

Description

Background of the Invention

[0001] The present invention relates to flare apparatus and methods of flaring flammable waste gases and diverted fuel stock. In one embodiment, the invention relates to ground flare burners, ground flares and associated methods.

[0002] Flare apparatus and methods are utilized to burn and dispose flammable waste gases and diverted fuel stock in a variety of applications. For example, flares are typically located at production facilities, refineries, processing plants and the like for disposing of flammable waste gases that are dumped and/or fuel stock streams that are diverted during venting, shut-downs, upsets or emergencies. The flaring of flammable waste gases and diverted fuel stock (hereinafter referred to as "fuel") without producing smoke is usually desirable or even mandatory. Smokeless flaring is accomplished by assuring that non-oxidized soot does not form in a sufficient quantity to leave the flame. This is accomplished by assuring that a sufficient amount of oxygen is mixed with the fuel to prevent a situation in which the mixture becomes too fuel rich to be effective.

[0003] In many applications, the length of the flame envelope created by the flare is also important. Examples of types of flares in which a relatively short flame envelope is desirable include aesthetic flares such as pit-type enclosed flares, ground flares and high pressure flares on floating production facilities. In such flares, it is often necessary to prevent the flames from being visible to the surrounding community. On the other hand, such flares need to have the capacity to combust a large volume of fuel at any given time. The length of the flame envelope tends to increase as the volume of fuel being flared increases.

[0004] Ground flares, also referred to as multi-point flares, are typically used in applications in which the amount of fuel to be flared at a given time can vary from a relatively small volume to a very high volume (for example, 1,000,000 pounds per hour or higher). In order to accommodate the variance in fuel volume and allow the fuel to be combusted in a smokeless manner, multiple stages of burners are utilized. The flow to each stage of burners is directed by a control system that is responsive to the pressure and volume of fuel to be flared. In this way, sufficient pressure is available to each burner in operation to assure that an appropriate amount of air is entrained and that sufficient mixing of the air and fuel occurs to ensure smokeless combustion in the range of application.

[0005] A ground flare system is typically spread out over a large area, for example, three acres, and surrounded by a large fence or other enclosure. The enclosure functions to exclude personnel and animals from the flame area and minimize radiation, visibility and noise to the surrounding area. The enclosure is typically made of

metal or some other heat refracting material and is from 20 to 60 feet high. As a result, the enclosure can be costly to erect and maintain.

[0006] The spacing of the burners and flow rate of fuel in a ground flare system is also important. The burners need to be close enough to one another for cross-lighting to occur and packed close enough in general to reduce the overall size of the system and the surrounding enclosure. For cost reasons, a minimal number of ignition pilots are desirable. Typical units include a single pilot at the end of each row of burners. On the other hand, the burners must not be so close to one another as to restrict air flow and hinder smokeless burning or cause the flames to coalesce into a ball of fire that exceeds the height of the enclosure. Also, the flow rate of the fuel must be controlled so that the height of the individual flames does not exceed the height of the enclosure.

[0007] One type of ground flare burner utilized heretofore includes a plurality of diffusion jets to distribute the fuel and draw in the air required for combustion. The jets are injected into the atmosphere at a sufficient velocity to draw combustion air into the jets. Upon ignition of the fuel, air from the surrounding environment is laterally entrained from above the discharge point of the fuel. As the velocity of the stream diminishes, the buoyancy effect of the hot gases then contributes to the overall mixing regimen of the fuel and air which allows combustion of the remaining fuel to be completed.

[0008] The overall flame envelope created by utilizing only diffusion jets to distribute the fuel and laterally entrain the air required for combustion includes a dense, central core of fuel. This central core of fuel remains intact until the outer portions of the flame envelope begin to burn off. As the outer portions of the flame envelope combust, air can then enter the inner confines of the flame envelope to complete the oxidation process. Unfortunately, due to the interaction of the individual fuel jets, the dense core of fuel formed at the center of the flame envelope makes it difficult to increase the flow rate of the fuel to support a larger capacity without causing the length of the flame envelope to increase and/or smoke to occur. An increase in the length of the flame envelope often requires the enclosure surrounding the ground flare to be higher which can significantly increase the cost of the enclosure.

[0009] By the present invention, a flare burner is provided which is useful in association with ground flares, high pressure flares and other types of flares. For example, the inventive flare burner overcomes the problems associated with the ground flare burners utilized heretofore. The invention also provides a ground flare apparatus and a method of burning fuel in a flare burner.

Summary of the Invention

[0010] In accordance with the invention, a flare burner is provided that is capable of combusting a high volume of fuel with a relatively short flame envelope. The decrease in the length of the flame envelope leads to many

advantages. For example, the height of the surrounding enclosure of a ground flare can be decreased or the volume of the fuel that can be flared with an existing enclosure height can be increased.

[0011] The inventive flare burner comprises a pre-mix zone including a pre-mix chamber, a supplemental fuel inlet for injecting fuel into the pre-mix zone, and a main fuel outlet. Preferably, the inventive flare burner further comprises a fuel feed conduit in fluid communication with the supplemental fuel inlet and the main fuel outlet.

[0012] The pre-mix chamber includes a top, a bottom and a sidewall connecting the top to the bottom. The sidewall includes an interior surface and an exterior surface. An air inlet is disposed in one of the bottom and the sidewall, and an air/fuel outlet is disposed in the top.

[0013] The supplemental fuel inlet is located in a position with respect to the pre-mix zone such that the injection of fuel from the supplemental fuel inlet into the pre-mix zone entrains air into the pre-mix zone whereby a mixture of fuel and air is formed in the pre-mix zone and caused to exit the air/fuel outlet of the pre-mix chamber.

[0014] The main fuel outlet is located in a position with respect to the top of the pre-mix chamber such that fuel can be injected from the main fuel outlet around the perimeter of the air/fuel outlet of the pre-mix chamber. In one embodiment, the main fuel outlet is spaced outwardly from the pre-mix chamber to provide a space between the exterior surface of the sidewall of the pre-mix chamber and the main fuel outlet. As discussed further below, this space allows fresh air to be entrained from below the burner to a point adjacent to the fuel ports disposed on an inner portion of the main fuel outlet. The enhanced mixing created by such entrainment can be important in certain applications, such as when heavy hydrocarbons or unsaturated fuels are being flared.

[0015] The fuel feed conduit conducts fuel to the supplemental fuel gas inlet and the main fuel gas outlet. The fuel can be supplied to the supplemental fuel inlet and the main fuel outlet at the same pressure or different pressures depending on the application.

[0016] The inventive flare burner can further comprise a fuel membrane disposed around the outside perimeter of the pre-mix chamber. The fuel membrane includes a fuel inlet and is in fluid communication with the main fuel outlet. In some embodiments, the fuel membrane is also in fluid communication with the supplemental fuel inlet. In order to provide the air entrainment space described above, the fuel membrane can be spaced outwardly from the exterior surface of the sidewall of the pre-mix chamber.

[0017] Depending on the particular configuration of the inventive flare burner, the pre-mix zone can consist of the pre-mix chamber alone or can include the pre-mix chamber together with areas below and/or above the actual pre-mix chamber. For example, when the air inlet of the pre-mix chamber is in the bottom of the pre-mix chamber and the supplemental fuel inlet is spaced below the

air inlet, the fuel and air begin to mix below the air inlet and pre-mix chamber. Also, the fuel and air typically continue to mix above the air/fuel outlet disposed in the top of the pre-mix chamber prior to ignition and combustion in the combustion zone.

[0018] The pre-mix chamber and fuel membrane can be formed in a variety of shapes and sizes. In one embodiment, the pre-mix chamber and fuel membrane have a round cross-section. In another embodiment, the pre-mix chamber and fuel membrane have a rectangular cross-section.

[0019] In order to enhance the entrainment of air caused by injecting fuel through the supplemental fuel inlet into the pre-mix zone, the interior surface of the pre-mix chamber can include a section that is a Coanda surface. The supplemental fuel inlet is located in a position with respect to the pre-mix chamber such that fuel can be injected from the supplemental fuel inlet onto the Coanda surface. The fuel tends to adhere to and follow the path of the Coanda surface and form into a relatively thin film which causes more air to be entrained into the pre-mix chamber and better mixing of the air with the fuel to occur in the pre-mix chamber.

[0020] The pre-mix chamber can have a length to inside hydraulic diameter ratio in the range of from about 0.25:1 to about 4:1. A unit with a pre-mix chamber having a length to inside hydraulic diameter ratio greater than 4:1 would function with an added benefit but would generally be cost prohibitive. In one embodiment, the pre-mix chamber has a length to inside hydraulic diameter ratio in the range of from about 1:1 to about 3:1. In another embodiment, the pre-mix chamber has a length to inside hydraulic diameter ratio of about 1:1 or less. A relatively short length of the pre-mix chamber can be advantageous in ground flare and other flare applications in which the length (or height) of the burner is important, or in applications in which highly reactive fuels might lead to internal burning. Also, in some configurations the fuel is injected from the supplemental fuel inlet under conditions (for example, a plurality of small jets; high pressure) that allow a uniform mixture of air and fuel to be achieved even when the pre-mix chamber has a very low length to inside hydraulic diameter ratio.

[0021] The inventive ground flare comprises a plurality of flare burners, a fence or other enclosure extending around the flare burners and a fuel supply line for supplying fuel to the flare burners. At least one of the flare burners is the inventive flare burner described above.

[0022] The invention also includes a method of flaring fuel with a flare burner wherein the fuel to be flared is injected through a fuel outlet of the burner into a combustion zone and ignited to create a flame envelope and combust the fuel. In accordance with the inventive method, a portion of the fuel is introduced into a pre-mix zone of the flare burner in a manner that entrains air into the pre-mix zone and creates a mixture of air and fuel within the pre-mix zone. The mixture of air and fuel is injected from the pre-mix zone into a central portion of the flame

envelope.

[0023] The amount of air entrained into the pre-mix zone and injected into the central portion of the flame envelope is preferably at least about 15% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone. In some applications, injection of a "fuel-rich" mixture of fuel and air (i.e., a mixture having less than 100% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone) into the central portion of the flame envelope is suitable. In most applications, however, injection of a "lean" mixture of fuel and air (i.e., a mixture having more than 100% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone) into the central portion of the flame envelope is desired. In most applications, the amount of air entrained into the pre-mix zone and injected into the central portion of the flame envelope is in the range of from about 125% to about 300% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone.

[0024] The amount of fuel introduced into the pre-mix zone is preferably in the range of from about 5% to about 50% of the total amount of fuel to be flared by the flare burner. Due to the injection of a pre-mixed fuel stream into a central portion of the flame envelope in accordance with the inventive method, the flame envelope includes combustion at its center as well as its outer surface. The resulting toroidal flame creates additional mixing and turbulence which results in more uniform and faster combustion of the flame envelope. As a result, the height of the flame envelope can be decreased or the volume of fuel that can be flared with a given flame envelope can be increased. Other advantages are achieved by the inventive flare burner and method as well.

[0025] It is, therefore, a general object of the present invention to provide a flare burner and associated method by which a high volume of fuel can be combusted in a relatively short and uniform flame envelope.

[0026] Other and further objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of preferred embodiments which follows when taken in conjunction with the accompanying drawings.

Brief Description of the Drawings

[0027] FIG. 1 is a front elevation view of a prior art ground flare burner.

[0028] FIG. 2 is a top view of the flare burner shown by FIG. 1.

[0029] FIG. 3 is a general depiction of the flame envelope created by the prior art flare burner shown by FIGS. 1 and 2.

[0030] FIG. 4 is a perspective view of a first embodiment of the inventive ground flare burner.

[0031] FIG. 5 is a sectional view taken along the line 5-5 of FIG. 4.

[0032] FIG. 6 is a top view of the burner shown by FIGS. 4 and 5.

[0033] FIG. 7 is a sectional view taken along the line 7-7 of FIG. 6 and showing optional risers or tip extensions.

[0034] FIG. 8 illustrates an alternative embodiment of an annular fuel injector body that can be utilized in association with the first, second and fourth embodiments of the inventive flare burner.

[0035] FIG. 9 is a perspective view of a second embodiment of the inventive flare burner.

[0036] FIG. 10 is a sectional view taken along lines 10-10 of FIG. 11.

[0037] FIG. 10A illustrates an alternative embodiment of the annular distribution manifold used in association with the second embodiment.

[0038] FIG. 11 is a top view of the flare burner shown by FIGS. 9 and 10.

[0039] FIG. 12 is a sectional view taken along lines 12-12 of FIG. 10.

[0040] FIG. 13 is a perspective view of a third embodiment of the inventive flare burner.

[0041] FIG. 14 is a sectional view taken along lines 14-14 of FIG. 13.

[0042] FIG. 15 is a top view of the flare burner shown by FIGS. 13 and 14.

[0043] FIG. 16 is a sectional view taken along lines 16-16 of FIG. 13 and showing optional risers or tip extensions.

[0044] FIG. 17 is a sectional view taken along lines 17-17 of FIG. 15.

[0045] FIG. 17A illustrates an alternative embodiment of the tubular distribution manifolds used in association with the third embodiment.

[0046] FIG. 18 is a sectional view taken along lines 18-18 of FIG. 14.

[0047] FIG. 19 is a perspective view of a fourth embodiment of the inventive flare burner.

[0048] FIG. 20 is a sectional view taken along lines 20-20 of FIG. 19.

[0049] FIG. 21 is a sectional view taken along lines 21-21 of FIG. 22 and showing an optional component of the burner.

[0050] FIG. 22 is a top view of the burner shown by FIGS. 19-21.

[0051] FIG. 23 illustrates an alternative embodiment of the supplemental fuel inlet of the burner shown by FIGS. 19-22.

[0052] FIG. 24 is a general depiction of the flame envelope created by each embodiment of the inventive flare burner.

[0053] FIG. 25 is a perspective view illustrating a modification that can be made to each embodiment of the inventive flare burner.

[0054] FIG. 26 is a sectional view taken along lines 26-26 of FIG. 25.

[0055] FIG. 27 is a top view of the burner shown by FIGS. 25 and 26.

[0056] FIG. 28 is a general depiction of the flame envelope created by each embodiment of the inventive flare burner as modified in the manner illustrated by FIGS. 25-27.

[0057] FIG. 29 is a schematic illustration of one embodiment of the inventive the ground flare.

Description of the Preferred Embodiments

[0058] Referring now to the drawings, and particularly to FIGS. 1-3, a prior art ground flare burner is illustrated and generally designated by the numeral 10. The prior art burner 10 includes a burner casting 12 attached to a fuel riser 14. The burner casting 12 includes a central portion 15 and a plurality of fuel outlet arms 16 concentrically arranged around the central portion and the top of the riser 14. Each fuel outlet arm 16 includes one or more fuel ports 18. Fuel is provided directly to the fuel ports 18, that is, the fuel is not first pre-mixed with air. As a result, the fuel jets created by the ports 18 are diffusion fuel jets.

[0059] FIG. 3 generally depicts a flame envelope 20 created by the burner 10. The fuel (generally depicted by black arrows) is injected into the combustion zone 22 through the ports 18 at a high velocity which draws air into the jets. Air from the surrounding environment is laterally entrained from above the discharge point of the fuel. As the velocity of the stream is diminished, the buoyancy effect of the hot gases then contributes to the overall mixing regimen of the fuel which allows combustion to be completed. The overall flame envelope 20 has a length 23 and includes a dense, central core of fuel 24. The central core of fuel 24 remains un-oxidized until the outer portions 26 of the flame 22 begin to burn off. Although the central portion of the flame envelope may include some air pockets 28, the amount of air in the air pockets is not sufficient to support homogenous combustion of the central core of fuel 24. The dense, central core of fuel 24 generally remains intact until sufficient attrition of the outer portions 26 of the fuel occurs to allow sufficient amounts of air to enter the inner confines of the flame envelope and allow completion of the oxidation process. Unfortunately, the dense core of fuel 24 in the center of the flame envelope 20 makes it difficult to increase the flow rate of the fuel to support a larger flame without causing the length of the flame to increase and/or smoke to occur.

The Inventive Flare Burner

[0060] Referring now to FIGS. 4-8, one embodiment of the inventive flare burner is illustrated and generally designated by the numeral 30. The flare burner 30 comprises a pre-mix zone 31 including a pre-mix chamber 32, and a supplemental fuel inlet 34 for injecting fuel into the pre-mix zone, a main fuel outlet 36 and a fuel feed conduit 38. As used herein and in the appended claims, "fuel" means the waste gas, diverted fuel stock and/or

other gas or liquid to be flared by the inventive flare burner, flare apparatus (for example, the inventive ground flare apparatus) and method. Liquids can form, for example, when the partial pressure of heavy unsaturated or saturated fuels is at or below saturated conditions. As shown by FIG. 4, a pilot 40 may be associated with the burner 30 (as well as the burners 130, 230 and 330 described below) to initially ignite the fuel and air mixture that is discharged by the burner.

[0061] In the embodiment illustrated by FIGS. 4-8, the pre-mix chamber 32 of the flare burner 30 provides the predominant portion of the pre-mix zone 31. A mixture (preferably a substantially homogenous mixture) of fuel and air can be formed in the pre-mix zone 31 including the pre-mix chamber 32. As discussed below, the mixture formed in the pre-mix zone 31 can be either fuel-rich or fuel-lean. The pre-mix chamber 32 includes a round cross-section and has a cylindrical shape. The pre-mix chamber includes a top 42, a bottom 44, a sidewall 46 connecting the top to the bottom, an air inlet 48 disposed in the bottom 44 and an air/fuel outlet 50 disposed in the top 42. As shown, the top 42 and bottom 44 are open thereby forming the air inlet 48 and air/fuel outlet 50. As a result, the air inlet 48 and air/fuel outlet 50 each also have a round cross-section. A lower portion 52 of the pre-mix chamber 32 is flared outwardly to impart a bell (well-rounded) shape to the lower section to enhance the rate of flow of the incoming fuel and air. Alternatively, the lower portion 52 of the pre-mix chamber 32 is not flared outwardly, i.e., the entire pre-mix chamber has a uniform cylindrical shape. As best shown by FIG. 5, the pre-mix zone 31 includes a pre-mix space 31 (a) below the pre-mix-chamber 32 (between the supplemental fuel inlet 34 and the bottom 44 and air inlet 48 of the pre-mix chamber), the interior 31 (b) of the pre-mix chamber, and a pre-mix space 31(c) immediately above the top 42 and air/fuel outlet 50 of the pre-mix chamber. In the embodiment shown by FIGS. 4-9, the primary mixing of the pre-mix air and fuel occurs in the interior 31(b) of the pre-mix chamber 32 and in the pre-mix space 31(c).

[0062] The pre-mix chamber 32 has a length (or height) to inside hydraulic diameter ratio in the range of from about 0.25:1 to about 4:1, preferably about 1:1 to about 3:1. The exact ratio of the length (or height) to inside hydraulic diameter of the pre-mix chamber 32 will depend in part on the type of fuel to be flared and the pressure available for entrainment and mixing. Generally, a longer pre-mix chamber can result in better mixing of fuel and air therein; however, this advantage is balanced against cost and other considerations. In a preferred embodiment, the length (or height) to inside hydraulic diameter ratio of the pre-mix chamber 32 is approximately 1.5:1. As used herein and in the appended claims, "inside hydraulic diameter" means four (4) times the area within the pre-mix chamber divided by the perimeter of the interior surface of the sidewall of the pre-mix chamber.

[0063] The supplemental fuel inlet 34 is located in a position with respect to the pre-mix zone 31 such that

the injection of fuel from the supplemental fuel inlet into the pre-mix zone entrains air into the pre-mix space 31 (a) and through the air inlet 48 into the pre-mix chamber 32 whereby a mixture, preferably a substantially homogeneous mixture, of fuel and air is formed in the pre-mix zone and caused to exit the air/fuel outlet 50 in the top 42 of the pre-mix chamber. The fuel and air continue to mix in the pre-mix space 31 (c). Combustion of the mixture of fuel and air does not typically occur until the mixture exits the air/fuel outlet 50, generally a detached distance from the air/fuel outlet. The distance from the air/fuel outlet 50 at which combustion occurs varies due to the amount of air in the mixture and the velocity at which the mixture is discharged from the air/fuel outlet. In some cases, due to short de-stage timing sequences, combustion can occur in the pre-mix zone (for example, in short duration, very low pressure scenarios). As shown by FIGS. 6 and 7, the supplemental fuel inlet 34 comprises a central fuel injector 54 having one or more fuel ports 58 therein.

[0064] An annular fuel membrane 60 is disposed around the outside perimeter of the pre-mix chamber 32. The fuel membrane 60 is connected to the fuel feed conduit 38 and in fluid communication with the main fuel outlet 36. The fuel membrane 60 comprises an open top 62, a bottom 64, and an external sidewall 66 and internal sidewall 67 connecting the top to the bottom. In the embodiment shown by FIGS. 4-8, the internal sidewall 67 of the membrane 60 is also the sidewall 46 of the pre-mix chamber 32. An annular seal 68 is attached to the bottom 64 of the fuel membrane 60 and extends around the sidewall 46 of the pre-mix chamber 32 to ensure the integrity of the membrane. In an alternate embodiment, as exemplified by FIGS. 25-28 and explained below, the fuel membrane 60 can be spaced outwardly from the sidewall 46 of the pre-mix chamber 32 in order to provide an annular space between the exterior surface of the sidewall 46 and the main fuel outlet 36. The annular space allows air to be entrained from below the burner to a point adjacent to the fuel ports 74 disposed on an inner portion of the main fuel outlet 36. In this embodiment, the internal sidewall 67 of the membrane 60 is separate from the sidewall 46 of the pre-mix chamber 32.

[0065] The main fuel outlet 36 is located in a position with respect to the top 42 of the pre-mix chamber such that fuel can be injected from the main fuel outlet 36 around the perimeter 69 of the air/fuel outlet 50 of the pre-mix chamber. As best shown by FIG. 6, the main fuel outlet 36 comprises a flat, annular fuel injector body 70 having a plurality of fuel ports 74 therein. The fuel jets created by the ports 74 are diffusion fuel jets. The annular fuel injector body 70 is attached to the open top 62 of the annular membrane 60 such that the fuel ports 74 are disposed around the perimeter 69 of the air/fuel outlet 50 of the pre-mix chamber. The inside and outside diameters of the annular membrane 60 and annular fuel injector body 70 are approximately the same. Fuel can be annularly injected from the main fuel outlet 36 (i.e., the annular

fuel injector body 70) around the perimeter 69 of the air/fuel outlet 50. The ports 74 can be sized and spaced to control the manner (e.g., direction and velocity) in which the fuel is injected from the ports. This feature in conjunction with the flow of fuel and air through the air/fuel outlet 50 allows the shape and length of the overall flame envelope to be controlled.

[0066] As shown by FIG. 7, if desired, the diffusion fuel ports 74 can be spaced from the fuel injector body 70 by a plurality of corresponding short gas risers or tip extensions 76. Spacing the ports 74 from the fuel injector body 70 with the risers 76 can result in better lateral entrainment of air in some applications. The risers also allow the configurations of the ports and resulting fuel flow properties to be mechanically changed if necessary.

[0067] An alternative embodiment of the annular fuel injector body 70 is shown by FIG. 8. In this embodiment, a plurality of fuel ports 74 is strategically spaced around the outside, inside and middle of the fuel injector body 70. Spacing of the fuel ports 74 around the fuel injector body 70 in this manner allows entrainment corridors between the jets to be utilized for better mixing and entrainment. As understood by those skilled in the art, the injector body 70 can include various iterations of the ports 74. The particular port configuration utilized will depend on various factors including the type of fuel to be flared (including the molecular weight, heating value, stoichiometry and temperature of the stream) and available pressure in connection therewith.

[0068] The fuel feed conduit 38 is in fluid communication with the supplemental fuel inlet 34 and the main fuel outlet 36 for conducting fuel thereto. The fuel feed conduit 38 includes a main branch 80 having a first end 82 and a second end 84. The first end 82 includes a flange 86 for connecting the first end to a source of the fuel (as understood by those skilled in the art, these types of connections are more typically made by welding the pipe sections directly together or with some other mechanical connection that does not require gaskets; e.g., the gaskets between corresponding flanges generally cannot withstand the radiant heat in the surrounding environment). The second end 84 is connected to a corresponding inlet 88 in the external sidewall 66 of the fuel membrane 60. The fuel feed conduit 38 also includes a supplemental branch 90 which connects the fuel feed conduit to the supplemental fuel inlet 34. The supplemental branch 90 includes a first end 92 and a second end 94. The first end 92 is connected to the main branch 90 of the feed conduit 38. A coupling 96 connects the second end 94 to the supplemental fuel inlet 34. Alternatively, separate fuel feed conduits or risers can conduct fuel to the supplemental fuel inlet 34 and main fuel outlet 36 (as opposed to the single integrated conduit or riser 38). The separate conduits or risers will typically run from a common fuel header.

[0069] Referring to FIG. 5, operation of the flare burner 30 will be described. A portion of the fuel to be flared (generally depicted by black arrows) is conducted

through the main branch 80 of the fuel feed conduit 38 to the fuel membrane 60 and to the main fuel outlet 36. A portion of the fuel to be flared is also conducted from through the supplemental branch 90 of the fuel feed conduit 38 to the supplemental fuel inlet 34. The injection of fuel from the supplemental fuel inlet 34 into the pre-mix zone 31 and pre-mix chamber 32 entrains air into the pre-mix space 31 (a) and through the air inlet 48 into the interior 31(b) of the pre-mix chamber whereby a mixture (preferably a substantially homogenous mixture) of fuel and air is formed in the pre-mix zone and caused to exit the air/fuel outlet 50. The fuel and air continue to mix for a short distance above the air/fuel outlet 50. The remaining fuel to be flared is annularly injected from the main fuel outlet 36 around the perimeter 69 of the air/fuel outlet 50 of the pre-mix chamber and hence around the air/fuel mixture exiting the air/fuel outlet of the pre-mix chamber. The burner is preferably designed and operated in a manner such that the amount of air entrained into the pre-mix zone 31 including the pre-mix chamber 32 is in excess of the stoichiometric amount of air required to combust the fuel injected into the pre-mix zone. The excess air is imparted to the center of the flame envelope for combustion of fuel therein. As explained further below, however, in some applications the burner is designed and operated in a manner such that the amount of air entrained into the pre-mix zone 31 including the pre-mix chamber 32 is equal to or less than the stoichiometric amount of air required to combust the fuel injected into the pre-mix zone (although it is still flammable). The injection of a "fuel-rich" mixture of fuel and air (i.e., a mixture having less than the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone) into the central portion of the flame envelope is desirable in some applications.

[0070] FIG. 24 generally depicts the flame envelope 100 created by the flare burner 30 (as well as the burners 130, 230 and 330 described below). As shown, excess air is injected from the pre-mix chamber 32 into a center portion 102 of the flame envelope 100. The excess air, depicted by air pockets 103 in FIG. 24 mixes with fuel in the center portion 102 of the flame envelope 100 to form, in effect, two initial zones of flammability, zone 104(a) and 104(b). The fuel in the center portion 102 of the flame would otherwise not encounter oxidizer (air) until the outer portions 105 of the flame envelope begin to combust, allowing the next layers of fuel access to the air. Supplying air to the center portion 102 of the flame envelope 100 not only creates a middle zone of flammability but also breaks the flame apart as the inner combustion zone expands under the heat of combustion. The addition of a distinct combusting flame inside the larger main flame adds significant turbulence to enhance mixing and break up the central core of fuel. As a result, more uniform and faster combustion of the flame envelope occurs which shortens the overall length of the flame or allows significantly more fuel to be flared with the same flame length. As the amount of excess air imparted to the center portion

102 of the flame envelope 100 increases, the length of the flame decreases or the volume of fuel that can be flared at a given flame height increases. For example, as shown by FIG. 24, the flame envelope 100 has a length 106 that is substantially less for the same amount of fuel than the length 23 of the prior art flame envelope 20 shown by FIG. 3.

[0071] Referring now to FIGS. 9-12, a second embodiment of the inventive flare burner is illustrated and generally designated by the reference numeral 130. Like the other embodiments of the inventive flare burner, the flare burner 130 comprises a pre-mix zone 131 including a pre-mix chamber 132, and a supplemental fuel inlet 134 for injecting fuel into the pre-mix zone, a main fuel outlet 136 and a fuel feed conduit 138. A pilot (as shown by FIG. 4) may be associated with the burner 130 to initially ignite the fuel and air mixture that is discharged by the burner.

[0072] In the embodiment illustrated by FIGS. 9-12, the pre-mix chamber 132 of the flare burner 130 provides the predominant portion of the pre-mix zone 131. A mixture (preferably a substantially homogenous mixture) of fuel and air can be formed in the pre-mix zone 131 including the pre-mix chamber 132. As discussed below, the mixture formed in the pre-mix zone 131 can be either fuel-rich or fuel-lean. The pre-mix chamber 132 includes a round cross-section and has a cylindrical shape. It includes a top 142, a bottom 144, a sidewall 146 connecting the top to the bottom, an air inlet 148 disposed in the bottom 144 and an air/fuel outlet 150 disposed in the top. As shown, the top 142 and bottom 144 are open thereby forming the air inlet 148 and air/fuel outlet 150. As a result, the air inlet 148 and air/fuel outlet 150 each also have a round cross-section.

[0073] As best shown by FIG. 10, the pre-mix zone 131 includes a pre-mix space 131(a) below the pre-mix-chamber 132 (between the supplemental fuel inlet 134 and the bottom 144 and air inlet 148 of the pre-mix chamber), the interior 131 (b) of the pre-mix chamber, and a pre-mix space 131(c) immediately above the top 142 and air/fuel outlet 150 of the pre-mix chamber. In the embodiment shown by FIGS. 9-12, the primary mixing of the air and fuel occurs in the interior 131 (b) of the pre-mix chamber 132 and in the pre-mix space 131 (c). The sidewall 146 of the pre-mix chamber 132 includes an interior surface 154 and an exterior surface 156. A lower section 158 of the sidewall 146 is flared outwardly in a curvilinear manner to impart an annular Coanda surface 160 to the interior surface 154 of the sidewall.

[0074] The pre-mix chamber 132 has a length (or height) to inside hydraulic diameter ratio in the range of from about 0.25:1 to 4:1, preferably about 1:1 to about 3:1. The exact ratio of the length (or height) to inside hydraulic diameter of the pre-mix chamber 132 will depend in part on the type of fuel to be flared and the pressure available for entrainment and mixing. Generally, a longer pre-mix chamber can result in better mixing of fuel and air therein; however, this advantage is balanced

against cost and other considerations. In a preferred embodiment, the length (or height) to inside hydraulic diameter ratio of the pre-mix chamber 132 is approximately 1.5:1.

[0075] The supplemental fuel inlet 134 is located in a position with respect to the pre-mix zone 131 such that the injection of fuel from the supplemental fuel inlet into the pre-mix zone entrains air into the pre-mix space 131 (a) and through the air inlet 148 into the pre-mix chamber whereby a mixture, preferably a substantially homogeneous mixture, of fuel and air is formed in the pre-mix zone and caused to exit the air/fuel outlet 150 in the top 142 of the pre-mix chamber. The fuel and air continue to mix in the pre-mix space 131(c). Combustion of the mixture of fuel and air does not typically occur until the mixture exits the air/fuel outlet 150, generally a detached distance from the air/fuel outlet. The distance from the air/fuel outlet 150 at which combustion occurs varies due to the amount of air in the mixture and the velocity at which the mixture is discharged from the air/fuel outlet. In some cases, due to short de-stage timing sequences, combustion can occur in the pre-mix zone (for example, in short duration, very low pressure scenarios). As shown by FIGS. 10 and 12, the supplemental fuel gas inlet 134 comprises an annular distribution manifold 164 having a plurality of fuel ports 166 therein. The fuel ports 166 are substantially round apertures. As shown by FIG. 10, the annular distribution manifold 164 is located in a position with respect to the pre-mix chamber 132 such that fuel can be annularly injected from the manifold 164 onto the annular Coanda surface 160.

[0076] FIG. 10A illustrates an alternative embodiment of the annular distribution manifold 164. In this embodiment, the fuel ports 166 are elongated apertures or slots. The slotted shape of the fuel ports 166 causes the fuel to be injected onto the annular Coanda surface 160 in a sheeted pattern which serves to enhance the entrainment and mixing effect created by the Coanda surface and allows the fuel to be injected from the manifold 164 at a higher rate. If desired, the slots 166 can be connected to form continuous elongated apertures or slots in the distribution manifold 164.

[0077] An annular fuel membrane 170 is disposed around the outside perimeter of the pre-mix chamber 132. The fuel membrane 170 is connected to the fuel feed conduit 138 and in fluid communication with both the main fuel outlet 136 and the supplemental fuel inlet 134. The fuel membrane 170 comprises an open top 172, a bottom 174, and an external sidewall 176 and internal sidewall 177 connecting the top to the bottom. In the embodiment shown by FIGS. 9-12, the internal sidewall 177 is also the sidewall 146 of the pre-mix chamber. An annular seal 178 is attached to the bottom 174 of the fuel membrane 170 and extends around the sidewall 146 of the pre-mix chamber 132 to ensure the integrity of the membrane. In an alternate embodiment, as exemplified by FIGS. 25-28 and explained below, the fuel membrane 170 can be spaced outwardly from the sidewall 146 of

the pre-mix chamber 132 in order to provide an annular space between the exterior surface of the sidewall 146 and the main fuel outlet 136. The annular space allows air to be entrained from below the burner to a point adjacent to the fuel ports 192 disposed on an inner portion of the main fuel outlet 136. In this embodiment, the internal sidewall 177 of the membrane 170 is separate from the sidewall 146 of the pre-mix chamber 132.

[0078] Supplemental fuel feed conduits 180(a), 180(b), 180(c) and 180(d) extend from the annular fuel membrane 170 to the supplemental fuel inlet 134 (i.e., to the annular distribution manifold 164) to deliver fuel from the fuel membrane 170 to the inlet 134 (i.e., the manifold 164). Each of the supplemental fuel feed conduits 180 (a), 180(b), 180(c) and 180(d) includes a first end 182 attached to the membrane 170 and a second end 184 attached to the inlet 134 (i.e., the manifold 164).

[0079] The main fuel outlet 136 is located in a position with respect to the top 142 of the pre-mix chamber 132 such that fuel can be injected from the main fuel outlet around the perimeter 186 of the air/fuel outlet 150 of the pre-mix chamber. As best shown by FIG. 11, the main fuel outlet 136 comprises a flat, annular fuel injector body 188 having a plurality of fuel ports 192 therein. The fuel jets created by the ports 192 are diffusion fuel jets. The annular fuel injector body 188 is attached to the open top 172 of the annular membrane 170 such that the fuel ports 192 are disposed around the perimeter 186 of the air/fuel outlet 150 of the pre-mix chamber 132. The inside and outside diameters of the annular membrane 170 and annular fuel injector body 188 are approximately the same. Fuel can be annularly injected from the main fuel outlet 136 (i.e., the annular fuel injector body 188) around the perimeter 186 of the air/fuel outlet 150. The ports 192 can be sized and spaced to control the manner (e.g., direction and velocity) in which the fuel is injected from the ports. This feature in conjunction with the flow of fuel and air through the air/fuel outlet 150 allows the shape and length of the overall flame envelope to be controlled.

[0080] As shown by FIG. 7, if desired, the diffusion fuel ports 192 can be spaced from the fuel injector body 188 by a plurality of corresponding short gas risers or tip extensions 196. Spacing the ports 192 from the fuel injector body 188 with the risers 196 can result in better lateral entrainment of air in some applications. The risers also allow the configurations of the ports and resulting fuel flow properties to be mechanically changed if necessary. The alternative embodiment of the fuel injector body 70 shown by FIG. 8 may also be used in lieu of the annular fuel injector body 188. As understood by those skilled in the art, the injector body 188 can include various iterations of the ports 192. The particular port configuration utilized will depend on various factors including the type of fuel to be flared (including the molecular weight, heating value, stoichiometry and temperature of the stream) and available pressure in connection therewith.

[0081] The fuel feed conduit 138 is in fluid communication with the supplemental fuel inlet 134 and the main

fuel outlet 136 for conducting fuel thereto. The fuel feed conduit 138 has a first end 200 and a second end 202. The first end 200 includes a flange 204 for connecting the first end to a source of the fuel (again, these types of connections are more typically made by welding). The second end 202 is connected to a corresponding inlet 206 in the external sidewall 176 of the annular gas membrane 170. Alternatively, separate fuel feed conduits or risers can conduct fuel to the supplemental fuel inlet 134 and main fuel outlet 136 (as opposed to the single integrated conduit or riser 138). The separate conduits or risers will typically run from a common fuel header.

[0082] Referring to FIG. 10, operation of the burner 130 will be described. Fuel to be flared (generally depicted by black arrows) is conducted through the fuel feed conduit 138 to the annular gas membrane 170. A portion of the fuel is conducted by the fuel membrane 170 to the main fuel outlet 136 (i.e., the annular injector body 188). The remaining portion of the fuel is conducted by the membrane 170 through the fuel feed conduits 180(a), 180(b), 180(c) and 180(d) to the supplemental fuel inlet 134 (i.e., the annular distribution manifold 164). Fuel is injected from the fuel ports 166 of the annular distribution manifold 164 through the pre-mix space 131 (a) onto the annular Coanda surface 160 on the interior surface 154 of the pre-mix chamber 132. The injection of fuel from the gas ports 166 into the pre-mix zone 131 and pre-mix chamber 132 entrains air into the pre-mix space 131 (a) and through the air inlet 148 into the interior 131(b) of the pre-mix chamber whereby a mixture (preferably a substantially homogenous mixture) of fuel and air is formed in the pre-mix zone and caused to exit the air/fuel outlet 150. The fuel and air continue to mix for a short distance above the air/fuel outlet 150. Injection of the fuel from the fuel ports 166 onto the Coanda surface 160 causes the fuel to adhere to and follow the path of the Coanda surface and form into a relatively thin film which results in a more efficient entrainment of the air and mixing of the air with the fuel. The fuel to be flared is injected from the main fuel outlet 136 (the annular injector body 188) around the perimeter 186 of the air/fuel outlet 150 of the pre-mix chamber 132 and hence around the air/fuel mixture exiting the air/fuel outlet 150 of the pre-mix chamber. The flare burner 130 is preferably designed and operated in a manner such that the amount of air entrained into the pre-mix zone 131 including the pre-mix chamber 132 is in excess of the stoichiometric amount of air required to combust the fuel injected into the pre-mix zone. The excess air is imparted to the center of the flame envelope for combustion of fuel therein. As explained further below, however, in some applications the burner is designed and operated in a manner such that the amount of air entrained into the pre-mix zone 131 including the pre-mix chamber 132 is equal to or less than the stoichiometric amount of air required to combust the fuel injected into the pre-mix zone. The injection of a "fuel-rich" mixture of fuel and air (i.e., a mixture having less than the stoichiometric amount of air required to sup-

port combustion of the fuel introduced into the pre-mix zone) into the central portion of the flame envelope is desirable in some applications.

[0083] The flare burner 130 achieves the same advantages that are achieved by the flare burner 30. The flame envelope 100 generally depicted by FIG. 24 is also created by the flare burner 130.

[0084] Referring now to FIGS. 13-18, a third embodiment of the inventive flare burner is illustrated and generally designated by the reference numeral 230. Like the other embodiments of the inventive flare burner, the flare burner 230 comprises a pre-mix zone 231 including a pre-mix chamber 232, and a supplemental fuel inlet 234 for injecting fuel into the pre-mix zone, a main fuel outlet 236 and a fuel feed conduit 238. A pilot (as shown by FIG. 4) may be associated with the burner 130 to initially ignite the fuel and air mixture that is discharged by the burner.

[0085] In the embodiment illustrated by FIGS. 13-18, the pre-mix chamber 232 of the flare burner 230 provides the predominant portion of the pre-mix zone 231. A mixture (preferably a substantially homogenous mixture) of fuel and air can be formed in the pre-mix zone 231 including the pre-mix chamber 232. As discussed below, the mixture formed in the pre-mix zone 231 can be either fuel-rich or fuel-lean. The pre-mix chamber 232 includes a rectangular cross-section and has a rectangular shape. It includes a top 242, a bottom 244, a sidewall 246 connecting the top to the bottom, an air inlet 248 disposed in the bottom 244 and an air/fuel outlet 250 disposed in the top. As shown, the top 242 and bottom 244 are open thereby forming the air inlet 248 and air/fuel outlet 250. As a result, the air inlet 248 and air/fuel outlet 250 each also have a rectangular cross-section.

[0086] As best shown by FIG. 14, the pre-mix zone 231 includes a pre-mix space 231(a) below the pre-mix-chamber 232 (between the supplemental fuel inlet 234 and the bottom 244 and air inlet 248 of the pre-mix chamber), the interior 231 (b) of the pre-mix chamber, and a pre-mix space 231 (c) immediately above the top 242 and air/fuel outlet 250 of the pre-mix chamber. In the embodiment shown by FIGS. 13-18, the primary mixing of the air and fuel occurs in the interior 31 (b) of the pre-mix chamber 232 and in the pre-mix space 231 (c).

[0087] The sidewall 246 of the pre-mix chamber 232 includes four sides 246(a), 246(b), 246(c) and 246(d). Each of the sides 246(a), 246(b), 246(c) and 246(d) includes an interior surface 254 and an exterior surface 256. A lower portion 258 of each of the sides 246(a), 246 (b), 246(c) and 246(d) is flared outwardly in a curvilinear manner to impart an annular Coanda surface 260 to the interior surface 254 of the side. The pre-mix chamber 232 has a length (or height) to inside hydraulic diameter ratio in the range of from about 0.25:1 to 4:1, preferably about 1.1 to about 3:1. The exact ratio of the length (or height) to inside hydraulic diameter of the pre-mix chamber 232 will depend in part on the type of fuel to be flared and the pressure available for entrainment and mixing.

Generally, a longer pre-mix chamber can result in better mixing of fuel and air therein; however, this advantage is balanced against cost and other considerations. In a preferred embodiment, the length (or height) to inside hydraulic diameter ratio of the pre-mix chamber 232 is approximately 1.5:1.

[0088] The supplemental fuel inlet 234 is located in a position with respect to the pre-mix zone 231 such that the injection of fuel from the supplemental fuel inlet into the pre-mix zone entrains air into the pre-mix space 231 (a) and through the air inlet 248 into the pre-mix chamber 232 whereby a mixture, preferably a substantially homogeneous mixture, of fuel gas and air is formed in the pre-mix zone and caused to exit the air/fuel outlet 250 in the top 242 of the pre-mix chamber. Combustion of the mixture of fuel and air does not typically occur until the mixture exits the air/fuel outlet 250, generally a detached distance from the air/fuel outlet. The distance from the air/fuel outlet 250 at which combustion occurs varies due to the amount of air in the mixture and the velocity at which the mixture is discharged from the air/fuel outlet. In some cases, due to short de-stage timing sequences, combustion can occur in the pre-mix zone (for example, in short duration, very low pressure scenarios).

[0089] As best shown by FIG. 18, the supplemental fuel inlet 234 comprises two tubular distribution manifolds 264(a) and 264(b), each having a plurality of fuel ports 266 therein. The fuel ports 266 are substantially round apertures. The distribution manifold 264(a) is located in a position with respect to the pre-mix chamber 232 such that fuel can be injected from the manifold 264(a) onto the Coanda surface 260 on the interior surface 254 of the side 246(a). Similarly, the distribution manifold 264(b) is located in a position with respect to the pre-mix chamber 232 such that fuel can be injected from the manifold 264(b) onto the Coanda surface 260 on the interior surface 254 of the opposing side 246(c). As understood by those skilled in the art, a variety of configurations of fuel ports and jets can be utilized to inject the fuel onto the Coanda surfaces in this embodiment. The number and spacing of fuel ports, for example, can vary depending on the desired thickness of the film to be created on the Coanda surfaces.

[0090] FIG. 17A illustrates an alternative embodiment of each of the tubular distribution manifolds 264(a) and 264(b). In this embodiment, the fuel ports 266 are elongated apertures or slots. The slotted shape of the fuel ports 266 causes the fuel to be injected onto the annular Coanda surface 260 in a sheeted pattern which serves to enhance the entrainment and mixing effect created by the Coanda surface and allows a higher volume of gas to be flared. If desired, the slots 266 can be connected to form continuous elongated apertures or slots in the distribution manifolds 264(a) and 264(b). In addition to round apertures and slots, the fuel ports 266 can be formed in other shapes as well depending on the particular application. Examples of other shapes include elongated ovals and rectangular slots.

[0091] A rectangular fuel membrane 270 is disposed around the outside perimeter of the pre-mix chamber 232. The fuel membrane 270 is connected to the fuel feed conduit 238 and in fluid communication with both the main fuel outlet 236 and the supplemental fuel inlet 234. The membrane 270 comprises an open top 272, a bottom 274, and an external sidewall 276 and internal sidewall 277 connecting the top to the bottom. In the embodiment shown by FIGS. 13-18, the internal sidewall 277 is also the sidewall 246 of the pre-mix chamber. A matching seal mechanism 278 is attached to the bottom 274 of the fuel membrane 270 and extends around the sidewall 246 of the pre-mix chamber 232 to ensure the integrity of the membrane. In an alternate embodiment, as exemplified by FIGS. 25-28 and explained below, the fuel membrane 270 can be spaced outwardly from the exterior surfaces 256 of the sides 246(a), 246(b), 246(c) and 246(d) of the sidewall 246 of the pre-mix chamber 232 in order to provide a space between the exterior surface of the sidewall 246 and the main fuel outlet 236. The space allows air to be entrained from below the burner to a point adjacent to the fuel ports 292 disposed on an inner portion of the main fuel outlet 236. In this embodiment, the internal sidewall 277 of the membrane 270 is separate from the sidewall 246 of the pre-mix chamber 232.

[0092] Supplemental fuel feed conduits 280(a), 280(b), 280(c) and 280(d) extend from the fuel membrane 270 to the supplemental fuel inlet 234, that is to the tubular distribution manifolds 264(a) and 264(b), to deliver fuel from the fuel membrane thereto. Each of the supplemental fuel feed conduits 280(a), 280(b), 280(c) and 280(d) includes a first end 282 attached to the fuel membrane 270 and a second end 284. The second ends 284 of the conduits 280(a) and 280(d) are attached to opposing ends of the tubular distribution manifold 264(a). The second ends 284 of the conduits 280(b) and 280(c) are attached to opposing ends of the tubular distribution manifold 264(b).

[0093] The main fuel outlet 236 is located in a position with respect to the top 242 of the pre-mix chamber 232 such that fuel can be injected from the main fuel outlet around the perimeter 286 of the air/fuel outlet 250 of the pre-mix chamber. As best shown by FIG. 15, the main fuel outlet 236 comprises a flat, rectangular fuel injector body 288 having a plurality of diffusion fuel ports 292 therein. The fuel jets created by the ports 292 are diffusion fuel jets. The fuel injector body 288 is attached to the open top 272 of the fuel membrane 270 such that the diffusion fuel ports 292 are disposed around the perimeter 286 of the air/fuel outlet 250 of the pre-mix chamber 232. The inside and outside diameters of the membrane 270 and fuel injector body 288 are approximately the same. Fuel can be injected from the main fuel outlet 236 (i.e., the fuel injector body 288) around the perimeter 286 of the air/fuel outlet 250. The ports 292 can be sized and spaced to control the manner (e.g., direction and velocity) in which the fuel is injected from the ports. This feature

in conjunction with the flow of fuel and air through the air/fuel outlet 250 allows the shape and length of the overall flame envelope to be controlled.

[0094] As shown by FIG. 16, if desired, the diffusion fuel ports 292 can be spaced from the fuel injector body 288 by a plurality of corresponding short gas risers or tip extensions 296. Spacing the ports 292 from the fuel injector body 288 with the risers 296 can result in better lateral entrainment of air in some applications. The risers also allow the configurations of the ports and resulting fuel flow properties to be mechanically changed if necessary. As understood by those skilled in the art, the injector body 288 can include various iterations of the ports 292. The particular port configuration utilized will depend on various factors including the type of fuel to be flared (including the molecular weight, heating value, stoichiometry and temperature of the stream) and available pressure in connection therewith.

[0095] The fuel feed conduit 238 is in fluid communication with the supplemental fuel inlet 234 and the main fuel outlet 236 for conducting fuel gas thereto. The fuel feed conduit 238 has a first end 300 and a second end 302. As shown, the first end 300 includes a flange 304 for connecting the first end to a source of the fuel gas (again, these types of connections are more typically made by welding). The second end 302 is connected to a corresponding inlet 306 in the external sidewall 276 of the annular fuel membrane 270. Alternatively, separate fuel feed conduits or risers can conduct fuel to the supplemental fuel inlet 234 and main fuel outlet 236 (as opposed to the single integrated conduit or riser 238). The separate conduits or risers will typically run from a common fuel header.

[0096] Referring to FIG. 14, in operation of the burner 230, fuel to be flared (generally depicted by black arrows) is conducted through the fuel feed conduit 238 to the fuel membrane 270. A portion of the fuel is conducted by the fuel membrane 270 to the main fuel outlet 236 (and the fuel injector body 288). The remaining portion of the fuel is conducted by the membrane 270 through the fuel feed conduits 280(a), 280(b), 280(c) and 280(d) to the supplemental fuel inlet 234 (and the tubular distribution manifolds 264(a) and 264(b) thereof). Fuel is injected from the fuel ports 266 of the distribution manifolds 264(a) and 264(b) onto the Coanda surface 260 on the interior surface 254 of the sides 246(a) and 246(c) of the pre-mix chamber 232. The injection of fuel from the fuel ports 266 into the pre-mix zone 231 and pre-mix chamber 232 entrains air into the pre-mix space 231 (a) and through the air inlet 248 into the interior 231 (b) of the pre-mix chamber whereby a mixture (preferably a substantially homogeneous mixture) of fuel and air is formed in the pre-mix zone and caused to exit the air/fuel outlet 250. The fuel and air continue to mix for a short distance above the air/fuel outlet 250. Injection of the fuel from the fuel ports 266 onto the Coanda surface 260 on the interior surface 254 of the sides 246(a) and 246(c) causes the fuel to adhere to and follow the path of the Coanda surface and

form into a relatively thin film thereon which results in a more efficient entrainment of the air and mixing of the air with the fuel. The fuel to be flared is injected from the main fuel outlet 236 (and the annular fuel injector body 288) around the perimeter 286 of the air/fuel outlet 250 of the pre-mix chamber 232 and hence around the air/fuel mixture exiting the air/fuel outlet of the pre-mix chamber. The flare burner 230 is preferably designed and operated in a manner such that the amount of air entrained into the pre-mix zone 231 including the pre-mix chamber 232 is in excess of the stoichiometric amount of air required to combust the fuel injected into the pre-mix zone. The excess air is imparted to the center of the flame envelope for combustion of fuel therein. As explained further below, however, in some applications the burner 230 is designed and operated in a manner such that the amount of air entrained into the pre-mix zone 231 including the pre-mix chamber 232 is equal to or less than the stoichiometric amount of air required to combust the fuel injected into the pre-mix zone. The injection of a "fuel-rich" mixture of fuel and air (i.e., a mixture having less than the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone) into the central portion of the flame envelope is desirable in some applications.

[0097] The flare burner 230 achieves the same advantages that are achieved by the flare burners 30 and 130. The flame envelope 100 generally depicted by FIG. 24 is also created by the flare burner 230.

[0098] The polygonal (rectangular in the embodiment illustrated) shape of the flare burner 230 may allow more flexibility in spacing the flare burners in a ground flare application. Also, such a shape may allow more flexibility in how the fuel is directed from the diffusion gas ports 292 due to the fact that the geometry can be rotated to change the interaction zones.

[0099] Referring now to FIGS. 19-23, a fourth embodiment of the inventive flare burner is illustrated and generally designated by the numeral 330. Like the other embodiments of the inventive flare burner, the flare burner 330 comprises a pre-mix zone 331 including a pre-mix chamber zone 332, and a supplemental fuel inlet 334 for injecting fuel into the pre-mix zone, a main fuel outlet 336 and a fuel feed conduit 338. A pilot 40 (as shown by FIG. 4) may be associated with the burner 330 to initially ignite the fuel and air mixture that is discharged by the burner.

[0100] A mixture (preferably a substantially homogeneous mixture) of fuel and air can be formed in the pre-mix zone 331 including the pre-mix chamber 332. As discussed below, the mixture formed in the pre-mix zone 331 can be either fuel-rich or fuel-lean. The pre-mix chamber 332 includes a round cross-section and has a cylindrical shape. The pre-mix chamber includes a top 342, a bottom 344, a sidewall 346 connecting the top to the bottom, an air inlet 348 disposed in the bottom 344 and an air/fuel outlet 350 disposed in the top 342. The sidewall 346 includes an interior surface 347 and an exterior surface 349. As shown, the top 342 and bottom

344 are open thereby forming the air inlet 348 and air/fuel outlet 350. As a result, the air inlet 348 and air/fuel outlet 350 each also have a round cross-section. The pre-mix chamber 332 has a length (or height) to inside hydraulic diameter ratio in the range of from about 0.25:1 to about 4:1.

[0101] In the embodiment shown by FIGS. 19, 20, 22 and 23 (which does not include the extension cylinder 400 discussed below), the pre-mix chamber 332 has a length (or height) to inside hydraulic diameter ratio of about 1:1 or less. Preferably, in the embodiment shown by FIGS. 19, 20, 22 and 23 (which does not include the extension cylinder 400 discussed below), the pre-mix chamber 332 has a length (or height) to inside hydraulic diameter ratio in the range of from about 0.25:1 to about 1:1. As discussed above, a longer pre-mix chamber generally allows better mixing of the fuel and air in the pre-mix chamber to occur. However, it has been discovered that the length (or height) of the pre-mix chamber 332, in the embodiment shown by FIGS. 19 and 20, is still sufficient for good mixing to occur as long as the delay in ignition is conserved by tempering the flame propagation speed. As best shown by FIG. 20, the pre-mix zone 331 in this particular embodiment (which does not include the extension cylinder 400 discussed below) includes a significant pre-mix space 331 (a) below the pre-mix-chamber 332 (between the supplemental fuel injector 334 and the bottom 344 and air inlet 348 of the pre-mix chamber), the interior 331 (b) of the pre-mix chamber, and a pre-mix space 331(c) immediately above the top 342 and air/fuel outlet 350 of the pre-mix chamber. In this embodiment, mixing of the air and fuel occurs in all three sections of the pre-mix zone 331.

[0102] The supplemental fuel inlet 334 is located in a position with respect to the pre-mix zone 331 such that the injection of fuel from the supplemental fuel inlet into the pre-mix zone entrains air into the pre-mix space 331 (a) and through the air inlet 348 into the pre-mix chamber 332 whereby a mixture, preferably a substantially homogeneous mixture, of fuel gas and air is formed in the pre-mix zone and caused to exit the air/fuel outlet 350 in the top 342 of the pre-mix chamber. Combustion of the mixture of fuel and air does not typically occur until the mixture exits the air/fuel outlet 350, generally a detached distance away from the air/fuel outlet. The distance from the air/fuel outlet 350 at which combustion occurs varies due to the amount of air in the mixture and the velocity at which the mixture is discharged from the air/fuel outlet. In some cases, due to short de-stage timing sequences, combustion can occur in the pre-mix zone (for example, in short duration, very low pressure scenarios).

[0103] As shown by FIGS. 19 and 22, the supplemental fuel inlet 334 comprises a burner casting 352 having a bull nose 353 and a plurality of fuel outlet arms 354 concentrically arranged around the bull nose and centered below the air inlet 348 of the pre-mix chamber 332. The supplemental fuel inlet 334 is concentric with the air inlet 348 and pre-mix chamber 332. In the embodiment shown

by FIGS. 19 and 20, the supplemental fuel inlet 334 is spaced below the air inlet 348 of the pre-mix chamber 332. The supplemental fuel inlet 334 can be in the range of from zero to two inches below the air inlet 348; preferably it is approximately one inch below the air inlet. The exact distance can vary depending on the type of fuel being flared, the particular application, the permitted length of the flame envelope and other factors.

[0104] Each fuel outlet arm 354 and the bull nose 353 include a plurality of fuel ports 356. The ports 356 are linearly arranged along the longitudinal axis of each fuel outlet arm 354. An alternative embodiment of the supplemental fuel inlet 334 is shown by FIG. 23. In this embodiment, each gas outlet arm 354 includes two rows of diffusion fuel ports 356, each port in each row being aligned such that it is not directly across from a port in the adjacent row. The supplemental fuel inlet 334, including the fuel outlet arms 354, is intentionally small to allow as much interaction between the discharged fuel and entrained air as possible. The "bluff body" effect created by the size and shape of the inlet 334 is minimized, leaving a clean approach of the air to the discharged fuel.

[0105] An annular fuel membrane 360 is disposed around the outside perimeter of the pre-mix chamber 332. The fuel membrane 360 is connected to the fuel feed conduit 338 and in fluid communication with the main fuel outlet 336. The membrane 360 comprises an open top 362, a bottom 364, and an external sidewall 366 and internal sidewall 367 connecting the top to the bottom. In a preferred embodiment, the external sidewall 366 is spaced approximately three inches from the internal sidewall 367 (this distance depends on the nature of the fuel and the overall configuration of the burner). In the embodiment shown by FIGS. 19, 20, 22 and 23, the internal sidewall 367 of the membrane 360 is also the exterior surface 349 of the sidewall 346 of the pre-mix chamber 332. In an alternate embodiment, as exemplified by FIGS. 25-28 and explained below, the fuel membrane 360 can be spaced outwardly from the exterior surface 349 of the sidewall 346 of the pre-mix chamber 332 in order to provide an annular space between the exterior surface 349 of the sidewall 246 and the main fuel outlet 336. The space allows air to be entrained from below the burner to a point adjacent to the fuel ports 374 disposed on an inner portion of the main fuel outlet 336. In this embodiment, the internal sidewall 367 of the membrane 360 is separate from the sidewall 346 of the pre-mix chamber 332.

[0106] The main fuel outlet 336 is located in a position with respect to the top 342 of the pre-mix chamber such that fuel can be injected from the main fuel outlet 336 around the perimeter 368 of the air/fuel outlet 350 of the pre-mix chamber. As best shown by FIG. 22, the main fuel outlet 336 comprises a flat, annular fuel injector body 370 having a plurality of fuel ports 374 therein. The fuel jets created by the ports 374 are diffusion fuel jets. The ports 374 are preferably spaced at six degree increments, although the spacing can vary depending on the

particular application. The annular fuel injector body 370 is attached to the open top 362 of the annular membrane 360 such that the fuel ports 374 are disposed around the perimeter 368 of the air/fuel outlet 350 of the pre-mix chamber. The inside and outside diameters of the annular membrane 360 and fuel injector body 370 are approximately the same. Fuel can be annularly injected from the main fuel outlet 336 (i.e., the fuel injector body 370) around the perimeter 368 of the air/fuel outlet 350. The ports 374 can be sized and spaced to control the manner (e.g., direction and velocity) in which the fuel is injected from the ports. This feature in conjunction with the flow of fuel and air through the air/fuel outlet 350 allows the shape and length of the overall flame envelope to be controlled.

[0107] As shown by FIG. 7, if desired, the diffusion fuel ports 374 can be spaced from the fuel injector body 370 by a plurality of corresponding short gas risers or tip extensions 376. Spacing the ports 374 from the fuel injector body 370 with the risers 376 can result in better lateral entrainment of air in some applications. The risers also allow the configurations of the ports and resulting fuel flow properties to be mechanically changed if necessary. As understood by those skilled in the art, the fuel injector body 370 can include various iterations of the ports 374. The particular port configuration utilized will depend on various factors including the type of fuel to be flared (including the molecular weight, heating value, stoichiometry and temperature of the stream) and available pressure in connection therewith.

[0108] The fuel feed conduit 338 is in fluid communication with the supplemental fuel inlet 334 and the main fuel outlet 336 for conducting fuel thereto. The fuel feed conduit 338 includes a main branch 380 having a first end 382 and a second end 384. The first end 382 includes a flange 386 for connecting the first end to a source of the fuel (again, these types of connections are more typically made by welding). The second end 384 is connected to a corresponding inlet 388 in the external sidewall 366 of the fuel membrane 360. The fuel feed conduit 338 also includes a supplemental branch 390 which connects the fuel feed conduit to the supplemental fuel inlet 334. The supplemental branch 390 includes a first end 392 and a second end 394. The first end 392 is connected to the main branch 390 of the feed conduit 338. The second end 394 is connected to the supplemental fuel inlet 334 (specifically the casting 352). Alternatively, separate fuel feed conduits or risers can conduct fuel to the supplemental fuel inlet 334 and main fuel outlet 336 (as opposed to the single integrated conduit or riser 338). The separate conduits or risers will typically run from a common fuel header.

[0109] Referring now specifically to FIG. 21, an alternative embodiment of the flare burner 330 is illustrated. This embodiment is the same as the embodiment of the burner 330 described above, except it also includes a pre-mix chamber extension cylinder 400. The pre-mix chamber extension cylinder 400 extends the length of

the pre-mix chamber 332. In this embodiment, the pre-mix chamber has a length (or height) to inside hydraulic diameter ratio in the range of from about 1:1 to about 4:1, more preferably in the range of from about 1:1 to about 3:1. Most preferably, in this embodiment, the pre-mix chamber has a length (or height) to inside hydraulic diameter ratio of about 1.5:1. The cylinder 400 comprises a top section 402, a bottom section 404 and a mid-section 406 connecting the top section and bottom section together. The mid-section 406 is attached to the internal sidewall 367 of the annular fuel membrane 360.

[0110] Due to the pre-mix chamber extension cylinder 400, the top 342 and air/fuel outlet 350 of the pre-mix chamber 332 are spaced above the main fuel outlet 336. The top 342 and air/fuel outlet 350 of the pre-mix chamber 332 are in the range of from about 0.5 inches to about 10 inches, preferably in the range of from about 6 inches to about 8 inches, above the main fuel outlet 336. The exact distance can vary depending on the type of fuel being flared, the particular application, the permitted height of the flame envelope and other factors. The bottom 344 of the pre-mix chamber 332 is approximately flush with or about one inch above the supplemental fuel inlet 334. As shown by FIG. 21, the pre-mix zone 331 in this particular embodiment (which includes the extension cylinder 400) includes a pre-mix space 331(a) below the pre-mix-chamber 332 (between the supplemental fuel injector 334 and the bottom 344 and air inlet 348 of the pre-mix chamber), the interior 331 (b) of the pre-mix chamber, and a pre-mix space 331(c) immediately above the top 342 and air/fuel outlet 350 of the pre-mix chamber. In this embodiment, the predominant mixing of the air and fuel occurs in the pre-mix chamber 332 (in the pre-mix zone 331 (b)).

[0111] The top section 402 of the pre-mix chamber extension cylinder 400 serves both as a wind shield as well as a physical barrier to delay ignition. Specifically, the top section 402 offsets the detrimental cross flow air effects which can force the flame inside the diameter of the pre-mix chamber and interfere with the smokeless capacity of the flare burner. The top section 402 also functions to isolate the pre-mix fuel stream from the diffusion flame ignition. Similarly, the bottom section 404 of the cylinder 400 serves as a bottom wind shield and helps prevent the flame from being pulled back and causing premature ignition. Again, the increased length of the pre-mix chamber 332 created by the extension cylinder 400 enhances mixing of the fuel and air in the pre-mix chamber. The extension cylinder is not necessary in all applications; e.g., it may not be necessary when cross-flow effects are not an issue or when low molecular weight fuels are being flared. The inclusion or non-inclusion of the shield will depend on the molecular weight and heating value of the fuel to be flared, whether the fuel contains saturated or unsaturated hydrocarbons, the involved temperature and pressure and other factors.

[0112] In the embodiment shown by FIG. 21, the internal sidewall 367 of the membrane 360 is attached to the

mid-section 406 of the extension cylinder 400. In an alternate embodiment, as exemplified by FIGS. 25-28 and explained below, the fuel membrane 360 can be spaced outwardly from the extension cylinder 400 (and hence the exterior surface of the pre-mix chamber 332) in order to provide a space between the exterior surface of the extension cylinder and the main fuel outlet 336. The space allows air to be entrained from below the burner to a point adjacent to the fuel ports 374 disposed on an inner portion of the main fuel outlet 336.

[0113] Referring to FIGS. 20 and 21, operation of the flare burner 330 will be described. A portion of the fuel to be flared (generally depicted by black arrows) is conducted through the main branch 380 of the fuel feed conduit 338 to the fuel membrane 360 and to the main fuel outlet 336. A portion of the fuel to be flared is also conducted from through the supplemental branch 390 of the fuel feed conduit 338 to the supplemental fuel inlet 334. The injection of fuel from the supplemental fuel inlet 334 into the pre-mix zone 331 and pre-mix chamber 332 entrains air into the pre-mix space 331 (a) and through the air inlet 348 into the pre-mix chamber whereby a mixture (preferably a substantially homogenous mixture) of fuel and air is formed in the pre-mix zone and caused to exit the air/fuel outlet 350. The fuel and air continue to mix for a short distance above the air/fuel outlet 350. The remaining fuel to be flared is injected from the main fuel outlet 336 around the perimeter 368 of the air/fuel outlet 350 of the pre-mix chamber and hence around the air/fuel mixture exiting the air/fuel outlet of the pre-mix chamber. Again, when the extension cylinder 400 is installed, additional mixing is gained and the pre-mix stream exiting the air/fuel outlet 350 is isolated from premature ignition by interaction with the diffusion flame formed upon discharge of the fuel from the main fuel outlet 336. Use of the extension cylinder 400 serves to enhance the overall effect created by utilization of the pre-mix stream. The flare burner 330 is preferably designed and operated in a manner such that the amount of air entrained into the pre-mix zone 331 including the pre-mix chamber 332 is in excess of the stoichiometric amount of air required to combust the fuel injected into the pre-mix zone. The excess air is imparted to the center of the flame envelope for combustion of fuel therein. As explained further below, however, in some applications the burner 330 is designed and operated in a manner such that the amount of air entrained into the pre-mix zone 331 including the pre-mix chamber 332 is equal to or less than the stoichiometric amount of air required to combust the fuel injected into the pre-mix zone. The injection of a "fuel-rich" mixture of fuel and air (i.e., a mixture having less than the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone) into the central portion of the flame envelope is desirable in some applications.

[0114] The flare burner 330 achieves the same advantages that are achieved by the flare burners 30, 130 and 230. The flame envelope 100 generally depicted by FIG.

24 is also created by the flare burner 330.

[0115] Referring now to FIGS. 25-28, a modification that can be made to the fourth embodiment of the inventive flare burner described above (the embodiment shown by FIGS. 19-23) is illustrated. The same modification can be made to the first, second and third embodiments of the inventive flare burner described above as well.

[0116] In this embodiment, the flare burner 330 includes the pre-mix chamber extension cylinder 400. However, instead of being attached directly to fuel membrane 360, the extension cylinder 400 (and hence the pre-mix chamber 332) is spaced inwardly from the fuel membrane to provide an air pathway between the extension cylinder and fuel membrane to allow air to effectively reach the fuel ports 374 disposed on the inner portion of the main fuel outlet 336. The diameter of the extension cylinder 400 (and hence the pre-mix chamber 332) is significantly smaller than the inside diameter of the fuel membrane 360. In this embodiment, the pre-mix chamber has a length (or height) to inside hydraulic diameter ratio in the range of from about 0.5:1 to about 4:1, more preferably in the range of from about 1:1 to about 3:1. Most preferably, the pre-mix chamber has a length (or height) to inside hydraulic diameter ratio in the range of from about 1.5:1.

[0117] Due to the smaller diameter of the extension shield 400, an annular space 430 exists between the internal sidewall 367 of the fuel membrane 360 and the exterior surface of the extension cylinder 400 (which is also the exterior surface 349 of the sidewall 346 of the pre-mix chamber 332). A plurality of thin, rectangular gasket plates 432 are utilized to center and hold the extension cylinder 400 (and hence the pre-mix chamber 332) within the fuel membrane 360. As illustrated, four plates 432 are disposed 90° apart within the annular space 430. One end of each plate 432 is attached to the internal sidewall 367 of the fuel membrane 360. The other end of each of the plates 432 is attached to the exterior surface of the extension cylinder 400 (which is also the exterior surface 349 of the sidewall 346 of the pre-mix chamber 332). Other than this above modification, the burner 330 illustrated by FIGS. 25-28 is the same in all respects as the embodiment illustrated by FIGS. 19-23 and described above.

[0118] The main fuel outlet 336 is still located in a position with respect to the top 342 of the pre-mix chamber such that fuel can be injected from the main fuel outlet 336 around the perimeter 368 of the air/fuel outlet 350 of the pre-mix chamber. The annular space 430 merely provides an air pathway between the extension cylinder and fuel membrane to allow fresh oxidizer to effectively reach the fuel ports 374 disposed on the inner portion of the main fuel outlet 336. The operation of the burner 330 remains the same, except fresh air is entrained from below the burner by the motive force of the inner row of fuel ports 374 through the annular space 430. The entrained air is in close proximity to the fuel being discharged by

the inner row of fuel ports 374 on the main fuel outlet 336 and mixes therewith. For example, the enhanced mixing regimen provided by the annular space 430 is useful when relatively heavy and unsaturated fuel stocks, which tend to smoke more readily, are flared. It optimizes the burner for soot free combustion.

[0119] As will be understood by those skilled in the art, the same modification can also be made to the other three embodiments of the inventive flare burner described above. For example, in modifying the embodiment illustrated by FIGS. 4-8, the cross-sectional diameter of the pre-mix chamber 32 is reduced and the pre-mix chamber 32 is spaced inwardly from the fuel membrane 60. Either the internal sidewall 67 of the annular fuel membrane 60 or the sidewall 46 of the pre-mix chamber 32 is added (as shown, the internal sidewall of the membrane and the sidewall of the pre-mix chamber are the same). The annular seal 68 is eliminated. Spacing the pre-mix chamber 32 inwardly from the fuel membrane 60 provides an air space between the pre-mix chamber and fuel membrane. Fresh air can then be entrained from below the burner to a point in close proximity to the fuel that is discharged from the fuel ports 74 on the inner portion of the main fuel outlet 36. The pre-mix chamber 32 can be centered within and attached to the fuel membrane 60 with a plurality of gussets as shown by FIGS. 25-28.

[0120] FIG. 28 generally depicts the flame envelope 100 created by the modified flare burner 330 illustrated by FIGS. 25-27 (as well as the burners 130, 230 and 330 if modified in the same manner). As shown, excess air is injected from the pre-mix chamber 332 into a center portion 102 of the flame envelope 100. The excess air, depicted by air pockets 103 in FIG. 28 mixes with fuel in the center portion 102 of the flame envelope 100 to form, in effect, two initial zones of flammability, zone 104(a) and 104(b). Air is also entrained from below the burner 330 through the annular space 430 to a point in close proximity to the fuel being discharged by the inner row of fuel ports 374 on the main fuel outlet 336. The air entrained through the annular space 430 enhances the mixing regimen and creates faster and more uniform combustion within the overall flame envelope 100. As shown by FIG. 28, the flame envelope 100 has a length 106 that is substantially less for the same amount of fuel than the length 23 of the prior art flame envelope 20 shown by FIG. 3.

General Information

[0121] The partial pre-mix approach of the present invention allows two flame zones to be initiated within the same flame envelope as the fuel is flared. The outer flame zone is typical to what would normally be observed with a burner of the type utilized heretofore, i.e., a type utilizing only diffusion mixing. The outer layers of gas are shredded away to expose consecutive layers of gas for repeated diffusion and subsequent combustion. The second

flame zone is created by the pre-mix zone of the burner which delivers a combustible mixture to the inside of the main flame envelope. This combusting flow field serves to create an appreciable turbulent regime at the core of the flame which is atypical of a normal diffusion flame. As the pre-mix zone becomes more fuel lean, the flame will become shorter due to the additional oxidizer delivered to the core of the flame. The excess air is utilized by the remaining flame cloud and functions to shorten the flame (or allow the mass flow to be increased) while also serving further as a quench mechanism to diminish emissions such as nitrous oxides and carbon monoxide. The excess air also reduces the formation of soot and results in the combustion of any unburned hydrocarbons.

[0122] Each of the flare burners 30, 130, 230 and 330 is preferably designed and operated such that the amount of air entrained into the pre-mix zone and injected into the central portion of the flame envelope is in the range of from about 15% to about 300% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone. Thus, both a fuel-rich approach (the injection of a mixture of fuel and air having less than 100% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone into the central portion of the flame envelope) and a fuel-lean approach (the injection of a mixture of fuel and air having more than 100% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone into the central portion of the flame envelope) can be utilized. Each approach has its own advantages as compared to the typical diffusion/free jet driven combustion regimen utilized heretofore. The particular approach utilized will depend upon the particular application including the type of fuel to be flared and the available pressure. The approach can be modified by typical porting and fuel delivery mechanisms.

[0123] When a fuel rich approach is utilized, the fraction of fuel injected into the center of the flame envelope will initiate a smaller envelope of combustion at the core of the flame which will serve to shorten the flame while also creating an additional turbulent combustion zone at the center of the flame envelope. When a fuel-lean approach is utilized, the flame envelope will be shortened appreciably due to the larger pre-mixed fuel fraction combusting at the core of the flame. The excess air carried by the pre-mix flow regimen then serves to further initiate combustion relative to the center of the remaining flame envelope. The additional turbulence created by the fuel expanding at the center of the flame during combustion then serves to increase the mixing regimen for the remaining fuel by fracturing the dense fuel core and pushing it to the outer flame boundary.

[0124] When a fuel-rich approach is utilized, it is important for the pre-mix stream delivered to the center of the flame envelope to remain within the range of combustibility. If not, the augmented mixing and combustion in the center of the flame envelope may not occur. The

enhanced mixing is benefited by a pre-mixed flame which initiates at the core of the flame and expands at an appreciable velocity to create significant turbulence at the core of the flame.

[0125] In most applications, however, injection of a "lean" mixture of fuel and air (i.e., a mixture having more than 100% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone) into the central portion of the flame envelope is desired. In most applications, the amount of air entrained into the pre-mix zone and injected into the central portion of the flame envelope is in the range of from about 125% to about 300% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone. Preferably, the amount of air entrained into the pre-mix zone is in the range of from about 150% to about 300%, more preferably from about 175% to about 300%, of the stoichiometric amount of air required to support combustion of the fuel injected into the pre-mix zone. As the amount of excess air entrained into the pre-mix zone increases (that is, as the amount of air entrained into the pre-mix zone in excess of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone increases), the benefit with respect to flame length and emissions also increases. Although an amount of air entrained into the pre-mix zone greater than 300% of the stoichiometric amount of air required to support combustion of the fuel injected into the pre-mix zone would be advantageous, it would require an extraneous source of air entrainment (such as steam injection) and possibly other modifications, and may therefore be cost prohibitive.

[0126] The amount of air entrained into the pre-mix zones of each of the burners 30, 130, 230 and 330 is highly dependent on the pressure and mass flow of the fuel injected from the supplemental fuel inlet, the type of fuel being flared, the structure of the supplemental fuel inlet including the number and size of the ports therein, the placement of the supplemental fuel inlet with respect to the air inlet into the pre-mix chamber and the size of the air inlet. In most applications, the ultimate goal is to achieve a highly dilute, preferably inflammable mixture of fuel and air. An inflammable, lean mixture will quickly assimilate the fuel required to become again combustible once inside the core of the flame envelope. Once a flammable mixture is achieved, the air and gas will then create a large flame zone on the inside of the flame envelope which will significantly increase the rate at which the fuel is oxidized while also creating significant turbulence to augment the diffusion mixing on the external surface of the flame zone as well. The additional mass transported to the center of the flame envelope also serves as a quench mechanism to lower the production of emissions such as nitrous oxides and carbon monoxide. The added rate at which combustion occurs while maintaining two flame fronts also serves to lower the production of carbon monoxide and soot, and further reduces the release of unburned hydrocarbons.

[0127] The fuel is injected into the pre-mix zone with sufficient momentum to entrain air radially and from below the burner into the jet(s) of fuel and pre-mix zone. Depending upon the molecular weight of the fuel and the delivery pressure available for entrainment, the burner can entrain air from up to 2 feet below the supplemental fuel inlet.

[0128] Preferably, the amount of fuel introduced into the pre-mix zone of each of the burners 30, 130, 230 and 330 is in the range of from about 5% to about 50%, more preferably in the range of from about 10% to about 30%, of the total amount of fuel to be flared by the flare burner. Most preferably, the amount of fuel introduced into the pre-mix chamber is in the range of from about 10% to about 25% of the total amount of fuel to be flared by the flare burner. The amount of fuel introduced into the pre-mix zone can be controlled by manipulating the diameter of the fuel ports and the pressure of the fuel.

[0129] The greater the percentage of fuel introduced into the pre-mix zone, the shorter the flame and the greater the smokeless capacity of the burner. However, a proper balance between the percentage of fuel injected into the pre-mix zone and the amount of air that can be entrained into the pre-mix zone must be achieved. When a fuel-lean approach is utilized, it is usually important for the amount of air entrained into the pre-mix zone to be at least about 125% of the stoichiometric amount of air required to support combustion of the fuel injected into the pre-mix zone. A lesser amount of air could create a very reactive (combustible) mixture that could make the burner prone to either burn-back or flashback at maximum rates, eventually causing damage to the burner. The greater the amount of entrained air the greater the quench effect and the lower the flame speed of the fuel. This condition is ideal for augmenting the delay in ignition of the pre-mix stream in order to ensure that the ignition point of the pre-mix stream is local to the core of the flame prior to combustion for maximum benefit.

[0130] A sufficiently dilute stream of air and fuel will assure that the mixture of air and fuel is not ignited until the mixture exits the air/fuel outlet and reaches the center of the flame envelope. Once the mixture of fuel and air exits the air/fuel outlet and enters the flame envelope, the mixture then assimilates sufficient additional fuel to reach a combustible mixture at which time the fuel ignites inside the main flame envelope. This flow regimen creates a flame within a flame or a toroidal flame geometry combusting with two individual flame fronts. The additional turbulence created by the gas expanding at the center of the flame during combustion then serves to increase the mixing regimen for the remaining fuel by fracturing the dense fuel core and pushing it to the outer flame boundary. This approach reduces the flame's height and ability to smoke, while also increasing the overall combustion efficiency due to increased mixing.

[0131] It is important that the air/fuel mixture in the pre-mix zones of each of the burners 30, 130, 230 and 330 does not combust until it exits the air/fuel outlet of the

pre-mix zone. Combustion inside of the pre-mix chamber, for example, would back pressure the pre-mix chamber and greatly reduce the amount of air entrained into the pre-mix chamber.

[0132] By delivering only a portion of the fuel to be flared to the pre-mix zones of each of the burners 30, 130, 230 and 330, the overall cross-sectional size of the burners is comparatively small. It would be size prohibitive to design and build a burner capable of supplying 100% of the air needed for combustion in a total pre-mix approach. The venturi or mixer portion of such a burner would necessarily be appreciably large and lack the ability to accommodate low fuel pressures.

[0133] Although the pre-mix chamber of each of the inventive burners 30, 130, 230 and 330 is relatively small, the set up is capable of providing sufficient air and fuel to create a pre-mixed air and fuel stream with an appreciable amount of entrained excess air. As a result, a significant increase in the overall flow of fuel may be realized with an equivalent flame height and diameter. Depending on the type of fuel to be flared, the inventive burners can easily accommodate a fuel flow rate that can be designed to deliver fuel in excess of 1.4 times the rate typically achievable by the diffusion jet-type burners utilized heretofore. In most cases, this can also be accomplished while maintaining roughly the same flame length and diameter. If a larger flame height can be tolerated, a fuel flow rate that is appreciably higher in flow rate can be achieved as compared to the diffusion jet-type burners utilized heretofore. In addition, in connection with each embodiment of the inventive burner, the ignition spacing and turn down capabilities can be conserved while the fuel flow rates are increased. In connection with low molecular weight fuels, the radiant fraction of the flame may also be somewhat decreased with the tempering of the flame, reducing the overall flame temperature. In some cases, this allows the burners to maintain or only minimally increase the distance between the burners and the fencing even though the fuel flow rate has been increased. The excess air delivered to the center of the flame serves not only to impart air to the center of the flame but also to decrease the timed rate in which the resulting fuel cloud is oxidized upon exiting the tip of the burner. This results in a cleaner, smoke-free flame that is proportionally shorter for a given heat release. The dilution and subsequent quench effect to the flame also serves to decrease nitrous oxide and carbon monoxide emissions. The flow of fuel and air through the pre-mix chamber also aids in cooling the burner assembly.

[0134] Various configurations of the supplemental fuel inlet have been described. Additional configurations are also possible, including multi-point injector bodies or headers drilled to maximize air entrainment and mixing in view of available fuel pressures. The lower section of each of the embodiments described above can include a Coanda surface or can be a straight section. If Coanda surfaces are utilized, the ports in the supplemental fuel inlet can be round orifices (jets) or slots. In addition to

Coanda technology, the fuel can be injected from the supplemental fuel inlet at a relatively high velocity to rapidly achieve a mixture of fuel and air that can be injected into the center of the flame envelope. The dimensions of the various components of the inventive flare burner including the dimensions of the pre-mix chamber and fuel membrane can vary. Further, a myriad of port configurations (for example, sizes of ports; spacing between ports) can be used in association with the main fuel outlet and the supplemental fuel inlet. The particular dimensions and configurations utilized will depend on the type of fuel and the molecular weight, temperature, heating value and reactivity thereof, operational parameters (for example, the available pressure) and other factors.

[0135] Although it is not generally necessary, a tertiary inerting fluid can be injected into the pre-mix zone of the inventive flare burner (any of the embodiments of the flare burner) to enhance the entrainment of air into the pre-mix zone. Examples of tertiary inerting fluids that can be used include steam, air and nitrogen. Steam is preferred.

[0136] The drawings illustrate round and rectangular (polygonal) embodiments of the inventive flare burner. Each embodiment of the inventive flare burner can be formed in other geometries as well. For example, in addition to round and rectangular shapes, elliptical, triangular, square, pentagonal, octagonal and other polygonal shapes can be employed. These other geometric shapes may prove beneficial from a cost or fabrication standpoint. The optimum approach is to create a dilute excess air stream which can then be delivered from the pre-mix chamber to the center of the main body of the flame. A fuel rich stream, however, still offers benefits over the diffusion only type burners utilized heretofore due to the enhanced mixing created by the inventive burner.

The Inventive Ground Flare

[0137] Referring now to FIG. 29, the inventive ground flare is schematically illustrated and generally designated by the reference numeral 420. The ground flare 420 comprises a plurality of flare burners 422, an enclosure 424 extending around the flare burners and a fuel supply line 426 for supplying fuel to the flare burners.

[0138] The flare burners are arranged in rows 430(a) - (f) and rows 432(a) - (e). Rows 430(a) - (f) form a first stage 434 of the flare burners 422, whereas the rows 432(a) - (e) form a second stage 436 of the flare burners. At least one of the flare burners 422 is one of the embodiments of the inventive flare burner described above. Preferably, each of the flare burners 422 in the second stage 436 of flare burners 422 (the burners utilized when a relatively high volume of fuel needs to be flared) is one of the embodiments of the inventive flare burner described above. If desired, each of the flare burners 422 in both the first stage 434 of burners and the second stage 436 of burners is one of the embodiments of the inventive

flare burner described above.

[0139] The fuel supply line 426 comprises a main line 440 which terminates in a distribution manifold 442. A first stage supply line 444 and a second stage supply line 446 are attached and in fluid communication with the distribution manifold 442. Individual first stage supply lines 450(a) - (f) run from the first stage fuel supply line 444 to corresponding burner rows 430(a) - (f). Similarly, individual second stage supply lines 452(a) - (e) run from the second stage fuel supply line 446 to corresponding burner rows 432(a) - (e). For example, the first end 382 of the main branch 380 of the fuel feed conduit 338 of the inventive flare burner 330 is attached to one of the individual supply lines 450(a) - (f) or 452(a) - (e). If another type of flare burner is also utilized in the ground flare 420, the fuel feed conduit of such burner is attached as appropriate to one of the individual supply lines 450(a) - (f) or 452(a) - (e).

[0140] A series of pilots 460(a) - (f) are in fluid communication with the first stage supply line 444 and positioned with the appropriate burner and fuel separation prior to ignition. Pilots are typically located adjacent to the first flare burner 422 in corresponding rows 430(a) - (f). Similarly, a series of pilots 462(a) - (e) are in fluid communication with the second stage supply line 446 and positioned adjacent to the first flare burner 422 in corresponding rows 432(a) - (e).

[0141] The enclosure 424 surrounds the flare burners 422 and comprises a plurality of posts 470 and fence sections 472 connected between the posts. The enclosure or fence is in the range of from about 30 feet to about 60 feet high. The enclosure 424 is designed such that air can be pulled into the ground flare through and under the enclosure.

[0142] In operation of the inventive ground flare 420, fuel to be flared is conducted through the main line 440 to the distribution manifold 442. A valve control system (not shown) functions to distribute the fuel to either the first stage fuel supply line 444 or both the first stage fuel supply line 444 and the second stage fuel supply line 446. If a relatively low volume of fuel is conducted to the distribution manifold 442, the valve system directs the fuel only to the first stage fuel supply line 444. If the volume of fuel gas conducted to the distribution manifold 442 is relatively high, the fuel is conducted to both the first stage fuel supply line 444 and the second stage fuel supply line 446. Additional staging can also be incorporated to cycle in and out as needed. Fuel is conducted from one or both of the fuel supply lines 444 and 446, depending on the volume of the fuel, to the corresponding individual supply lines 450(a)-(f) and/or 452(a) - (e). The fuel is conducted from the individual supply lines 450(a) - (f) and/or 452(a) - (e) to the flare burners 422 in the corresponding rows 430(a) - (f) and 432(a) - (e).

[0143] As necessary, the pilots 460(a) - (f) and 460(a) - (e) ignite the fuel discharged from the corresponding first burner 422 in each of the row. The ignited fuel from the first burner 422 in each row then ignites the fuel being

discharged from the adjacent burner which in turn ignites the fuel being discharged from the next burner in the row and so on until the fuel being discharged from each of the burners in the row has been ignited. The air required for combustion is pulled through and/or under the walls of the enclosure 424. It is not necessary to separately supply air to the burners 422 or ground flare.

[0144] The inventive ground flare can be used to combust from a relatively small volume of fuel (for example, 3,000 pounds per hour or less) to a very large volume of fuel gas (for example, 10,000 to 15,000 pounds per hour and up depending on the molecular weight of the fuel to be flared, pressure availability, temperature and other factors). Even at a very high flow rate (for example, 10,000 pounds per hour), the flame envelope created by the inventive ground flare burner can be contained in a typical ground flare enclosure. Due to the structure of the inventive flare burner, a higher volume of fuel can be flared with smaller ports and higher pressures without significantly increasing the height of the flame envelopes created by the ground flare. Alternatively, the flame heights can be decreased allowing the enclosure 424 to be reduced in height. The inventive burners pump air from below the burners which allows the burners to be placed closer to the ground, again resulting in a reduction in the required height of the enclosure 424. A smaller portion of land may be required due to a smaller number of burners and related components.

[0145] In many cases, existing ground flares can be retrofitted with the inventive flare burner 422 to allow more fuel to be flared without causing the height of the flame envelope to significantly exceed the height of the enclosure surrounding the ground flare. Also, due to the structure of the burner, the smokeless rate for a given flare tip may be significantly larger in range. With a realized increase in throughput, more gas can be delivered per an individual header. This can result in fewer headers coupled with fewer control mechanisms such as gas control valves, shut-off valves, regulators and physical piping. Increased capacity with fewer headers also allows for a smaller enclosure 434.

[0146] The inventive ground flare can be used to flare various types of fuel gas. Examples include saturated and unsaturated hydrocarbons such as propane and propylene and mixtures thereof, alone or with hydrogen, water vapor and/or inert gases such as nitrogen, carbon monoxide, argon, etc.

[0147] The above description of the inventive ground flare is intended to illustrate the ground flare and particularly how the inventive flare burner is used in association therewith. As understood by those skilled in the art, ground flare installations can vary widely in terms of how they are configured, the number and types of burners, headers, flow systems, control valves and related components, the type and height of the enclosure surrounding the installation and in many other ways. The inventive ground flare encompasses any ground flare installation in which the inventive flare burner is utilized.

The Inventive Method

[0148] In accordance with the inventive method, fuel is burned in one of the inventive flare burners 30, 130, 230, or 330. Referring to FIG. 24, the fuel is injected through a fuel injector body (i.e., the main fuel outlet 36, 136, 236 or 336) into the combustion zone 101 and ignited to create a flame envelope 100 and combust the fuel. A portion of the fuel to be burned is introduced into the pre-mix zone including the pre-mix chamber of the burner (i.e., the pre-mix chamber 32, 132, 232 or 332) in a manner that entrains air into the pre-mix zone and creates a mixture (preferably a substantially homogenous mixture) of air and fuel within the pre-mix zone. The mixture of air and fuel is then injected from the pre-mix chamber into a central portion 104 of the flame envelope. Again, as discussed above, the amount of air entrained into the pre-mix zone and injected into the central portion of the flame envelope can range from a fuel rich but combustible mixture to a mixture having entrained air in excess of the stoichiometric amount required for combustion. This pre-mixed fuel and air stream injected into the center of the flame envelope initiates a second flame zone, creating a toroidal shaped flame envelope. The overall result is faster and more uniform combustion of the overall flame envelope thereby achieving the advantages discussed above in connection with the inventive flare burner.

[0149] As discussed above, the amount of air entrained into the pre-mix zone and injected into the central portion of the flame envelope is preferably at least about 15% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone. In some applications, injection of a "fuel-rich" mixture of fuel and air (i.e., a mixture having less than 100% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone) into the central portion of the flame envelope is suitable. In most applications, however, injection of a "lean" mixture of fuel and air (i.e., a mixture having more than 100% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone) into the central portion of the flame envelope is desired. In most applications, the amount of air entrained into the pre-mix zone and injected into the central portion of the flame envelope is in the range of from about 125% to about 300% of the stoichiometric amount of air required to support combustion of the fuel introduced into the pre-mix zone.

[0150] The amount of fuel introduced into the pre-mix zone and pre-mix chamber (i.e., the pre-mix chamber 32, 132, 232 or 332) is in the range of from about 5% to about 50%, more preferably from about 10% to about 30%, most preferably from about 10% to about 25%, of the total amount of fuel to be flared by the flare burner.

[0151] In order to further illustrate the invention, the following examples are given.

Example 1

[0152] The first embodiment of the inventive flare burner, flare burner 30, was compared to a prior art high capacity diffusion-type ground flare burner, namely the burner illustrated in FIGS. 1 and 2. Two of the inventive flare burners were tested, one approximately 30 inches in length and the other approximately 16 inches in length. The inventive flare burners were ported to match the three square inches of flow area contained in the prior art flare burner.

[0153] The inventive flare burners were first tested singularly. Tests were carried out using propane and propylene. Approximately 20% of the fuel was injected into the pre-mix chamber of each of the inventive flare burners. The remaining fuel was then injected around the perimeter of the air/fuel mixture discharged from the pre-mix chamber. It was determined that with both types of fuels, each of the inventive flare burners were able to support a significant flow of fuel while developing a smokeless flame. The flame envelope from each burner was found to be very stable, capable of significant turn-down ratios, and also very symmetrical throughout the range of heat releases fired. The flame envelopes from each burner were observed as being very short in length and having a small diameter.

[0154] The inventive flare burner having a length of approximately 30 inches was then compared to the prior art burner. The two flare burners were tested side by side. The burners were attached to the same header to insure that the same volume of fuel was supplied to each burner.

[0155] It was observed that the inventive flare burner produced a shorter flame envelope in most of the test points observed. The inventive flare burner remained lit at lower pressures during turn down, indicating a somewhat expanded range of operability. At maximum fuel flow rates, the flame envelope generated by the inventive flare burner was shorter in overall length as compared to the prior art high capacity diffusion-type ground flare burner. In this scenario, however, the vertical cross-section (width) of the flame envelope created by the prior art flare burner was larger than the flame envelope created by the inventive flare burner. No burn-back was observed with the inventive flare burner until the pressure was notably under 1 psig. Radiation from the flame envelope generated by the inventive flare burner appeared to be equivalent to or slightly less than the radiation generated by the flame envelope produced by the prior art flare burner. During turn down conditions, the prior art flare burner smoked at approximately the same rate as the inventive flare burner. Trailing smoke typically could be noted from both burners at about the same flow rate and pressure. However, the inventive flare burner appeared to maintain a less dense trail of smoke at lower pressures than the diffusion type burner tip during initial testing. The prior art burner transitioned to heavier smoke production as pressure was reduced.

Example II

[0156] The third embodiment of the inventive flare burner, flare burner 230, was also tested and compared to the prior art flare burner discussed above. The performance of this embodiment of the inventive flare burner appeared to be at least equivalent to the prior art burner. However, the inventive burner produced more smoke at low pressure than the first embodiment of the inventive flare burner described in Example I. The range of smokeless operation was comparative to the smokeless performance of the prior art flare burner.

[0157] In this test, the corners of the pre-mix chamber of the inventive flare burner created complex flow patterns which visually appeared to inhibit the mixing regimen in the pre-mix chamber to some extent. As a result, spurious stratified fuel rich zones were observed to form at the corners of the pre-mix discharge area, resulting in visible smoke strata observed throughout the surface of the flame zone. On the other hand, the inventive flare burner tested was able to handle almost three times the amount of fuel that could be handled by the prior art flare burner.

[0158] A weld used in assembling the test unit of the inventive flare burner described in this example was faulty and ultimately failed (only after appreciable testing was carried out). The weld in question was utilized only for the test unit (which was made out of carbon steel); the failure of the weld was not due to a design issue and has no relevance to the operation or performance of the actual burner. In any event, the tests showed that the flare burner 230 is very capable of handling large fuel flows with minor smoke issues.

[0159] Thus, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those which are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit of this invention as defined by the appended claims.

Claims

1. A flare burner, comprising:

a pre-mix zone including a pre-mix chamber, said pre-mix chamber having a top, a bottom, a sidewall connecting said top to said bottom, an air inlet disposed in one of said bottom and said sidewall and an air/fuel outlet disposed in said top;

a supplemental fuel inlet for injecting fuel into said pre-mix zone, said supplemental fuel inlet being located in a position with respect to said pre-mix zone such that the injection of fuel from said supplemental fuel inlet into said pre-mix zone entrains air into said pre-mix zone whereby a mixture of fuel and air is formed in said pre-

mix zone and caused to exit said air/fuel outlet of said pre-mix chamber; and

a main fuel outlet located in a position with respect to said top of said pre-mix chamber such that fuel can be injected from said main fuel outlet around the perimeter of said air/fuel outlet of said pre-mix chamber.

2. The flare burner of claim 1 wherein said air inlet is disposed in said bottom of said pre-mix chamber.

3. The flare burner of claim 1 or 2, further comprising a fuel membrane disposed around the outside perimeter of said pre-mix chamber, said membrane including a fuel inlet and being in fluid communication with said main fuel outlet.

4. The flare burner of claim 3, wherein said fuel membrane and said main fuel outlet are spaced outwardly from said pre-mix chamber to provide an air entrainment space therebetween.

5. The flare burner of claim 3 or 4, wherein said membrane is also in fluid communication with said supplemental fuel inlet.

6. The flare burner of claim 3, 4 or 5, wherein said pre-mix chamber, including said air/fuel outlet, and said fuel membrane and said main fuel outlet each have a round cross-section such that fuel can be injected annularly from said main fuel outlet around the perimeter of said air/fuel outlet.

7. The flare burner of any one of the preceding claims, further comprising a fuel feed conduit in fluid communication with said supplemental fuel inlet and said main fuel outlet for conducting fuel to said supplemental fuel inlet and said main fuel outlet.

8. The flare burner of any one of the preceding claims, wherein said main fuel outlet comprises a plurality of fuel ports disposed around the perimeter of said air/fuel outlet of said pre-mix chamber.

9. The flare burner of any one of the preceding claims, wherein said sidewall of said pre-mix chamber includes an interior surface and an exterior surface, said interior surface having a section that is a Coanda surface.

10. The flare burner of claim 9 wherein said supplemental fuel inlet is located in a position with respect to said pre-mix chamber such that fuel can be injected from said supplemental fuel inlet onto said Coanda surface.

11. The flare burner of claim 9 or 10 when dependent from claim 3, wherein:

- said air inlet is disposed in said bottom of said pre-mix chamber and said pre-mix chamber, said air inlet, said membrane and said supplemental fuel inlet each have a round cross-section; and
said Coanda surface annularly extends around said interior surface of said sidewall of said pre-mix chamber.
- 12.** The flare burner of claim 11 wherein said supplemental fuel inlet is located in a position with respect to said pre-mix chamber such that fuel can be annularly injected from said supplemental fuel inlet onto said Coanda surface.
- 13.** The flare burner of any one of claims 9 to 12, wherein said interior surface includes two opposing sections that are Coanda surfaces, and said supplemental fuel inlet is in a position with respect to said pre-mix chamber such that fuel can be injected from said supplemental fuel inlet onto each of said Coanda surfaces.
- 14.** The flare burner of any one of the preceding claims, wherein said pre-mix chamber has a length to inside hydraulic diameter ratio in the range of from about 0.25:1 to about 4:1.
- 15.** A flare burner, comprising:
- a pre-mix zone including a pre-mix chamber, said pre-mix chamber having a top, a bottom, a sidewall connecting said top to said bottom, an air inlet disposed in said bottom, an air/fuel outlet disposed in said top and a length to inside hydraulic diameter ratio in the range of from about 0.25:1 to about 4:1;
 - a supplemental fuel inlet for injecting fuel into said pre-mix zone, said supplemental fuel inlet being located in a position with respect to said pre-mix zone such that the injection of fuel from said supplemental fuel inlet into said pre-mix zone entrains air into said pre-mix zone whereby a mixture of fuel gas and air is formed in said pre-mix zone and caused to exit said air/ fuel outlet of said pre-mix chamber;
 - a main fuel outlet located in a position with respect to said top of said pre-mix chamber such that fuel can be injected from said main fuel outlet around the perimeter of said air/fuel outlet of said pre-mix chamber; and
 - a fuel feed conduit in fluid communication with said supplemental fuel inlet and said main fuel outlet for conducting fuel to said supplemental fuel inlet and said main fuel outlet.
- 16.** The flare burner of claim 15, wherein said pre-mix chamber, including said air inlet and said air/fuel out-
- let, and said main fuel outlet have round cross-sections.
- 17.** The flare burner of claim 15 or 16, further comprising an annular fuel membrane disposed around the outside perimeter of said pre-mix chamber, said membrane being in fluid communication with said main fuel outlet and having a top, a bottom and a sidewall connecting said top to said bottom.
- 18.** The flare burner of claim 17, wherein said main fuel outlet is attached to said top of said fuel membrane and comprises a plurality of fuel ports extending around the perimeter of said air/fuel outlet of said pre-mix chamber.
- 19.** The flare burner of claim 18, wherein said fuel membrane and said main fuel outlet are spaced outwardly from said pre-mix chamber to provide an air entrainment space therebetween.
- 20.** The flare burner of any one of the preceding claims, wherein said main fuel outlet is spaced outwardly from said pre-mix chamber to provide an air entrainment space therebetween.
- 21.** The flare burner of any one of the preceding claims, wherein said pre-mix chamber has a length to inside hydraulic diameter ratio of about 1:1 or less.
- 22.** The flare burner of any one of the preceding claims, wherein said supplemental fuel inlet is spaced below said air inlet of said pre-mix chamber.
- 23.** The flare burner of any one of the preceding claims, wherein said air/fuel outlet of said pre-mix chamber is spaced above said main fuel outlet.
- 24.** A ground flare comprising a plurality of flare burners, an enclosure extending around the flare burners and a fuel supply line for supplying fuel to the flare burners, wherein at least one of the flare burners is constructed in accordance with any one of the preceding claims.
- 25.** A method of flaring fuel with a flare burner in which fuel to be flared is injected through a fuel outlet of the burner into a combustion zone and ignited to create a flame envelope and combust the fuel, the method comprising:
- introducing a portion of the fuel to be burned into a pre-mix zone of said burner in a manner that entrains air into said pre-mix zone and creates a mixture of air and fuel within said pre-mix zone; and
 - injecting said mixture of air and fuel from said pre-mix zone into a central portion of said flame

envelope.

- 26.** The method of claim 25, wherein the amount of air entrained into said pre-mix zone and injected into said central portion of said flame envelope is in the range of from about 125% to about 300% of the stoichiometric amount of air required to support combustion of the fuel introduced into said pre-mix zone. 5
- 27.** The method of claim 26, wherein the amount of air entrained into said pre-mix zone and injected into said central portion of said flame envelope is in the range of from about 150% to about 300% of the stoichiometric amount of air required to support combustion of the fuel introduced into said pre-mix zone. 10 15
- 28.** The method of any one of claims 25 to 27, wherein the amount of the fuel introduced into said pre-mix zone is in the range of from about 5% to about 50% of the total amount of fuel to be flared by said flare burner. 20
- 29.** The method of claim 28, wherein the amount of the fuel introduced into said pre-mix zone is in the range of from about 10% to about 30% of the total amount of fuel to be flared by said flare burner. 25

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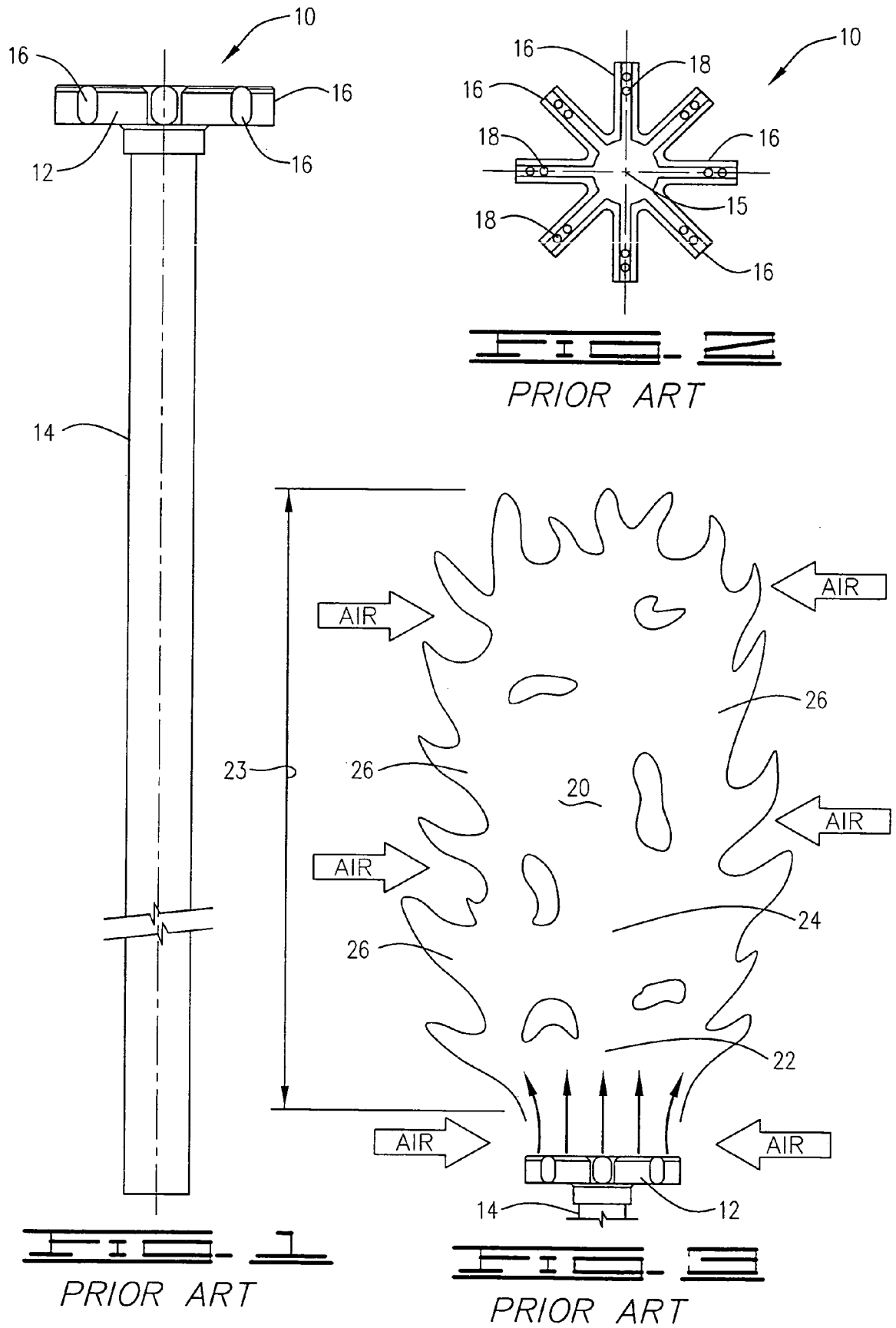
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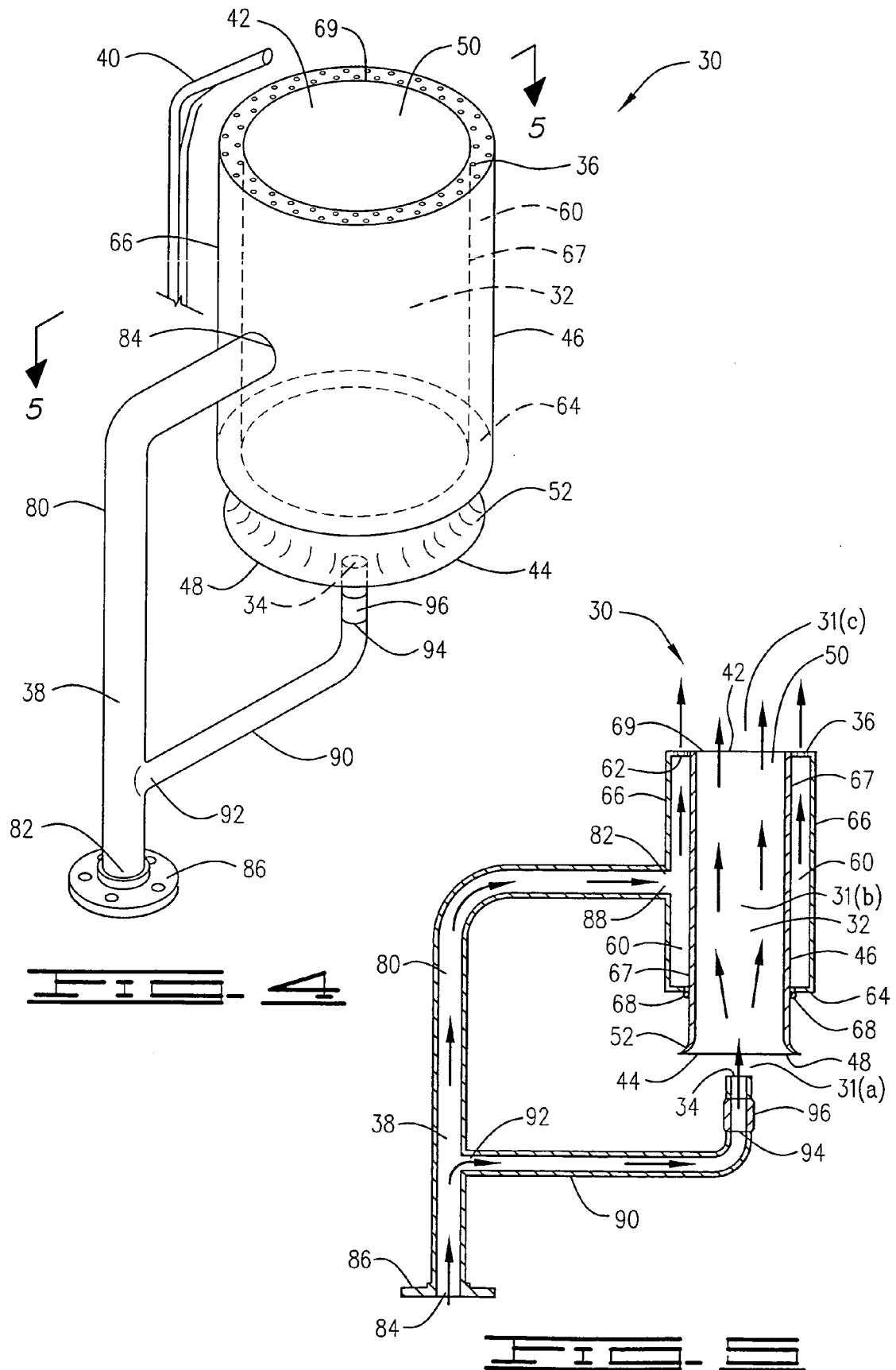
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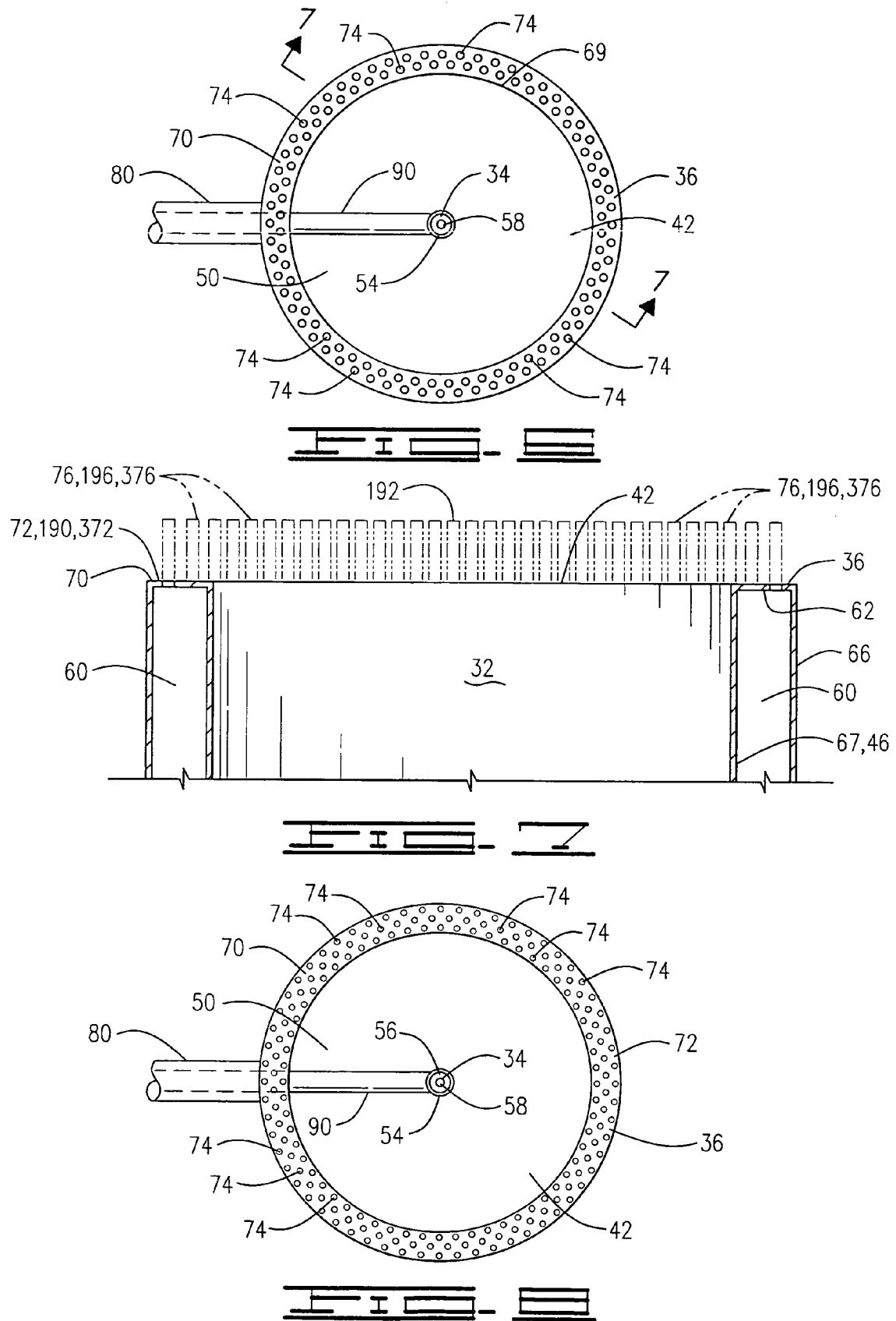
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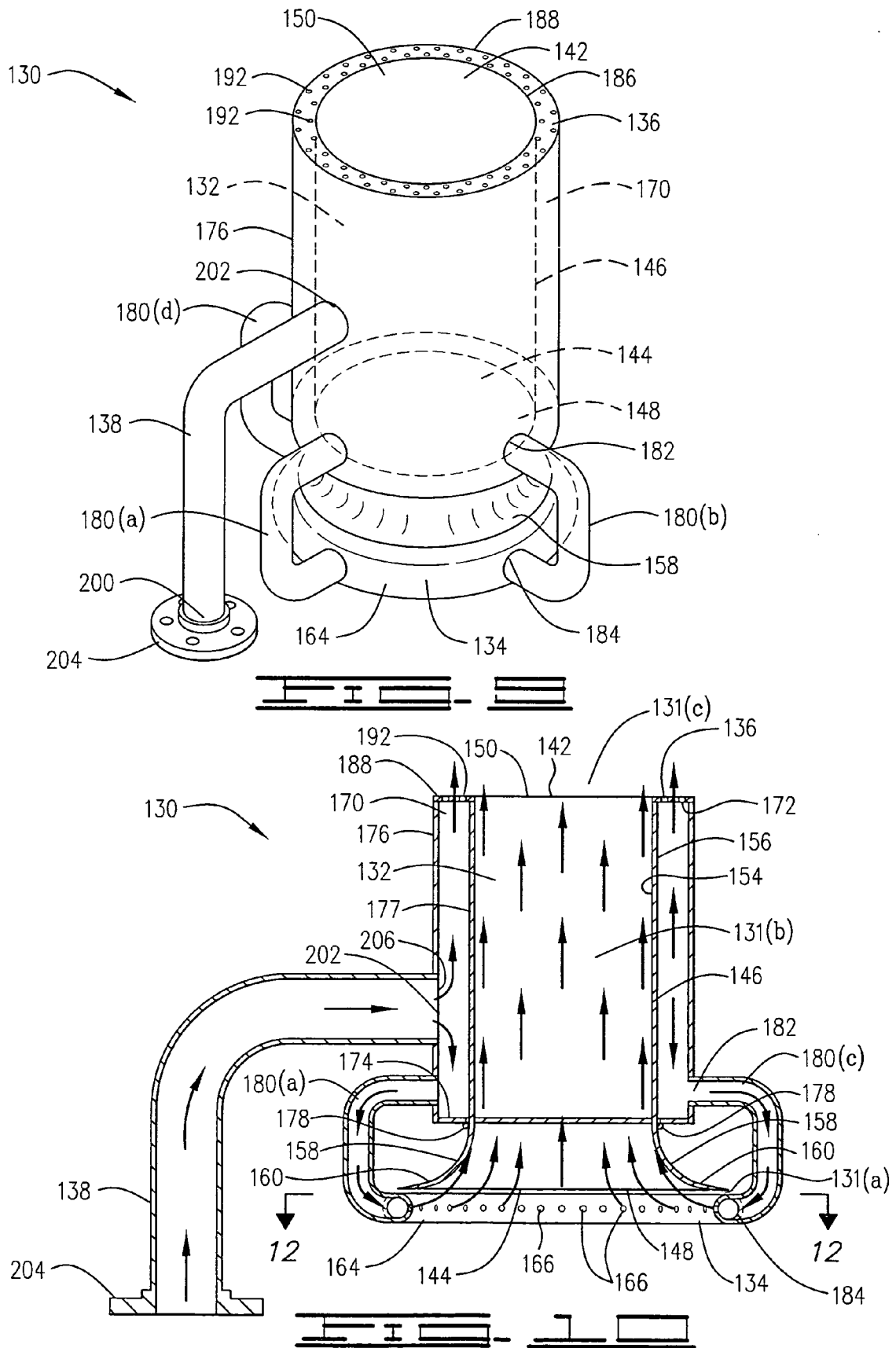
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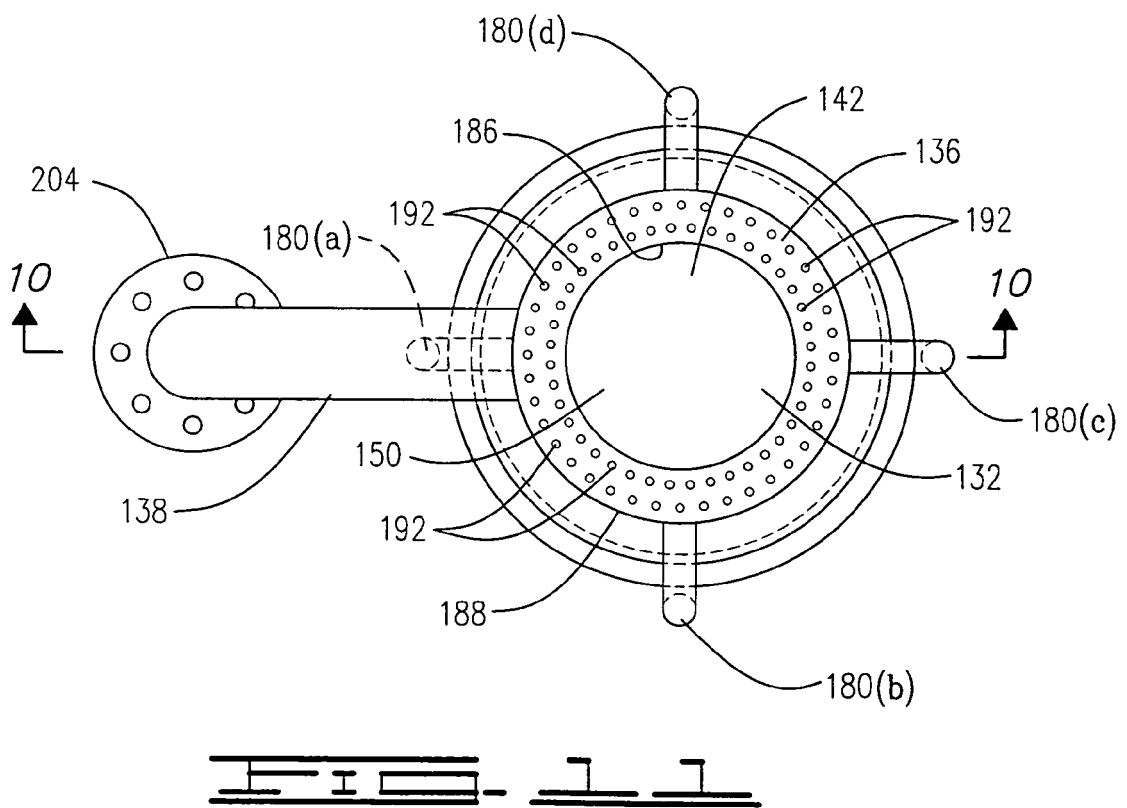
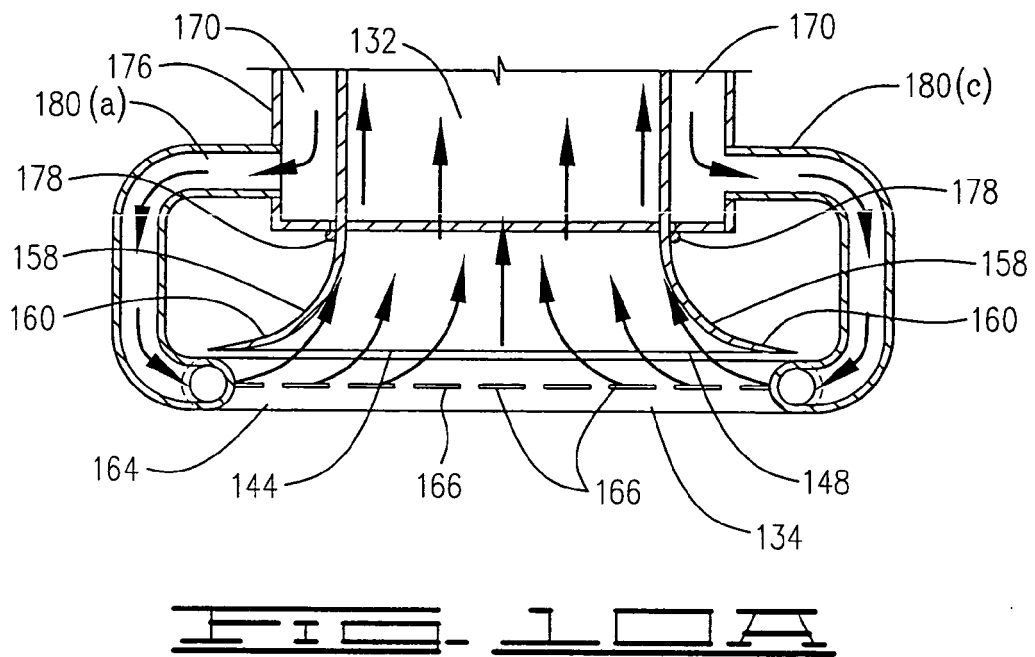
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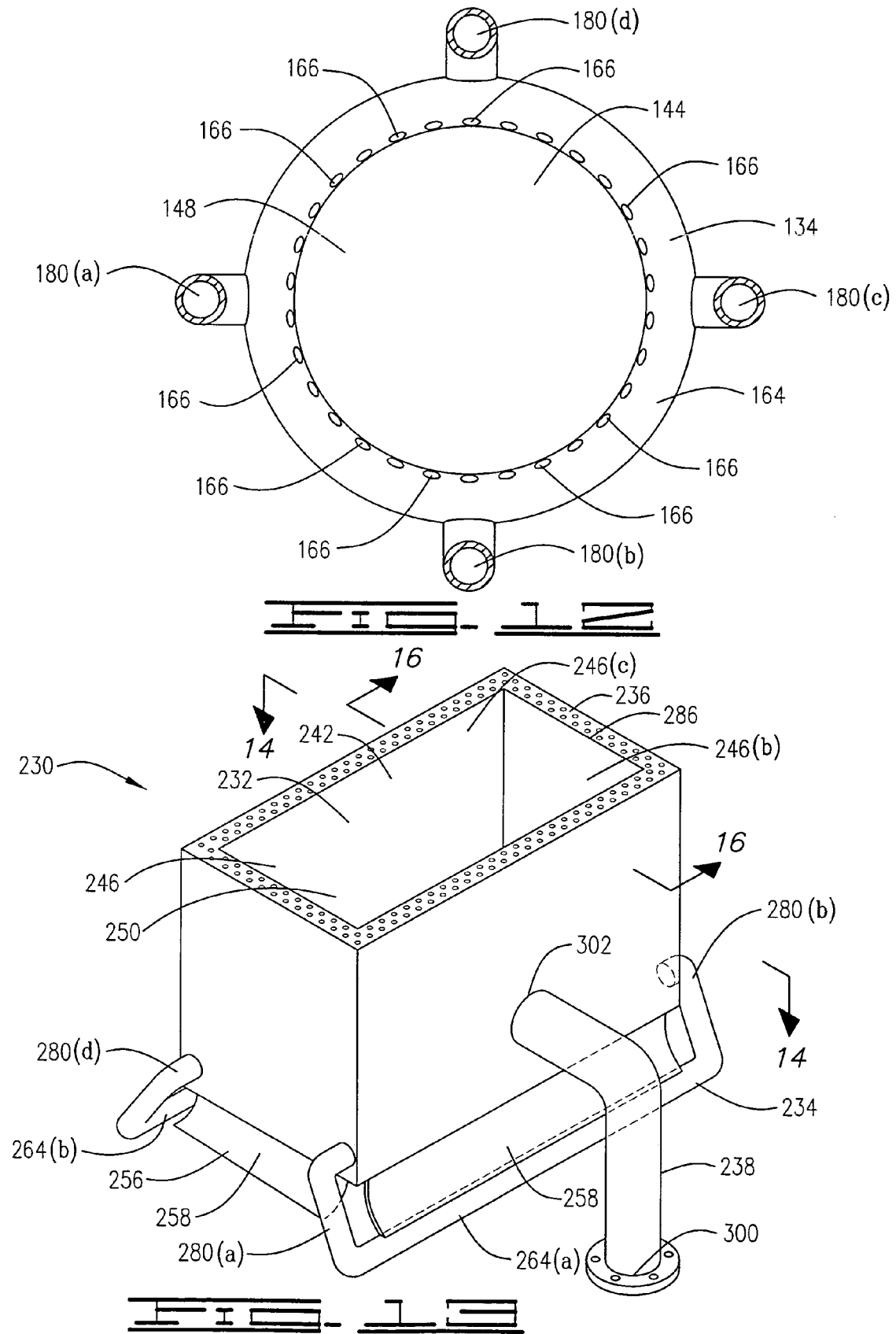


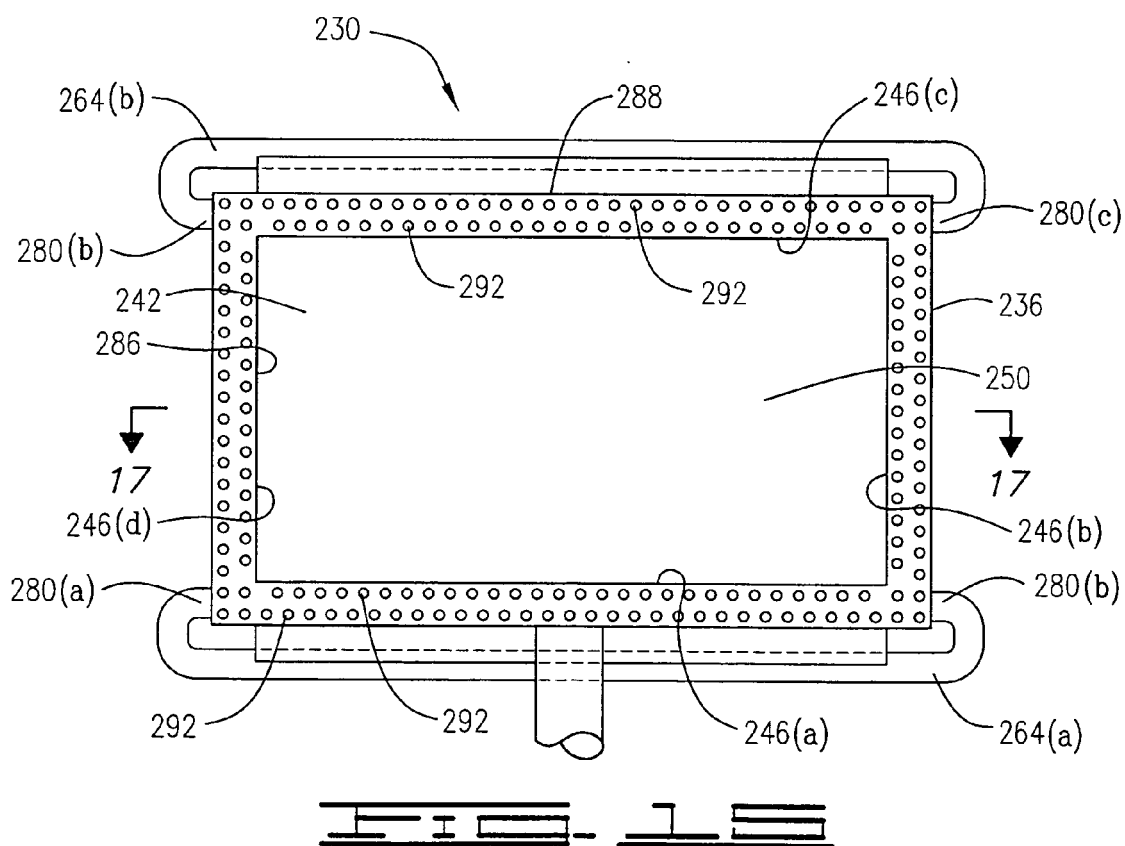
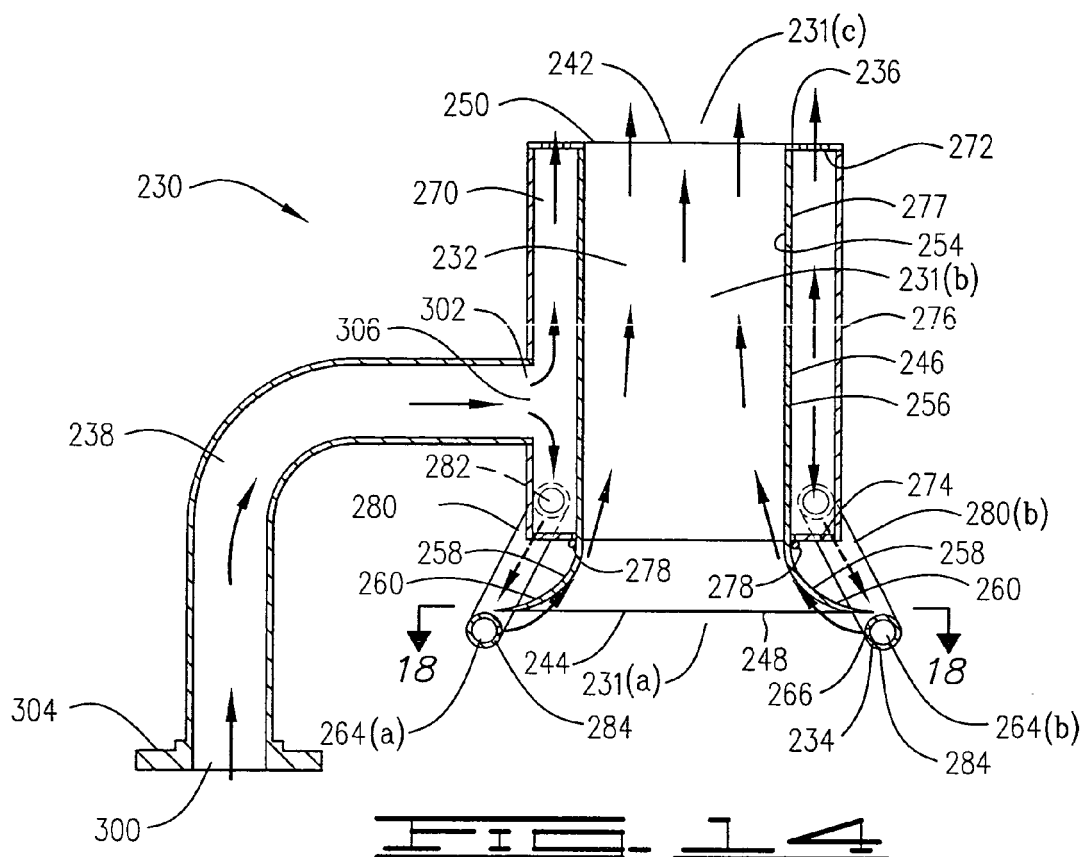


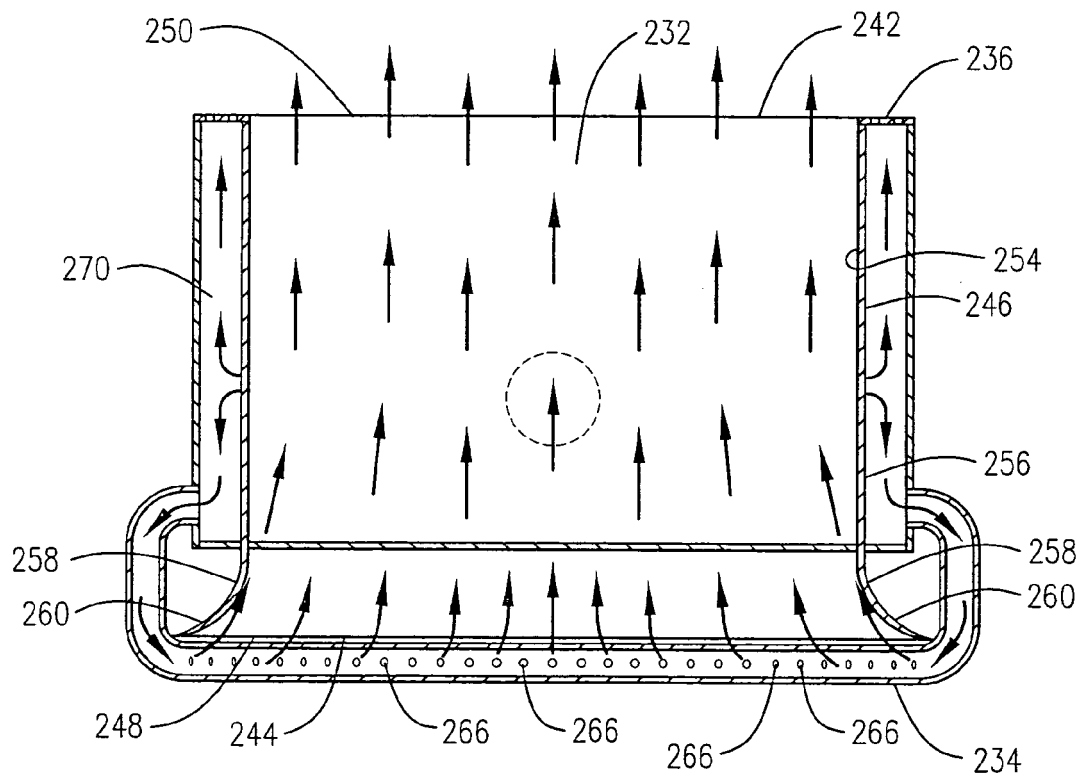
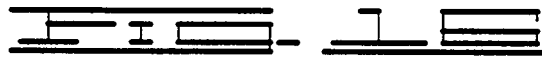
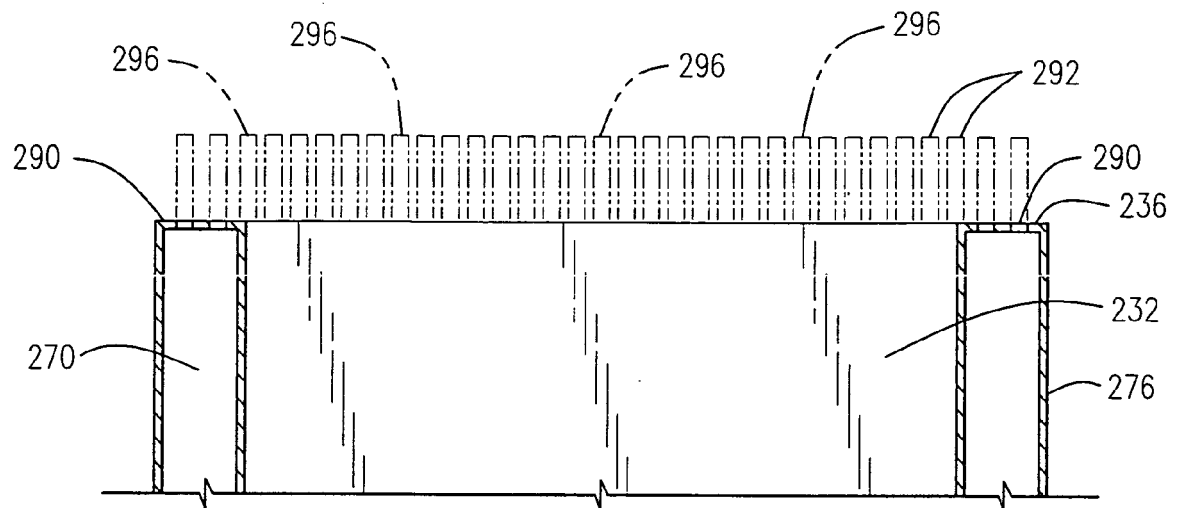












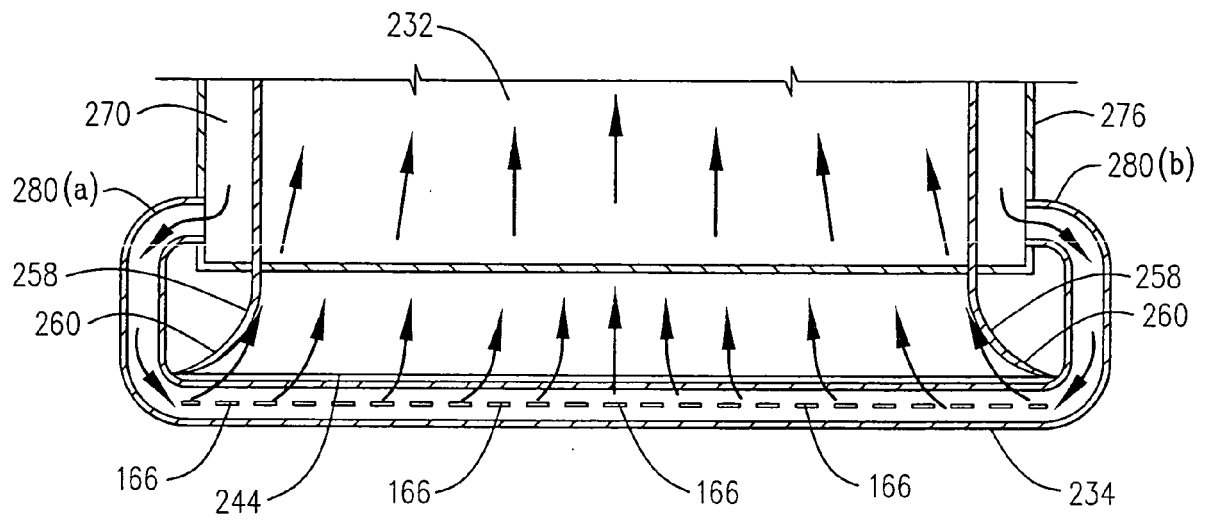


FIG. 17A

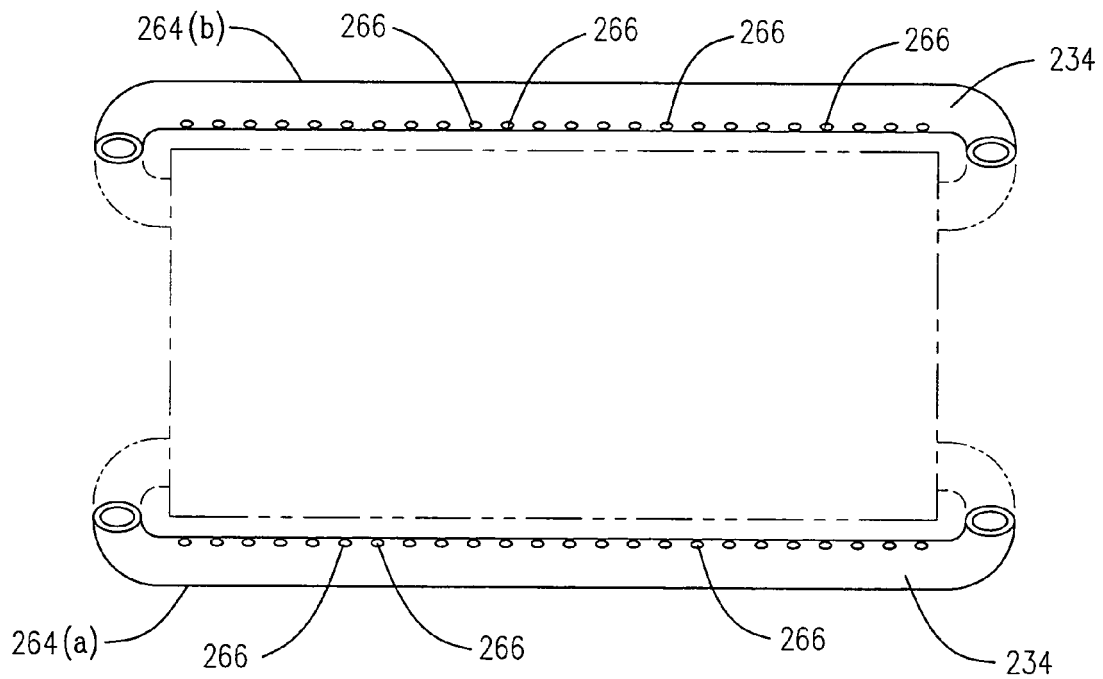
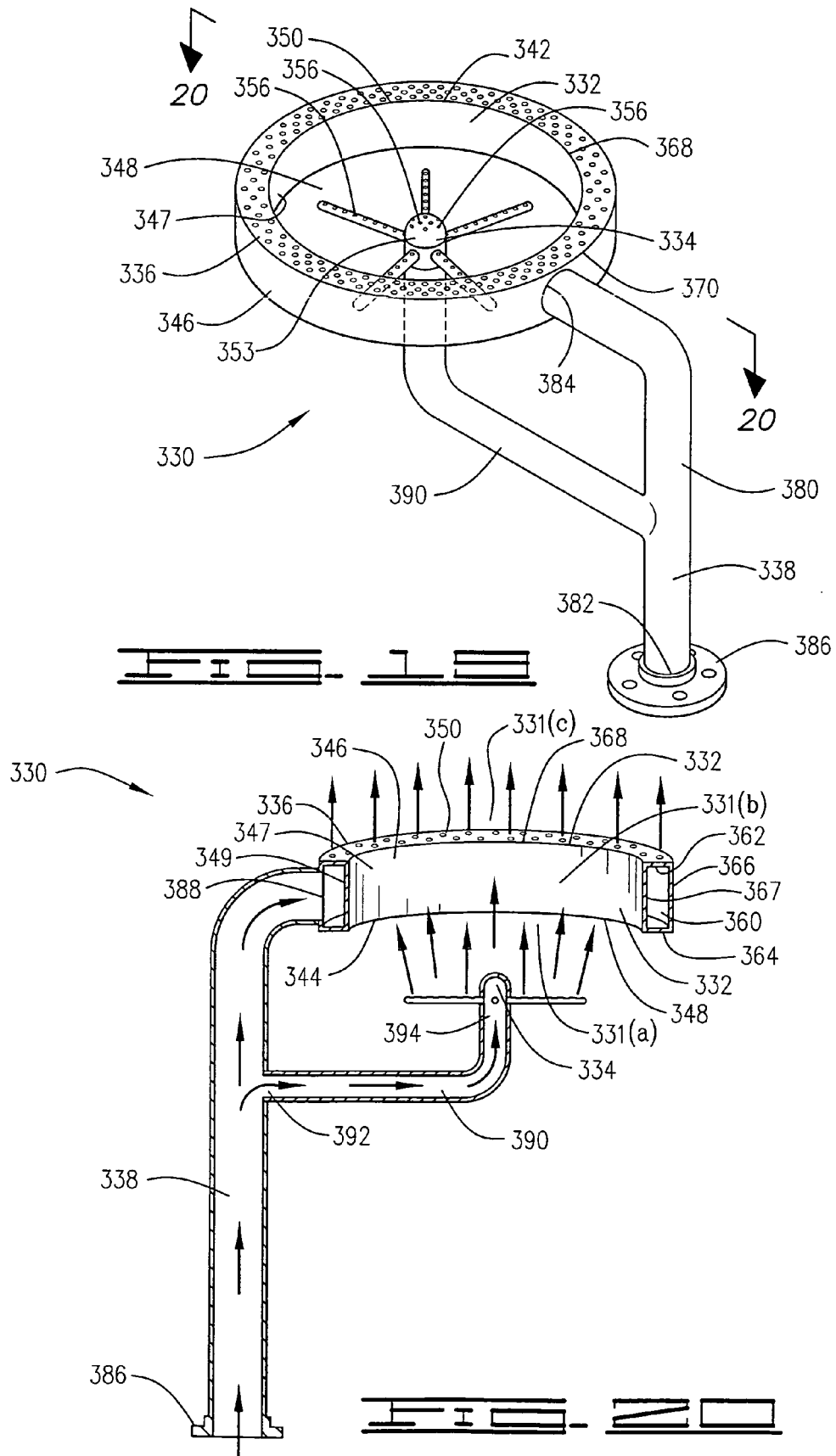
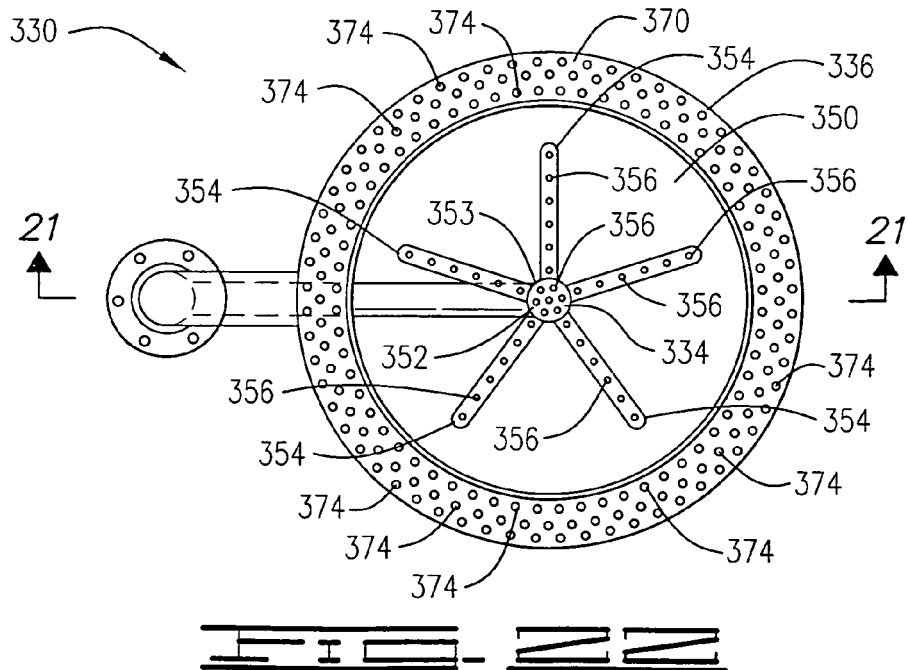
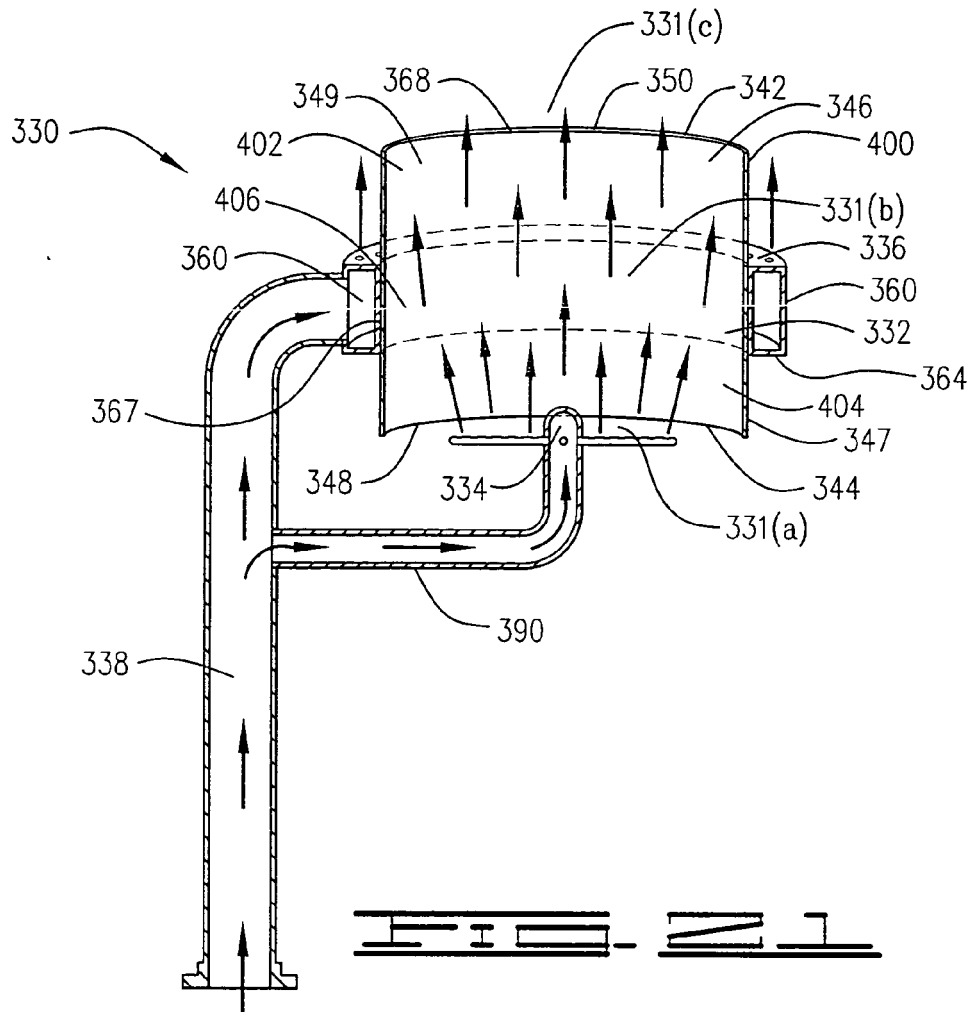


FIG. 18





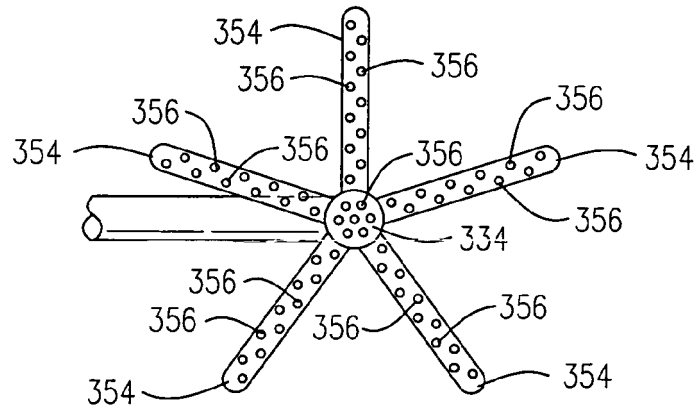


FIG. 23

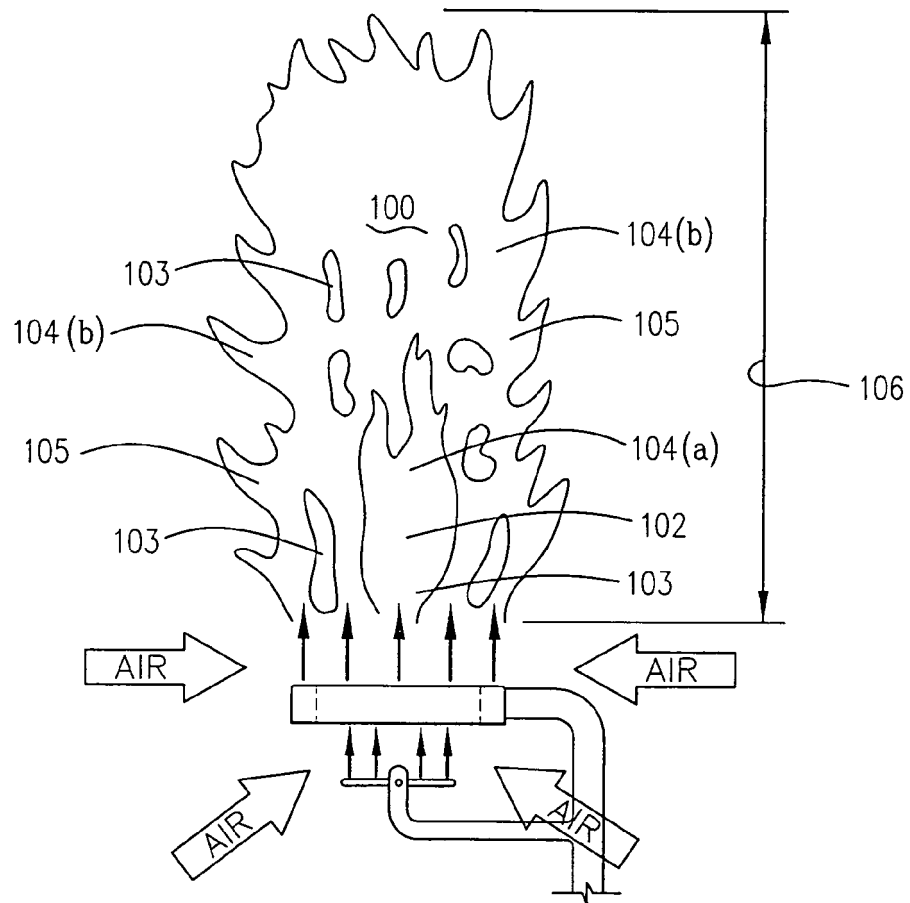


FIG. 24

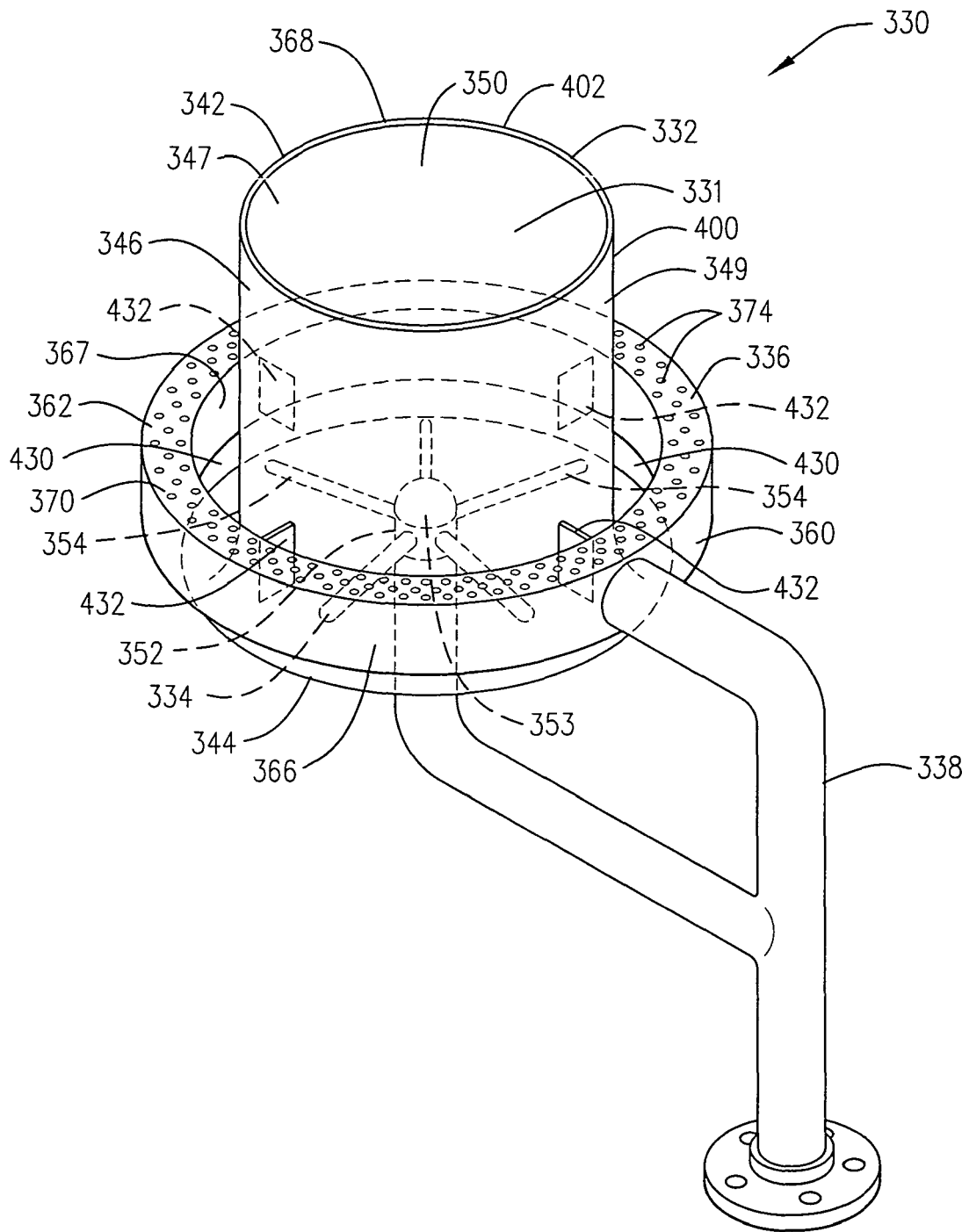


FIG. 25

