By adding the flameless combustion zone behind the main flame, new ground has been broken in addressing what is considered the "prompt NO<sub>x</sub> regime" of NO<sub>x</sub> production.

The joining of all of these various aspects of the invention allows the burner of the invention to deliver NO<sub>x</sub> emissions in the range of single digits to the mid  
15 teens (ppm) depending on the number of burners in the array, and the species and concentrations of the species in the fuel mix. Thus, in accordance with the invention, it has been discovered that it is possible to combine many known theories of NO<sub>x</sub> abatement into a single burner that provides stable operation and appropriate turndown while performing in a range that has not previously been thought possible. In accordance  
20 with the invention, shorter flame patterns are possible especially when the fuel comprises heavy hydrocarbons; larger turn down ratios are possible on high hydrogen fuels, particularly when an internal baffle is utilized; much lower noise is experienced around a burner with multiple ports and small jets; either cupped or flat tiles may be utilized interchangeably; staged air tile design allows for NO<sub>x</sub> adjustment while running; burner  
25 adjustment capabilities in the tile allow for NO<sub>x</sub> adjustment; tips are easily removed and serviced by design; and the direction of the staged jets at turndown help to stabilize the primary flame.

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**I CLAIM:**

1. A low NO<sub>x</sub> burner nozzle assembly for a radiant wall burner including an elongated hollow burner tube and a discharge nozzle, said burner tube having a central, longitudinally extending axis and defining a conduit extending along  
5 said axis for supplying a mixture of fuel and air to a radiant combustion area of a combustion zone that surrounds the nozzle assembly, said discharge nozzle being mounted on said tube at a downstream end of the conduit adjacent said zone and being adapted for receiving said mixture of fuel and air from the conduit and directing the same into said area in an essentially radial direction relative to said axis, said discharge nozzle  
10 comprising: a plurality of flow directing members arranged in an array which extends circumferentially around said discharge nozzle, said members being arranged to define therebetween a plurality of passageways which extend in a generally radial direction relative to said axis; and an end cap mounted on said members in a location to close said conduit and prevent flow of said mixture in a direction along said axis, whereby the  
15 mixture is caused to flow through said passageways in a generally radial direction.

2. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 1, wherein said members are arranged so that some of said passageways have a larger flow area than others of said passageways.

3. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 1, wherein  
20 said members are in the form of plates which are essentially rectangular in shape.

4. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 1, wherein said passageways extend also in an axial direction.

5. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 1, wherein said end cap has a lateral edge which is located at a first radial distance from said axis, and said members each have an outer edge located at a second radial distance from said  
25 axis, said second radial distance being greater than said first radial distance such that passageways defined by the members of said portion thereof extend radially beyond said lateral edge.

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6. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 1, wherein said end cap has an axially extending hole therein, and said nozzle assembly includes a centrally located staged fuel burner nozzle comprising a length of tubing which extends along the axis of said conduit and a staged burner nozzle tip at a downstream end of said length of tubing, said staged fuel burner nozzle being arranged so as to protrude axially through said hole, said tip having a fuel delivery orifice therein for delivering fuel to said zone in spaced relationship to said radiant combustion area.

7. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 6, wherein said staged fuel burner nozzle is positioned such that a downstream portion of said length of tubing protrudes beyond said end cap such that said tip is positioned in spaced relationship relative to said end cap.

8. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 7, wherein is included an elongated protective sheath disposed in surrounding relationship to said portion of said length of tubing and said tip.

9. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 8, wherein said sheath includes an opening disposed in alignment with said orifice.

10. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 1, wherein said burner tube comprises a venturi tube having a throat that is in communication with an air supply and a source of fuel gas under pressure, said venturi tube being arranged such that the flow of fuel gas through said throat induces a flow of air from said source whereby said mixture of fuel and air is created in said throat and caused to flow toward said discharge nozzle.

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11. A low NO<sub>x</sub> radiant wall burner comprising a burner tile having a central opening surrounded by a radiant tile face and an elongated low NO<sub>x</sub> burner nozzle assembly extending through said opening, said nozzle assembly including an elongated hollow burner tube and a discharge nozzle, said burner tube having a central,  
5 longitudinally extending axis and defining a conduit extending along said axis for supplying a mixture of fuel and air to radiant combustion area in a combustion zone surrounding said discharge nozzle, said radiant combustion area being adjacent said face, said discharge nozzle being mounted on said tube at a downstream end of the conduit adjacent said area and being adapted for receiving said mixture of fuel and air from the  
10 conduit and directing the same into said area in an essentially radial direction relative to said axis, said discharge nozzle comprising: a plurality of flow directing members arranged in an array which extends circumferentially around said discharge nozzle, said members being arranged to define therebetween a plurality of passageways which extend in a generally radial direction relative to said axis; and an end cap mounted on said  
15 members in a location to close said conduit and prevent flow of said mixture in a direction along said axis, whereby the mixture is caused to flow through said passageways in a generally radial direction.

12. A burner as set forth in claim 11, wherein the passageways are arranged such that the radially flowing mixture of fuel and air, when ignited, provides a  
20 generally laterally extending flame which extends through said area across said face and has an outer peripheral extremity at a location in said zone spaced radially from said axis.

13. A burner as set forth in claim 11, wherein at least one duct is provided in said tile for directing oxygen to a location in said zone adjacent the outer peripheral extremity of the flame.

25 14. A burner as set forth in claim 13, wherein said duct has one end in communication with said zone at said face and another end in communication with said opening.

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15. A burner as set forth in claim 14, wherein said one end of the duct is arcuate in shape and projects a fan-shaped flow of air into said zone.

16. A burner as set forth in claim 11, wherein said face is a dished face.

5 17. A low NO<sub>x</sub> burner nozzle assembly for a radiant wall burner including an elongated hollow burner tube, a discharge nozzle, and a central staged fuel nozzle, said burner tube having a central, longitudinally extending axis and defining a conduit extending along said axis for supplying a mixture of fuel and air to a radiant combustion area in combustion zone surrounding said discharge nozzle, said discharge  
10 nozzle being mounted on said tube at a downstream end of the conduit adjacent said area and being adapted for receiving said mixture of fuel and air from the conduit and directing the same in an essentially radial direction relative to said axis into said area, said discharge nozzle including an end cap positioned to prevent flow of said mixture in a direction along said axis, said central staged fuel nozzle comprising: a length of tubing  
15 which extends along the axis of said conduit; and a staged burner nozzle tip at a downstream end of said length of tubing, said staged fuel burner nozzle being arranged so as to protrude axially through a hole in said end cap, said tip having a fuel delivery orifice therein disposed for delivering fuel to said zone in spaced relationship to said area of said zone.

20 18. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 17, wherein said staged fuel burner nozzle is positioned such that a downstream portion of said length of tubing protrudes beyond said end cap such that said tip is positioned in spaced relationship relative to said end cap.

25 19. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 18, wherein is included an elongated protective sheath disposed in surrounding relationship to said portion of said length of tubing and said tip.

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20. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 19, wherein said sheath includes an opening disposed in alignment with said orifice.

21. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 17, wherein said delivery orifice is disposed to eject fuel gas at an upward and outward angle  
5 relative to a plane that is perpendicular to said axis.

22. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 21, wherein said angle is at least about 30°.

23. A nozzle for a low NO<sub>x</sub> radiant wall burner comprising an elongated element providing a longitudinally extending conduit for supplying a mixture  
10 of fuel and air to a combustion zone, said conduit having a central, longitudinally extending axis, and a nozzle tip structure located at an end of the conduit adjacent said zone for receiving said mixture of fuel and air from the conduit and directing the same into said zone, said tip structure comprising: a plurality of flow directing members, said members being arranged to define therebetween a plurality of passageways which extend  
15 in a generally radial direction relative to said axis; an end cap mounted on said members for closing off the free end of the nozzle; and an internal baffle positioned and arranged to redirect at least a portion of the mixture flowing from the end of the conduit and cause the same to flow through said passageways in a generally radial direction.

24. A method for operating a burner comprising: providing a mixture  
20 of fuel and air at a centrally located point adjacent a face of a burner tile; separating said mixture into a plurality of separate streams and causing said streams to flow radially outwardly from said point across the face of said tile; and causing the velocity of some of said streams to be greater than the velocity of others of said streams.

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25. A method for operating a burner comprising: providing a mixture of fuel and air at a centrally located point adjacent a face of a burner tile; separating said mixture into a plurality of separate streams and causing said streams to flow radially outwardly from said point across the face of said tile; causing said streams to combust  
5 to form flames, each having an outer peripheral terminus spaced radially from said point; and providing secondary air to said flame at a location adjacent said termini.

26. A method for operating a burner comprising: providing a mixture of fuel and air; causing said mixture to flow along a path to a centrally located point adjacent a face of a burner tile; separating said mixture into a plurality of separate streams  
10 and causing said streams to flow radially outwardly from said path across the face of said tile; causing said streams to combust to form flames in an area of a combustion zone adjacent said face; and providing staged fuel to said zone at a location spaced from said area.

27. A method as set forth in claim 26, wherein the oxygen content of  
15 the gases at said location are not more than about 4% by volume.

28. A low NO<sub>x</sub> burner nozzle assembly comprising: an elongated hollow burner tube providing a longitudinally extending conduit for supplying a mixture of fuel and air to a combustion zone, said burner tube having an outer wall surrounding said conduit, a longitudinally extending central axis and a pair of spaced ends; a  
20 discharge nozzle at one of the ends of the burner tube; an inlet for a mixture of fuel and air at the other end of the burner tube; and at least one port extending through said wall at a location between the discharge nozzle and said inlet communicating the conduit with an external area located outside of the burner tube.

29. A nozzle assembly as set forth in claim 28, wherein said port has  
25 a center axis which is essentially perpendicular to said central axis.

30. A nozzle assembly as set forth in claim 28, wherein said port has a center axis which is at an angle relative to said central axis.



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31. A nozzle assembly as set forth in claim 28, comprising a plurality of ports extending through said wall at respective locations between the discharge nozzle and said inlet.

32. A nozzle assembly as set forth in claim 31, wherein said ports are  
5 arranged in one or more rows which extend around said outer wall.

33. A nozzle assembly as set forth in claim 31, wherein each of said ports has a center axis which is essentially perpendicular to said central axis.

34. A nozzle assembly as set forth in claim 33, wherein said center axes are arranged in a common plane which is essentially perpendicular to said central  
10 axis.

35. A nozzle assembly as set forth in claim 28, wherein said location is closer to said discharge nozzle than it is to said inlet end.

36. A nozzle assembly as set forth in claim 34, wherein said common plane is positioned closer to said discharge nozzle than to said inlet end.

15 37. A low NO<sub>x</sub> radiant wall burner nozzle assembly comprising an elongated tubular element providing a longitudinally extending conduit for supplying a mixture of fuel and air to a combustion zone, said element including an outer wall surrounding said conduit, a pair of spaced ends, and a central, longitudinally extending axis, said nozzle assembly comprising: a discharge nozzle located at one end of the  
20 element adjacent said zone for receiving said mixture of fuel and air from the conduit and directing the same into said zone; and at least one port extending through said wall at a location between the discharge nozzle and the other end of the element communicating the conduit with an external area located outside of the element, said discharge nozzle including a plurality of flow directing members which are arranged to define  
25 therebetween a plurality of passageways which extend in generally radial directions relative to said axis, and an end cap mounted on said members in a location to redirect

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at least a portion of the mixture flowing from the end of the conduit and cause the same to flow through said passageways in a generally radial direction.

38. A nozzle assembly as set forth in claim 37, wherein said members are arranged so that some of said passageways have a larger flow area than others of said  
5 passageways.

39. A nozzle assembly as set forth in claim 37, comprising a plurality of ports extending through said wall, and wherein said ports are arranged in one or more rows which extend around said outer wall.

40. A low NO<sub>x</sub> radiant wall burner comprising a burner tile having a  
10 central opening and a nozzle assembly which extends through said central opening, said nozzle assembly comprising: an elongated tubular element providing a longitudinally extending passageway for supplying a mixture of fuel and air to a combustion zone and having an outer wall surrounding said passageway, a pair of spaced ends, and a central, longitudinally extending axis; a discharge nozzle located at one end of the element  
15 adjacent said zone for receiving said mixture of fuel and air from the passageway and directing the same into said zone; and at least one port extending through said wall at a location between the discharge nozzle and the other end of the element.

41. A burner assembly as set forth in claim 40, wherein said discharge nozzle includes a plurality of flow directing members which are arranged to define  
20 therebetween a plurality of passageways which extend in generally radial directions relative to said axis, and an end cap mounted on said members in a location to redirect at least a portion of the mixture flowing from the end of the conduit and cause the same to flow through said passageways in a generally radial direction.

42. A burner assembly as set forth in claim 41, wherein said members  
25 are arranged so that some of said passageways have a larger flow area than others of said passageways.

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43. A burner assembly as set forth in claim 41, comprising a plurality of ports extending through said wall, and wherein said ports are arranged in one or more rows which extend around said outer wall.

44. A burner assembly as set forth in claim 41, wherein the  
5 passageways are arranged such that the redirected mixture of fuel and air, when ignited, provides a generally laterally extending flame having an outer peripheral extremity at a location in said zone spaced radially from said axis.

45. A method for operating a burner comprising: causing a mixture of fuel and air to flow toward a centrally located point adjacent a face of a burner tile;  
10 causing additional air to flow toward a location adjacent said face which is spaced laterally from said point; and separating a portion of said mixture and intermixing the same with said additional air to create an ultra lean admixture capable of flameless oxidation before the additional air reaches said location.

46. A method for operating a burner comprising: causing a mixture of  
15 fuel and air to flow toward a centrally located point adjacent a face of a burner tile; separating a first portion of said mixture into a plurality of separate streams and causing said streams to flow radially outwardly from said point across the face of said tile; causing said streams to combust to form flames, each having an outer peripheral terminus spaced radially from said point; providing secondary air to said flame at a location  
20 adjacent said termini; adding a second portion of said mixture to said secondary air at a location upstream from said location to create an admixture capable of flameless oxidation at the face of said tile; and flamelessly oxidizing said admixture at said face to create relatively cool oxidation products.

47. A method as set forth in claim 46, where said oxidation products  
25 are admixed with said flames to thereby dilute and cool the same.

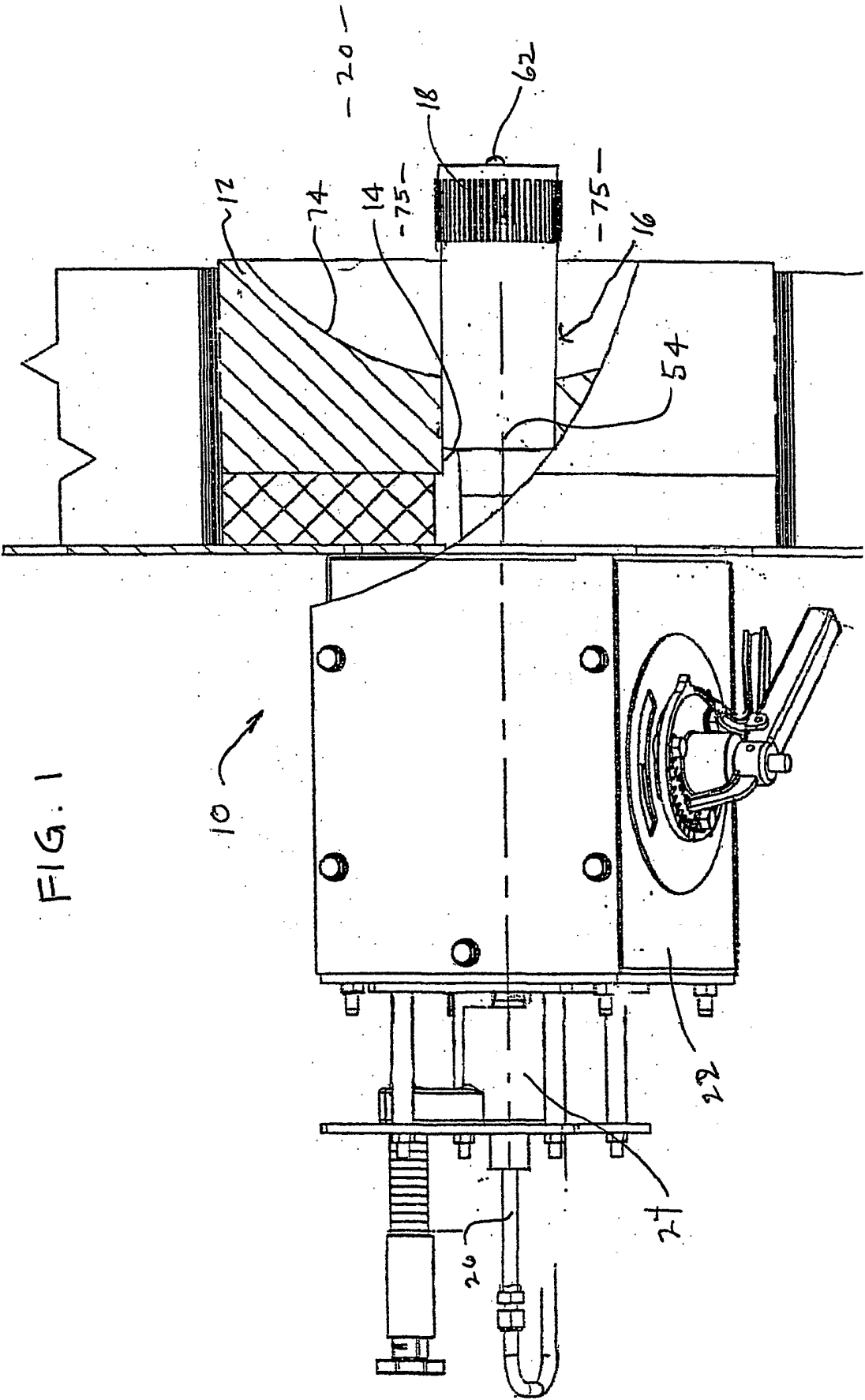
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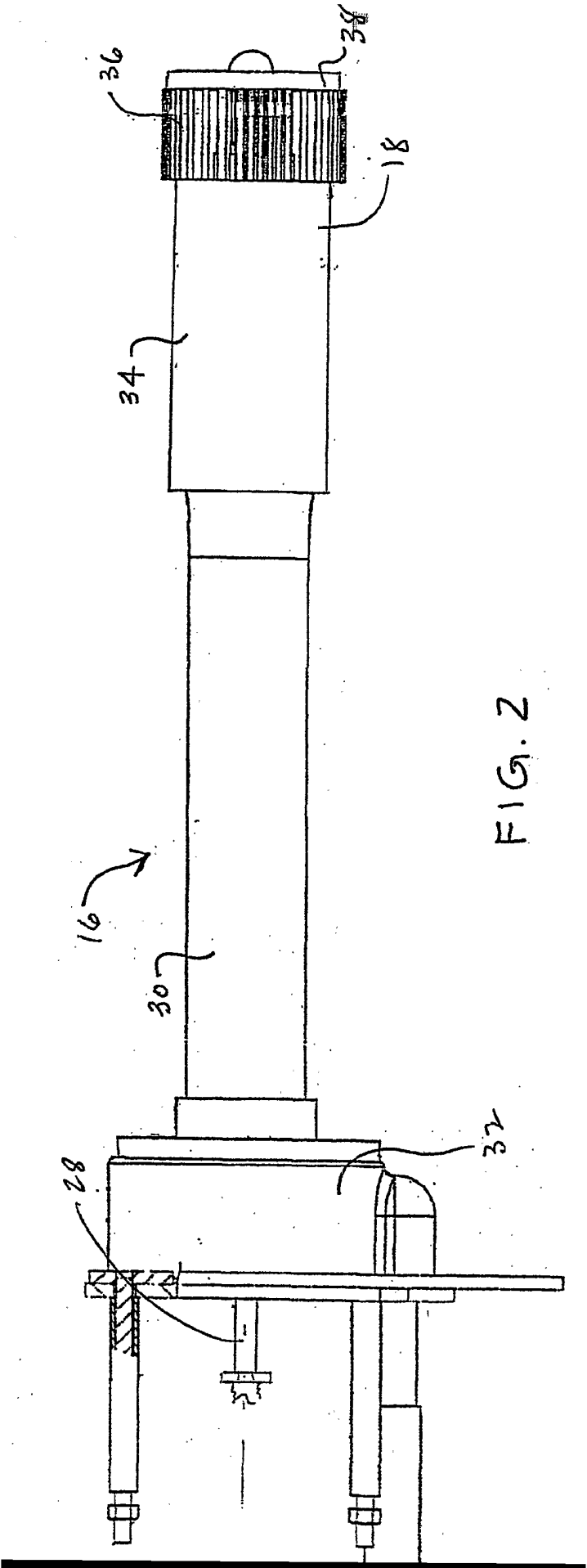
48. A method for operating a burner comprising: causing a mixture of fuel and air to flow toward a centrally located point adjacent a face of a burner tile; separating a first portion of said mixture into a plurality of separate streams and causing said streams to flow radially outwardly from said point across the face of said tile; causing said streams to combust to form flames, each having an outer peripheral terminus spaced radially from said point; providing a flow of recirculated flue gas to said flame at a location adjacent said termini; adding a second portion of said mixture to said recirculated flue gas at a location upstream from said location to create an admixture capable of flameless oxidation at the face of said tile; and flamelessly oxidizing said admixture at said face to create relatively cool oxidation products.

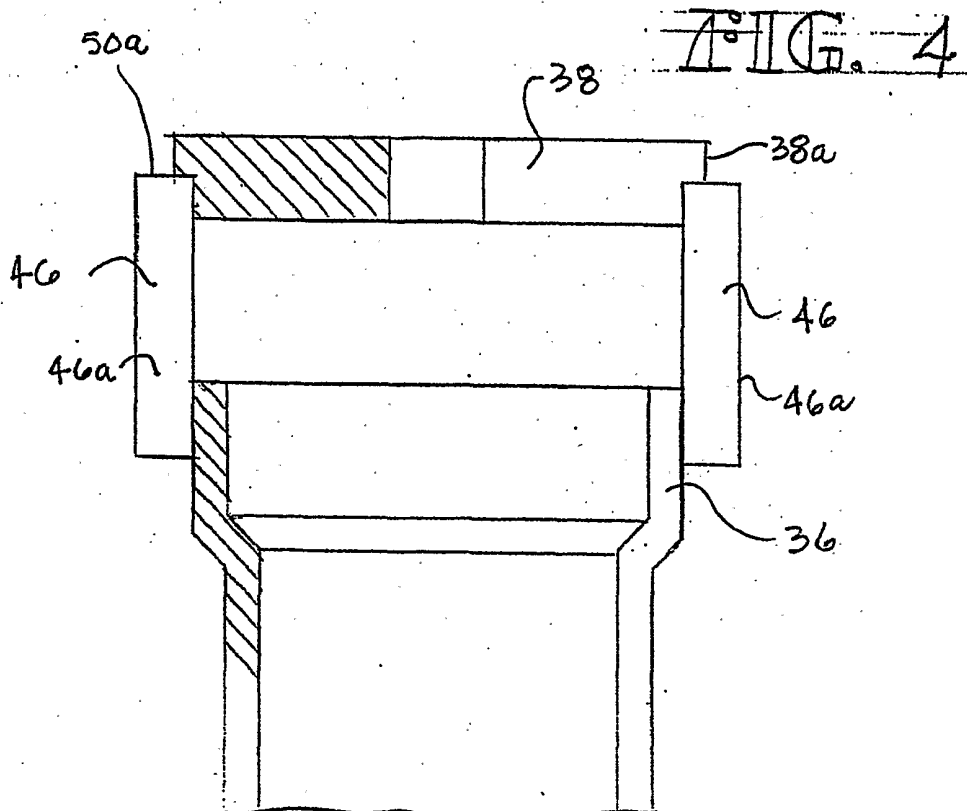
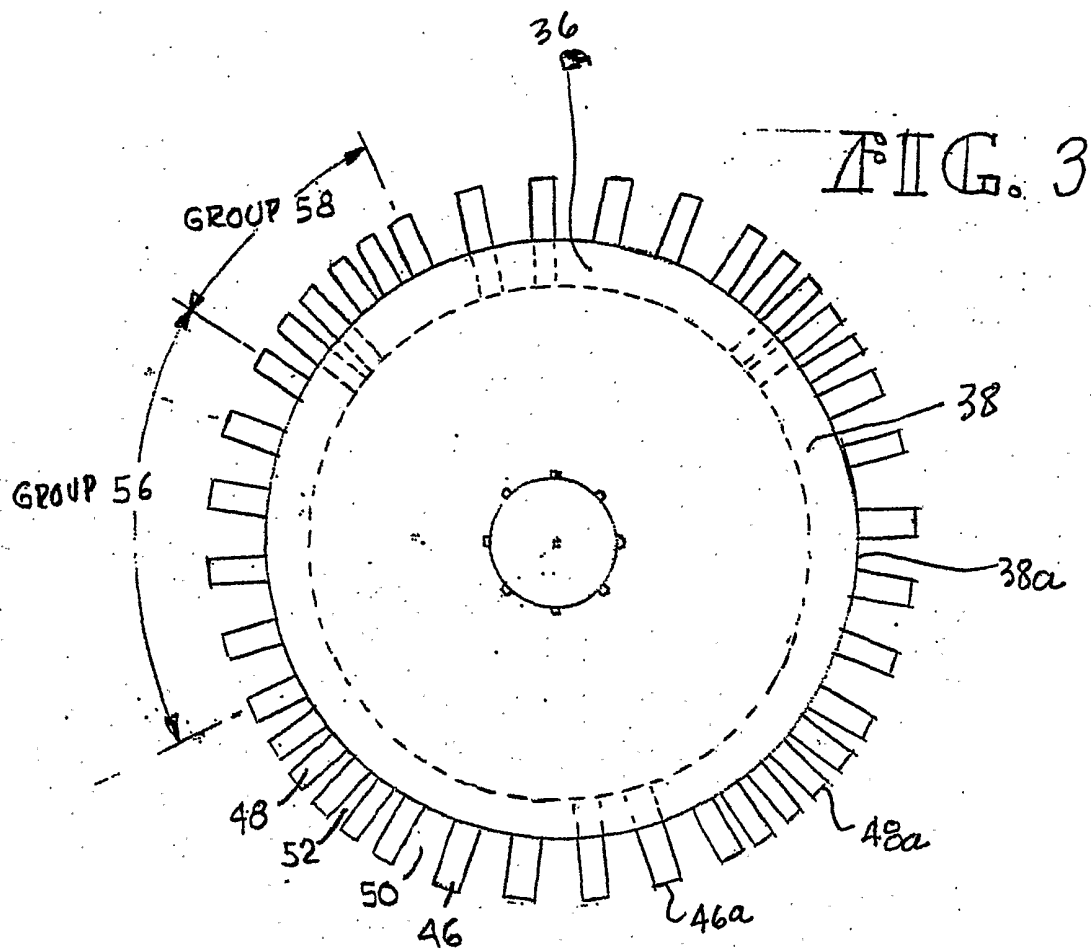
49. A method for operating a burner comprising: causing a mixture of fuel and air to flow toward a centrally located point adjacent a face of a burner tile; separating a first portion of said mixture into a plurality of separate streams and causing said streams to flow radially outwardly from said point across the face of said tile; causing said streams to combust to form flames, each having an outer peripheral terminus spaced radially from said point; providing a mixture of secondary air and recirculated flue gas to said flame at a location adjacent said termini; adding a second portion of said mixture of fuel and air to said mixture of secondary air and recirculated flue gas at a location upstream from said location to create an admixture capable of flameless oxidation at the face of said tile; and flamelessly oxidizing said admixture at said face to create relatively cool oxidation products.

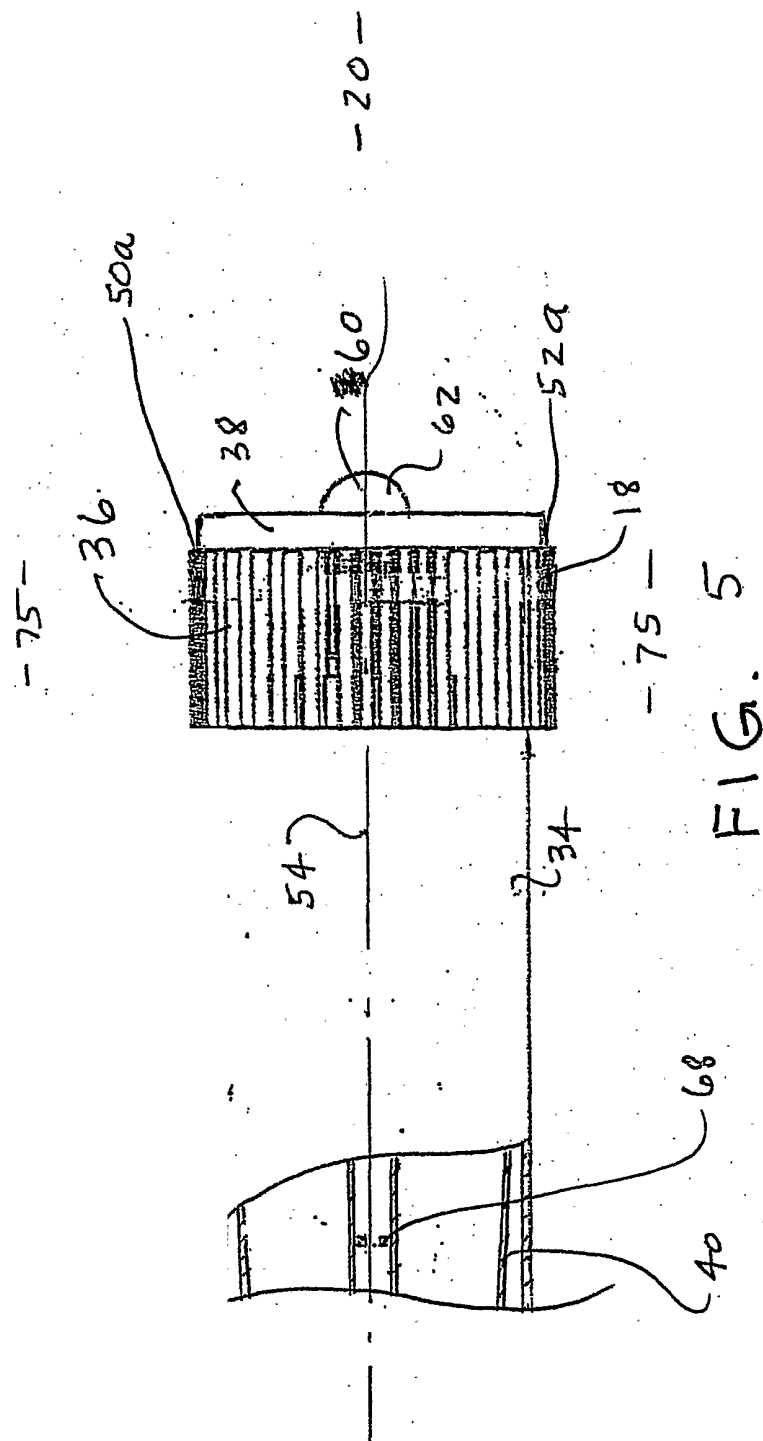
50. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 19, wherein said sheath includes one or more openings arranged to vent the sheath by allowing gases between the sheath and said portion of said length of tubing to escape into the combustion zone.

51. A low NO<sub>x</sub> burner nozzle assembly as set forth in claim 17, wherein said delivery orifice is disposed to eject fuel gas in a direction along said axis.











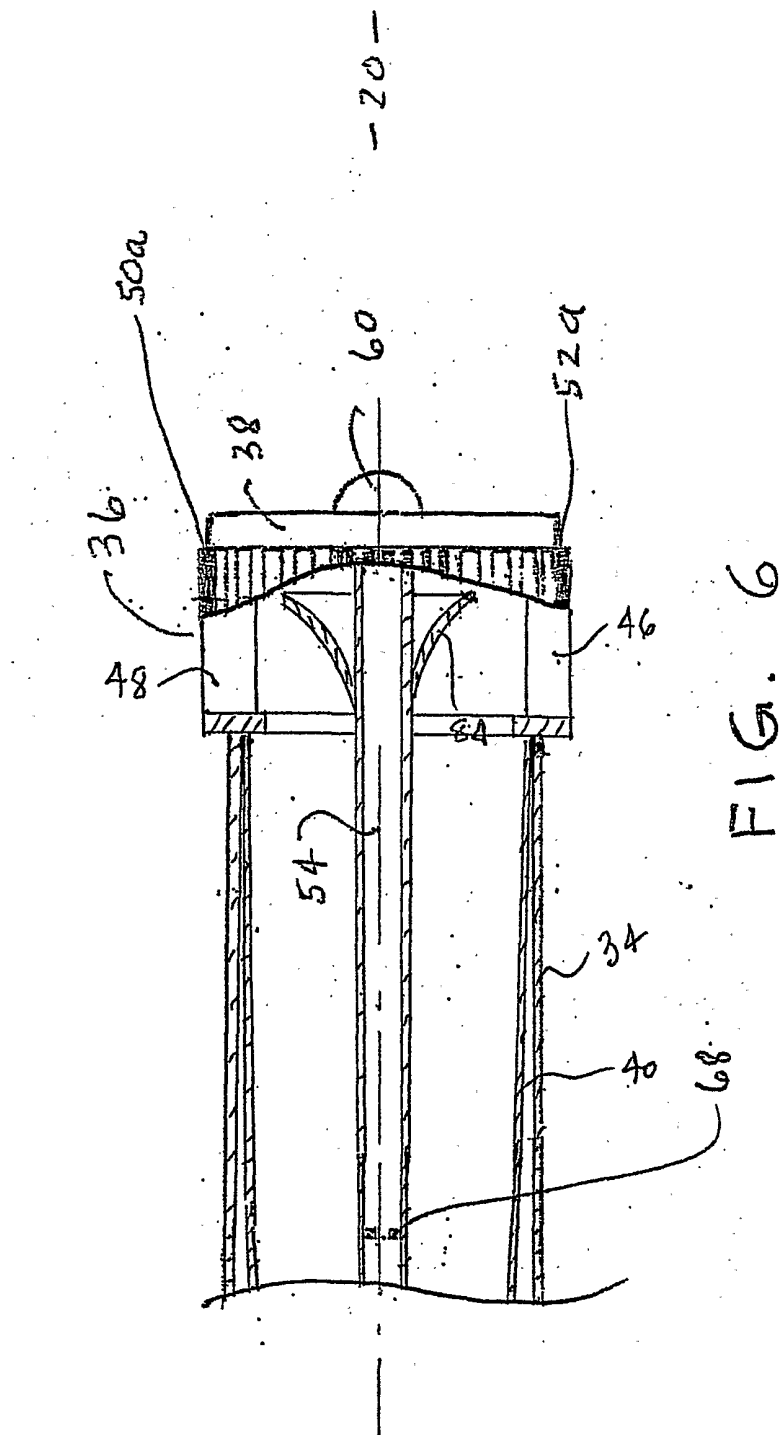
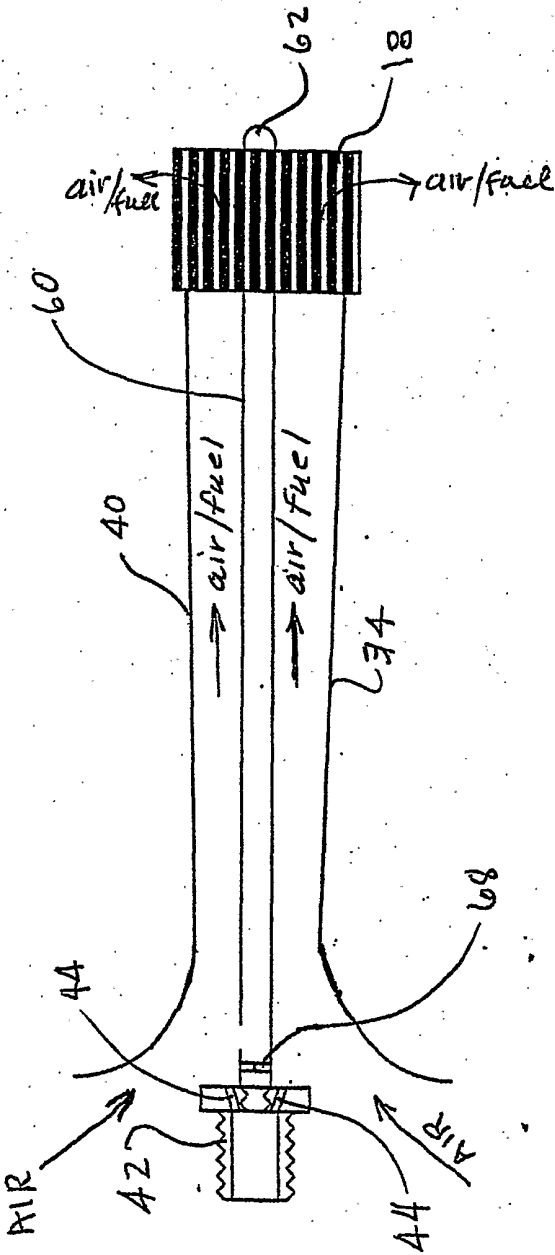
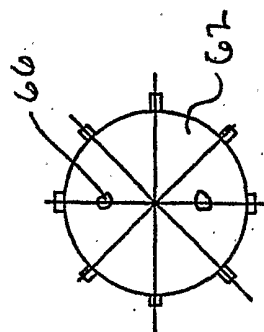
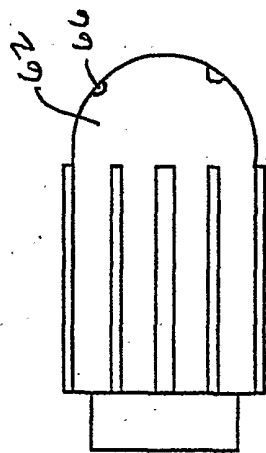
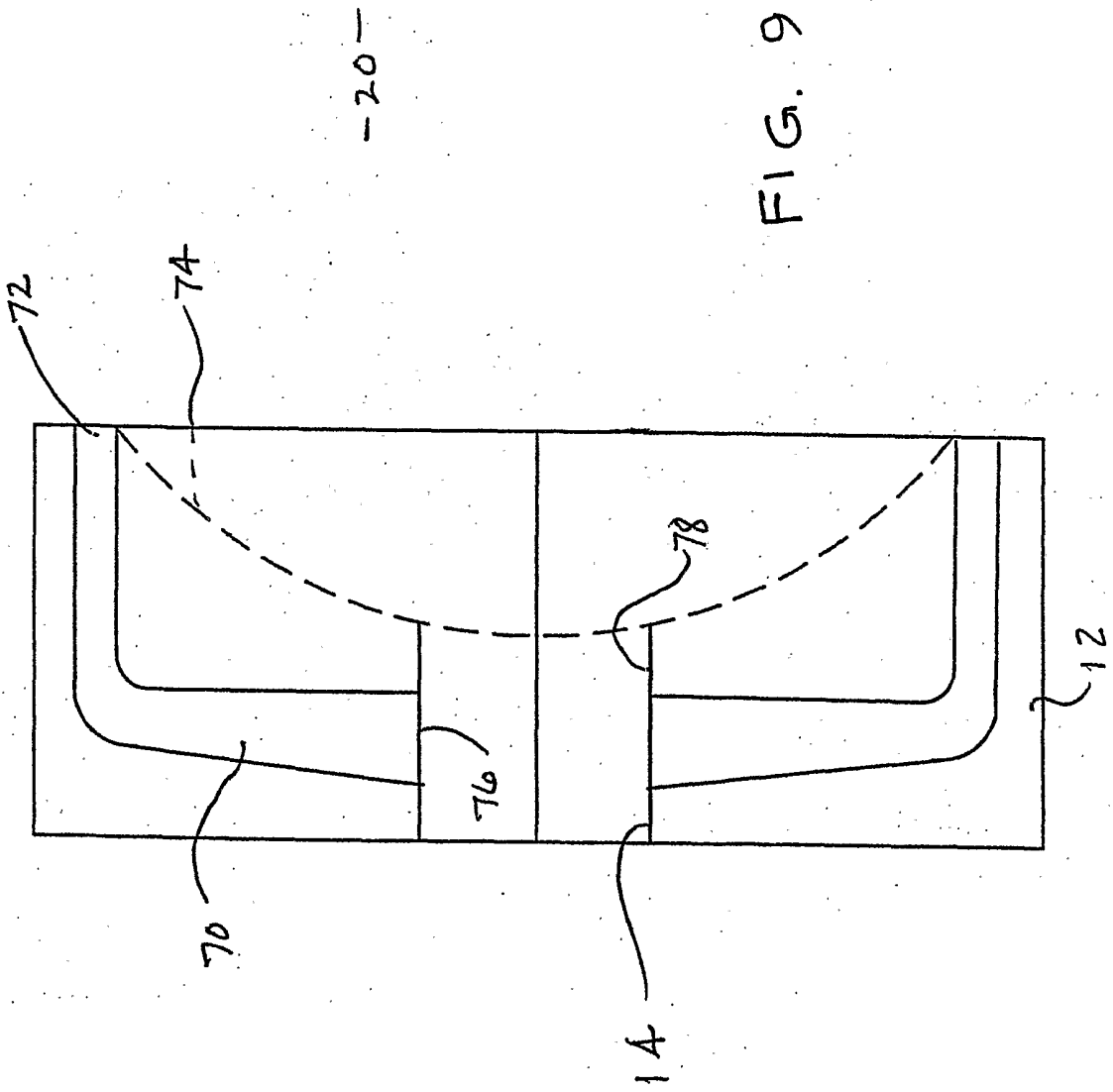


FIG. 7







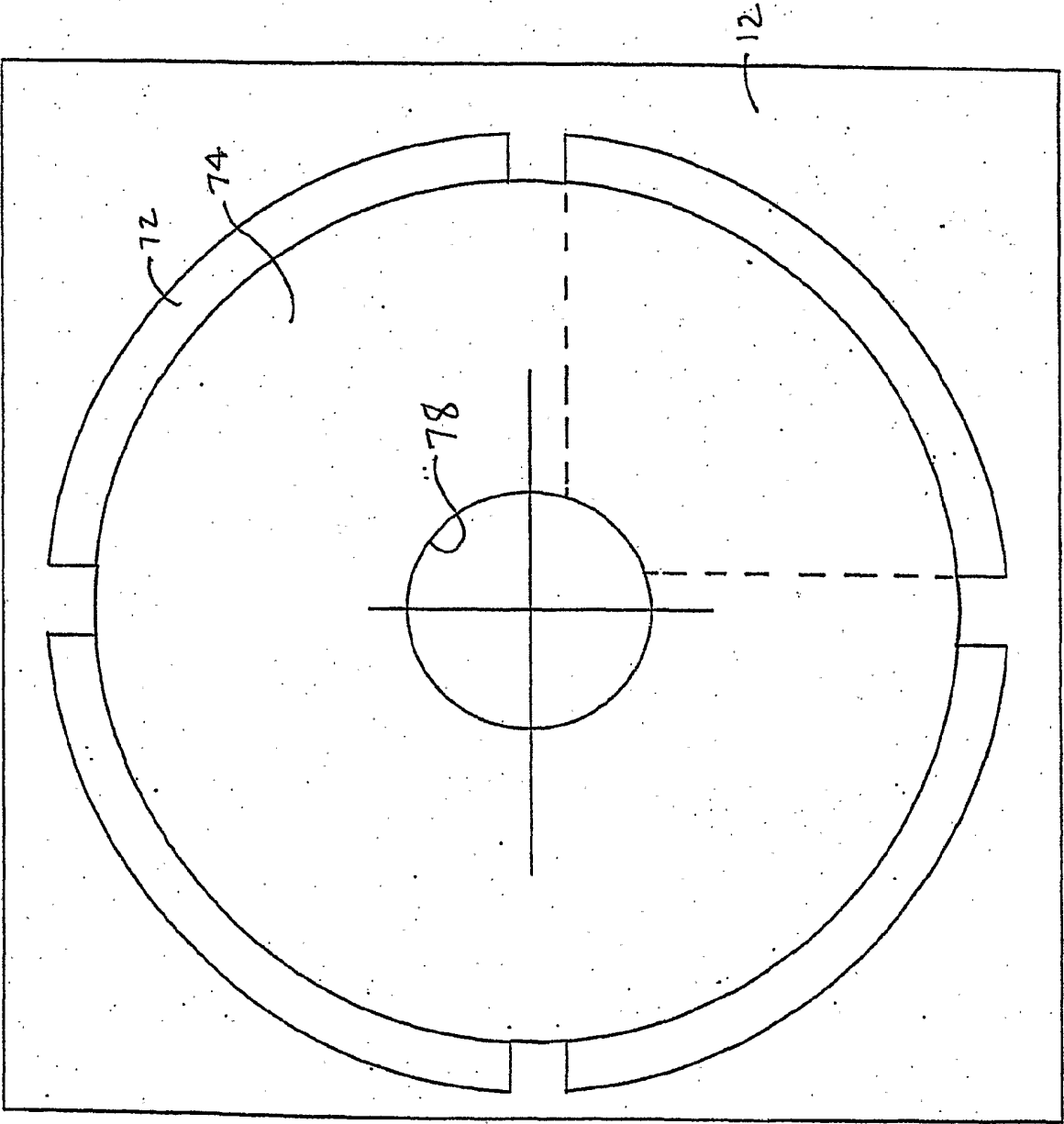
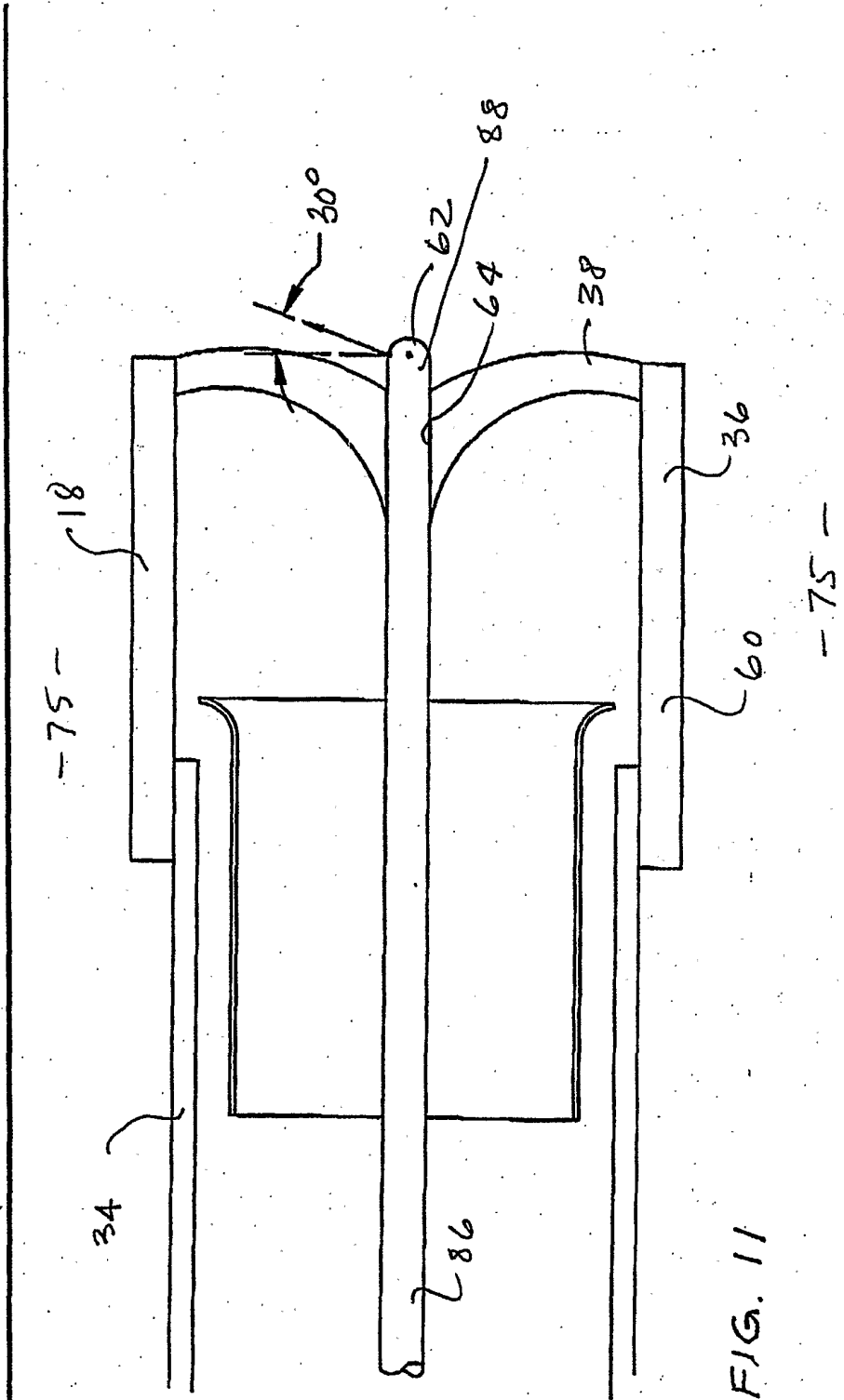


FIG. 10



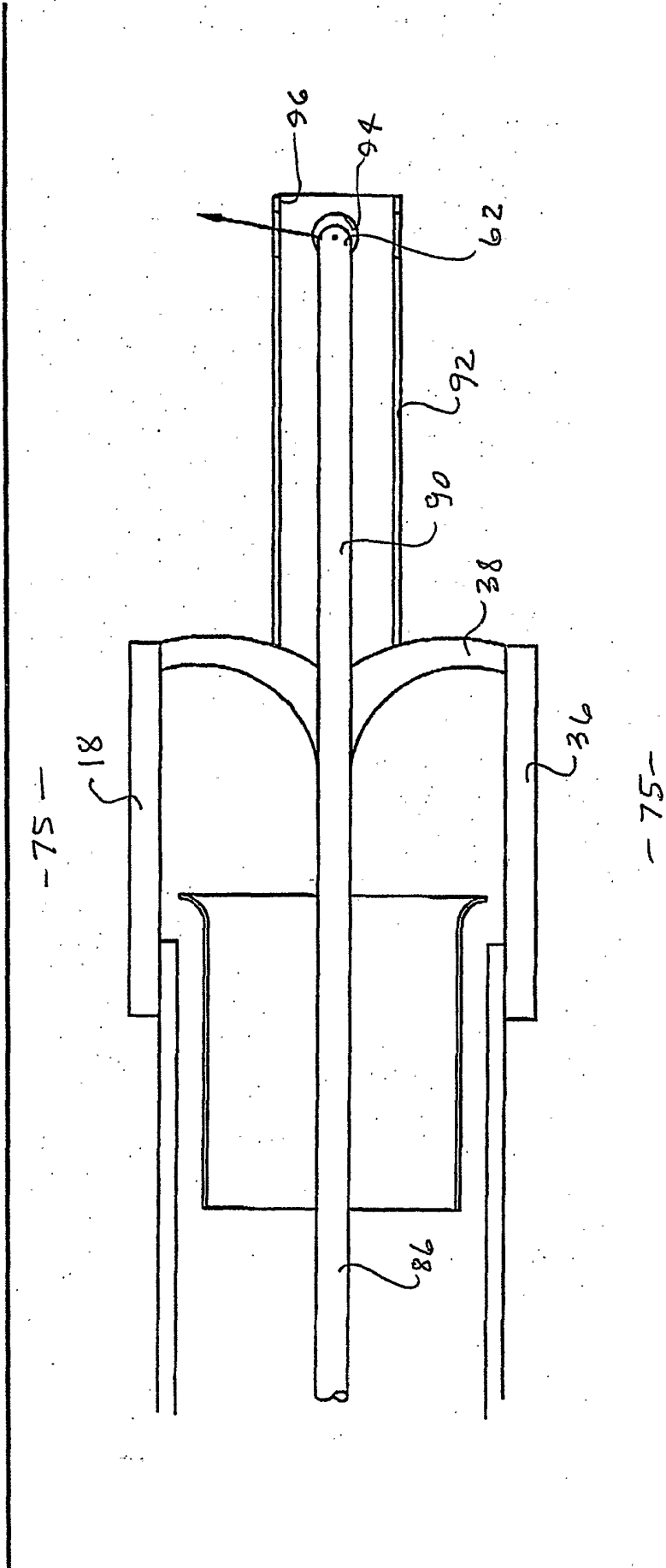


FIG. 12

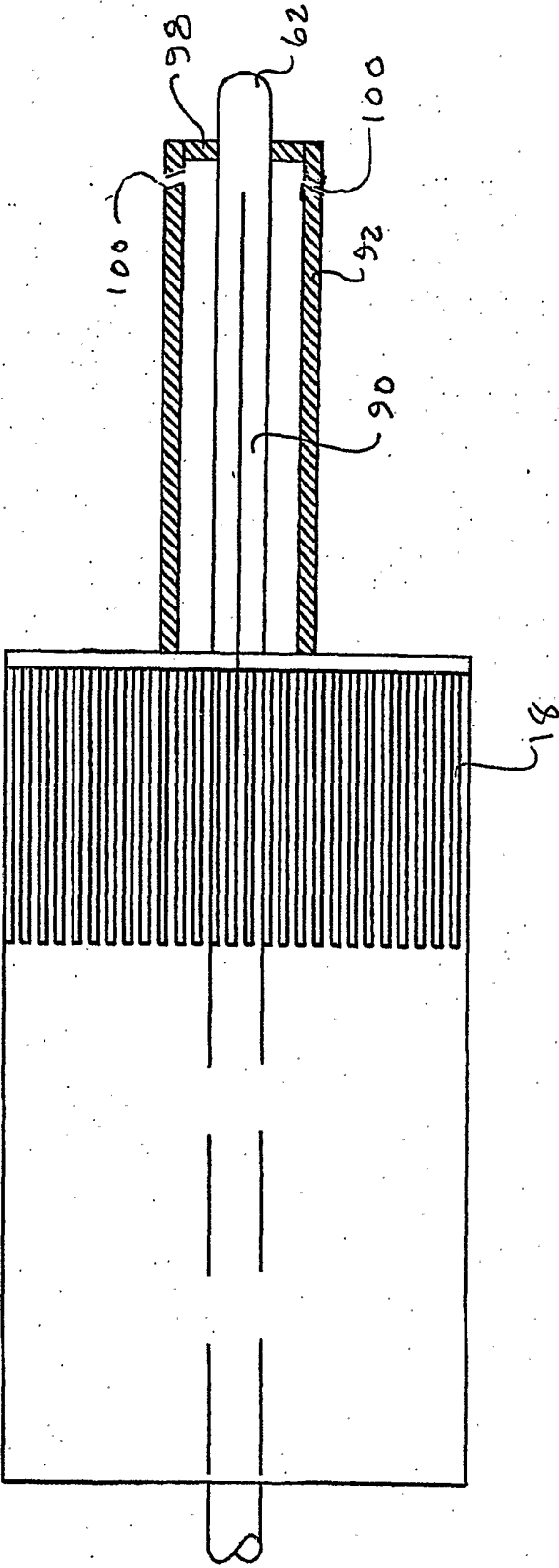


FIG. 13



FIG. 14

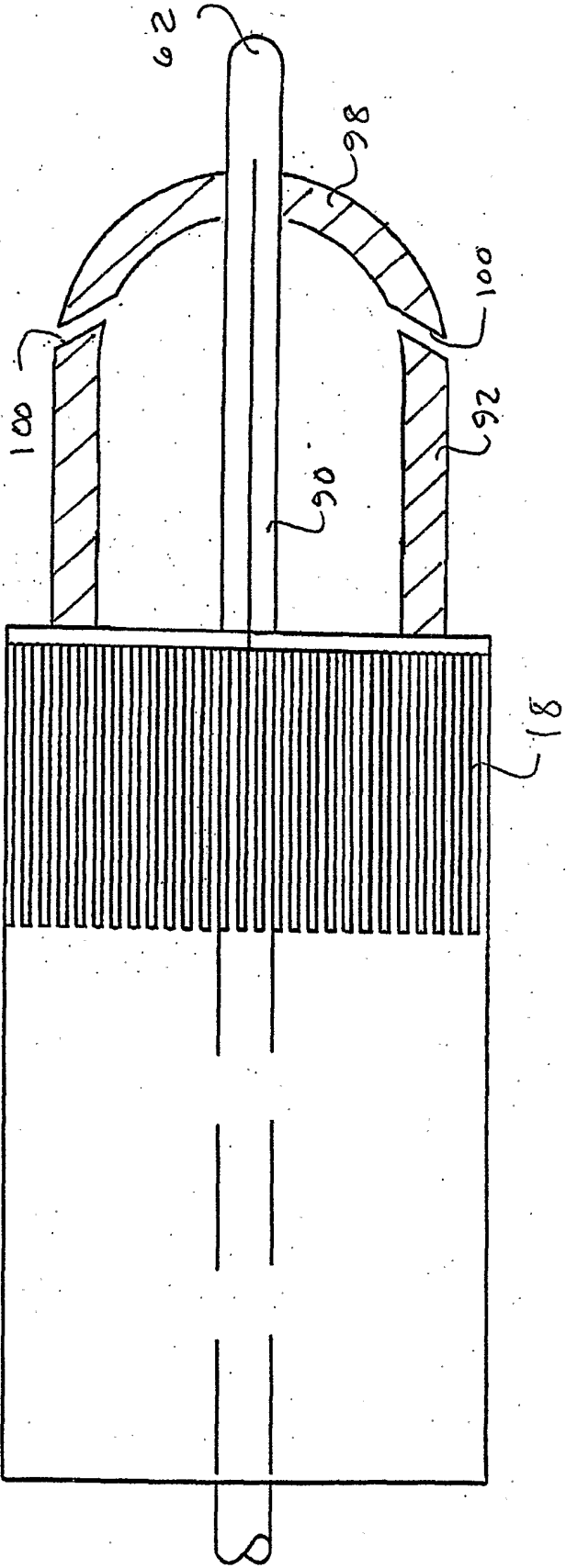
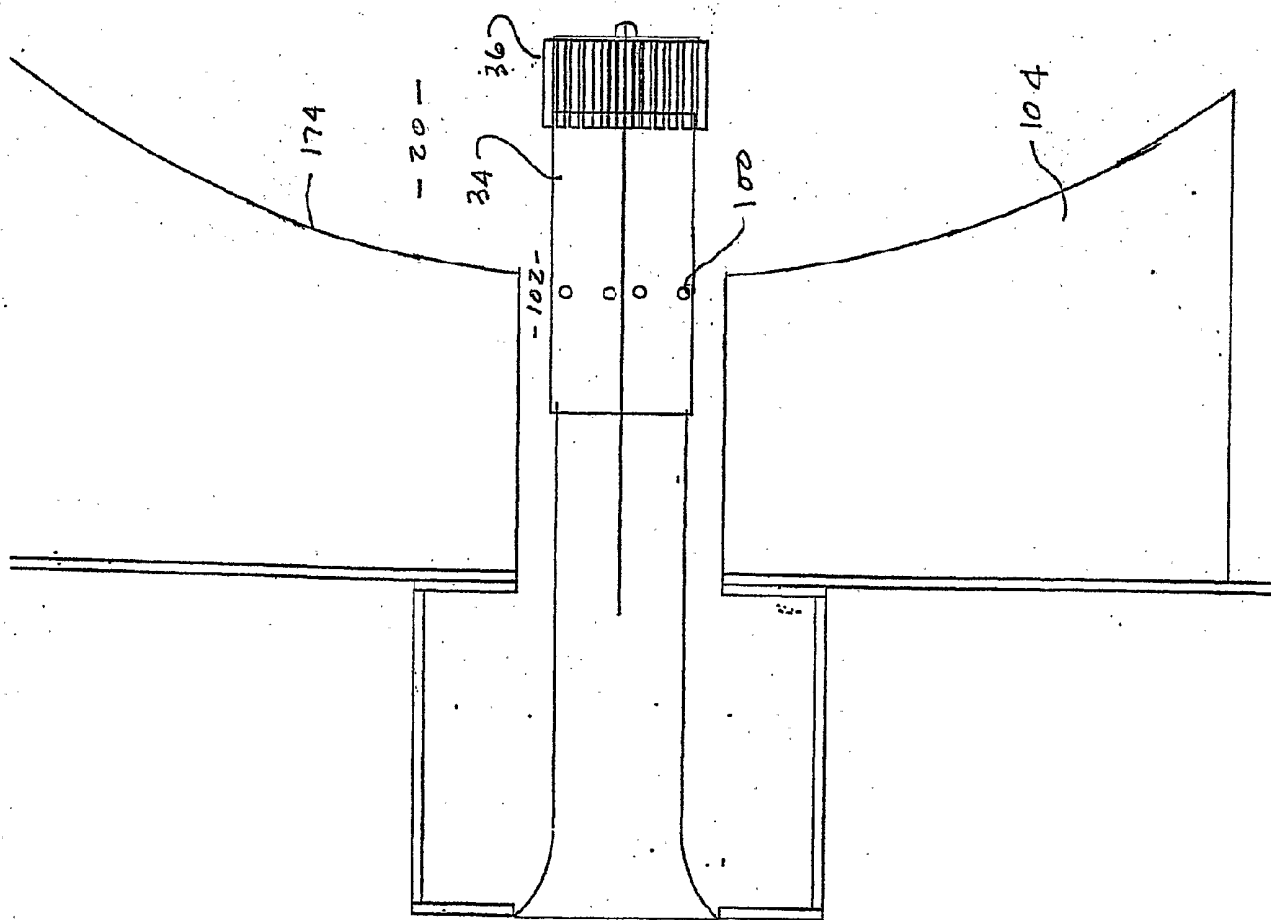


FIG. 15



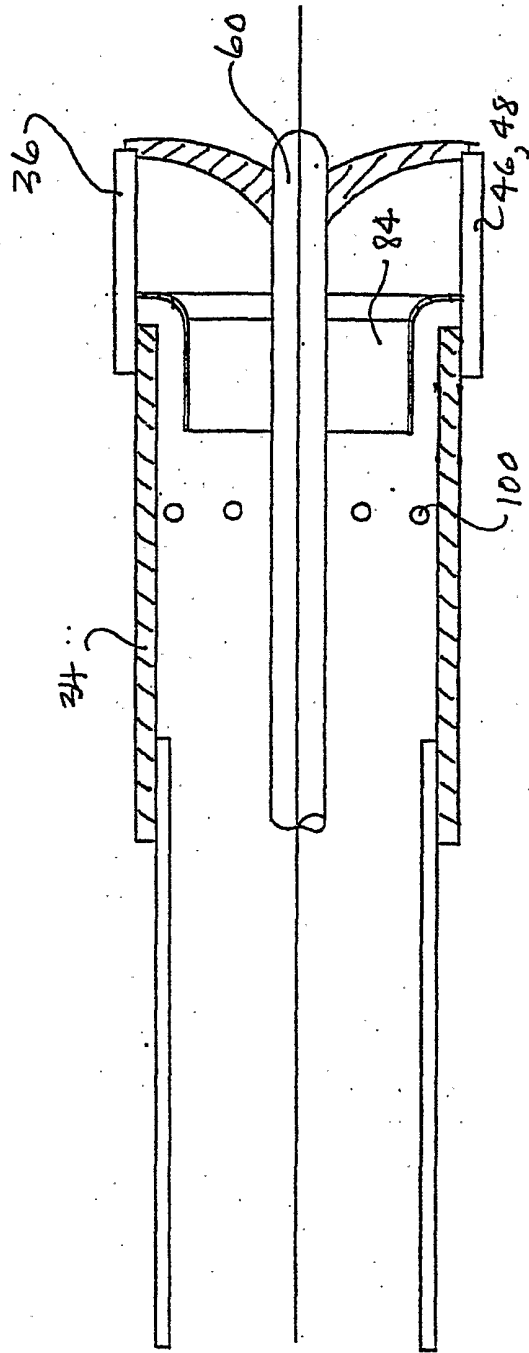


FIG. 16

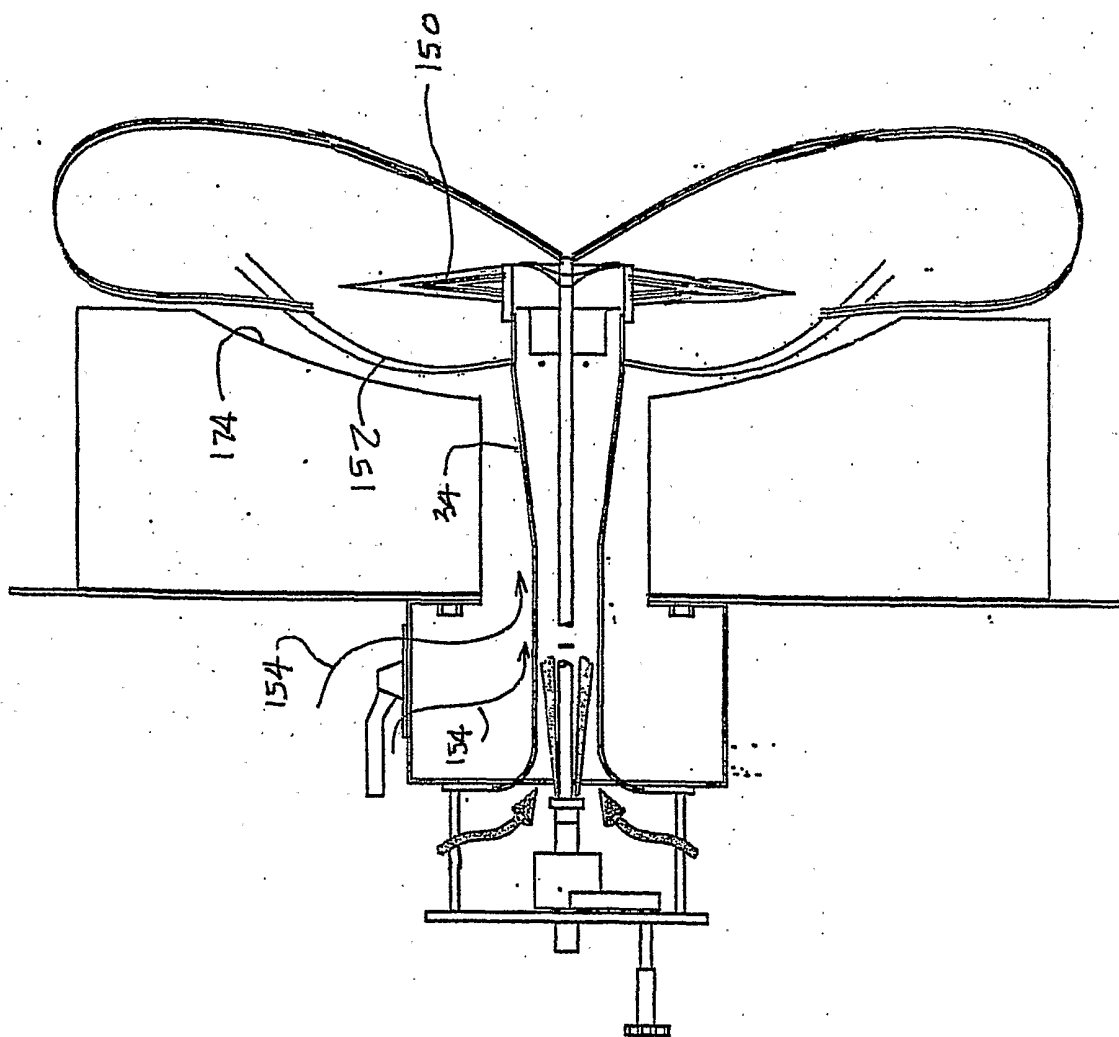


FIG. 17

# INTERNATIONAL SEARCH REPORT

International Application No

PC1/US 01/07809

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 F23D14/12 F23D14/06 F23C6/04 F23D14/48 F23M5/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 F23D F23C F23M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages  | Relevant to claim No.                               |
|------------|---|---|
| X          | US 5 271 729 A (VAN EERDEN JOHN J ET AL)<br>21 December 1993 (1993-12-21)   | 1, 4, 6, 7,<br>10-12,<br>16-18,<br>23, 24,<br>45-47 |
| Y          |   | 26  |
| A          | column 3, line 7 - line 60<br>column 4, line 5 - line 31<br>column 5, line 11 - line 62<br>column 6, line 56 - column 7, line 17<br>figure 1<br>---<br>-/-- | 21, 25,<br>28, 48, 49                               |

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### ° Special categories of cited documents :

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\*P\* document published prior to the international filing date but later than the priority date claimed

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\*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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\*&\* document member of the same patent family

Date of the actual completion of the international search

11 July 2001

Date of mailing of the international search report

20/07/2001

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## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/US 01/07809

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category °      | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No.   |
|-----------------|--|---|
| X<br><br>Y<br>A | US 4 257 762 A (GLOMM HORST M ET AL)<br>24 March 1981 (1981-03-24)<br><br>column 3, line 21 - line 66<br>column 4, line 27 - line 60<br>column 5, line 5 - line 31<br>figures 1,3<br>----- | 1,11,12,<br>23-25,<br>28,29,<br>31-37,<br>39-41,<br>43-46<br>26<br>17,47-49 |
| X<br><br>A      | US 3 684 424 A (ZINK JOHN SMITH ET AL)<br>15 August 1972 (1972-08-15)<br>column 1, line 66 -column 2, line 32<br>figure 1<br>-----   | 1,10-12,<br>23<br>17,28   |

# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/US 01/07809

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)   | Publication<br>date  |
|---|---------------------|--|--|
| US 5271729 A                              | 21-12-1993          | DE 4241883 A<br>CA 2107630 A<br>EP 0592081 A   | 16-06-1994<br>08-04-1994<br>13-04-1994   |
| US 4257762 A                              | 24-03-1981          | CA 1132038 A<br>DE 2935290 A<br>EP 0008842 A<br>JP 1304827 C<br>JP 55035895 A<br>JP 60029851 B | 21-09-1982<br>10-04-1980<br>19-03-1980<br>28-02-1986<br>13-03-1980<br>12-07-1985 |
| US 3684424 A                              | 15-08-1972          | NONE   |  |