

**BURNER ASSEMBLY AND METHOD FOR
REDUCING NO_x EMISSIONS****BACKGROUND**

[0001] Gas burners are employed in a wide variety of commercial and industrial applications. For example, gas burners may be used to vaporize cryogenic fluid such as liquefied natural gas. Specifically, cryogenic fluid can be heated in a submerged combustion vaporizer (SCV). An SCV typically includes heat exchanger tubing and a water tank in which the tubing is submerged. The cryogenic fluid flows through the tubing. The SCV further includes a gas burner that fires into a duct system. The duct system has perforated sections, known as sparger tubes, that direct the burner exhaust to bubble upward through the water in the tank. The exhaust then heats the water and the submerged tubing so that the cryogenic fluid flowing through the tubing also becomes heated. Nitrogen oxides (NO_x) in the exhaust are carried upward from the tank through a flue and discharged into the atmosphere with the exhaust.

[0002] Despite many improvements in gas burners over the years, there remains a continued need for further improvements. For example, there remains a need for burners that are improved in at least one of efficiency, performance, emissions control, and cost.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Fig. 1A is a perspective, cross-sectional view of an embodiment of a burner assembly according to the invention.

[0004] Fig. 1B is a detail of a portion of the burner assembly illustrated in Fig. 1A.

[0005] Fig. 2 is a partial cross-sectional elevation view of a main burner incorporating a water supply and a spray nozzle that can be used in the burner assembly illustrated in Fig. 1A.

[0006] Fig. 3A is a top view of a portion of the main burner illustrated in Fig. 2.

[0007] Fig. 3B is an elevation view of the portion of the main burner illustrated in Fig. 3A.

[0008] Fig. 4 is a cross-sectional elevation view of a distal end portion of the main burner illustrated in Fig. 2.

[0009] Fig. 5A is an elevation view of a portion of a water spray subassembly that can be used in the burner assembly illustrated in Fig. 1.

[0010] Fig. 5B is a top view of the water spray subassembly illustrated in Fig. 5A.

[0011] Fig. 6 is an enlarged cross-sectional elevation view of a distal end portion of the main burner illustrated in Fig. 2.

[0012] Fig. 7 is an enlarged cross-sectional elevation view of another embodiment of a main burner.

DETAILED DESCRIPTION OF THE INVENTION

[0013] Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

[0014] Generally, the burner assembly in the illustrated examples is a water cooled burner that is mostly or completely free of refractory material. A fuel source, which is preferably a supply of natural gas; and an oxidant source, which is preferably an air blower, provide the burner with streams of those reactants.

[0015] The burner assembly preferably includes a water injection system. This system includes a water line that communicates with a water source. The water source is preferably a tank of stored water, but could optionally be the publicly available water supply.

[0016] The burner assembly is especially useful in combination with LNG submerged combustion vaporizers (SCVs). Such vaporizers are useful for heating and/or vaporization of cryogenic and low temperature fluids. Though frequently used with oxygen, nitrogen, ethylene, ammonia, and propane, such vaporizer systems are optionally used for vaporization of LNG, e.g., in base-load and peak-shaving regasification facilities.

[0017] The SCV is an indirect fired heat exchanger with the burner and a process tube coil that may be contained within a single vessel. The design is based on the submerged exhaust principle whereby the burner combustion products are discharged into a water bath, which is used as the heat transfer media for vaporizing the LNG in the tube coil.

[0018] In a single burner SCV, combustion air is generally introduced into the burner at two locations. Most of the air enters an upper volute section (secondary combustion air), with the remainder (primary combustion air) being supplied to the region around the fuel gas injector. With this arrangement, the burner fires upwardly into the central section between the two volutes, where the combustion gases are co-reacted with the secondary combustion air. The secondary combustion air enters the upper volute via a tangential inlet, imparting a swirling motion to the air. This results in intimate mixing with the combustion gases rising from the burner and subsequent gas recirculation back along the axis of the burner before discharging into a set of sparger tubes located under the process tube bundle.

[0019] Single point water injection has been discovered herein to reduce NO_x emissions. By mounting a water spray at the tip of the burner nozzle, the flame temperature can be lowered, thus retarding thermal NO_x. NO_x levels can thus be lowered by at least 50%.

[0020] According to preferred aspects of the present invention, the SCV employs a gas nozzle design with water injection that controls the single burner at maximum operating conditions to produce NO_x emissions, corrected to 3% dry oxygen (O₂), as low as 30 parts per million (ppm) or less. The water injection can be performed using a water spray nozzle cone having, for example, a vertical 60 degree to 90 degree solid cone angle.

[0021] A hollow cone, such as a 210 degree hollow cone, is used to direct water as it is injected into the system. The hollow cone nozzle provides improved results as compared to a solid cone. It is believed that the improved performance results from the fact that the water spray is introduced to combustion air at a different location, thus cooling the flame. Accordingly, NO_x emissions from the burner can be reduced to 20 ppm or lower.

[0022] Referring generally to the figures, this invention provides a burner assembly such as assembly 10 configured for combusting fuel in a combustion zone to reduce NO_x emissions. The burner assembly 10 includes an air nozzle subassembly including an air nozzle conduit 24, such as that provided by a main burner air nozzle and cooling coil, extending along an axis toward the distal end portion of the burner assembly 10. The air nozzle conduit has an interior region to accommodate air flow 56.

[0023] The burner assembly 10 also includes a gas nozzle subassembly such as gas nozzle assembly 28 including a fuel gas conduit 34 (e.g., including a fuel gas pipe) positioned at least partially within the interior region of the air nozzle conduit. The fuel gas conduit is configured to direct fuel in a direction generally along the axis for delivery to or toward the combustion zone. The burner assembly 10 further includes an annular passage defined between the air nozzle conduit and the fuel gas conduit (e.g., an annular passage between the main burner air nozzle and cooling coil 24 and the fuel gas pipe 34). The annular passage is configured to direct air in a direction generally along the axis for delivery to or toward the combustion zone.

[0024] A water spray subassembly is provided including a water outlet configured to direct water at an angle with respect to the axis. The water outlet is further configured to direct water in a direction toward the annular passage for mixing with air upstream of the combustion zone. Water is used by way of example only, as other coolant compositions which may or may not include water may be used.

[0025] The water outlet of the water spray subassembly optionally includes a water spray nozzle such as nozzle 26 or 90. The water spray nozzle can be configured to direct water in a direction radially outwardly with respect to the axis. Specifically, the water spray nozzle, such as nozzle 90, may be configured to direct water at a spray angle A₃ greater than 180 degrees such that an angle A₄ between the axis and a spray direction of the water is less than 90 degrees, or at a spray angle A₃ from 190 to 230 degrees such that an angle A₄ between the axis and a spray direction of the water is less than 85 degrees, or at a spray angle A₃ of about 210 degrees such that an angle A₄ between the axis and a spray direction of the water is about 75 degrees.

[0026] The water spray nozzle can therefore be configured to direct water in a hollow cone such that water is not directed outwardly from the water spray nozzle along the axis A. The water spray subassembly optionally includes a water conduit such as water pipe 44 positioned to extend within the fuel gas conduit, the water spray nozzle being coupled to a distal end of the water conduit. The burner assembly optionally includes an inner annular passage defined between the water conduit and the fuel gas conduit, the inner annular passage being configured to direct fuel in a direction generally along the axis for delivery to the combustion zone. The air nozzle conduit of the air nozzle subassembly may include cooling coils through which water can be circulated.

[0027] This invention also provides a method for retrofitting an existing burner assembly for combusting fuel in a combustion zone with reduced NO_x emissions. The method can be used with a burner assembly having an air nozzle subassembly including an air nozzle conduit, such as the main burner air nozzle and cooling coil 24; a gas nozzle subassembly including a fuel gas conduit, such as the fuel gas pipe 34; and a water spray subassembly including a water outlet, such as nozzle 26 or 90. The method includes configuring the water outlet to direct water at an angle with respect to an axis of the air nozzle conduit and in a direction toward an annular passage between the air nozzle conduit and the fuel gas conduit for mixing with air upstream of the combustion zone.

[0028] The method optionally includes configuring a water spray nozzle, such as nozzle 26 or 90, of the water spray subassembly to direct water in a direction radially outwardly with respect to the axis. Specifically, it includes configuring the water spray nozzle to direct water at a spray angle A3 greater than 180 degrees such that an angle A4 between the axis and a spray direction of the water is less than 90 degrees, or at a spray angle A3 from 190 to 230 degrees such that an angle A4 between the axis and a spray direction of the water is less than 85 degrees, or at a spray angle A3 of about 210 degrees such that an angle A4 between the axis and a spray direction of the water is about 75 degrees.

[0029] The method optionally includes configuring the water spray nozzle to direct water in a hollow cone such that water is not directed outwardly from the water spray nozzle along the axis A.

[0030] This invention also provides a method for using a burner system for combusting fuel in a combustion zone with reduced NOx emissions. The method includes directing fuel in a direction generally along an axis for delivery to the combustion zone through a fuel gas conduit; directing air toward the combustion zone in a direction generally along the axis through an annular passage defined between an air nozzle conduit and the fuel gas conduit; and directing water at an angle with respect to the axis and in a direction toward the annular passage for mixing with air upstream of the combustion zone.

[0031] The directing water step of the method optionally includes directing water in a direction radially outwardly with respect to the axis. For example, it includes directing water at a spray angle A3 greater than 180 degrees such that an angle A4 between the axis and a spray direction of the water is less than 90 degrees, or at a spray angle A3 from 190 to 230 degrees such that an angle A4 between the axis and a spray direction of the water is less than 85 degrees, or at a spray angle A3 of about 210 degrees such that an angle A4 between the axis and a spray direction of the water is about 75 degrees. The directing water step may also include directing water in a hollow cone from a water spray nozzle such that water is not directed outwardly from the water spray nozzle along the axis.

[0032] Referring specifically to Fig. 1A, a burner assembly 10 according to one embodiment of this invention includes a top volute 12 and a bottom volute 14 for the circulation of air. A cone assembly 16 having a water jacket extends between the bottom volute 14 and the top volute 12, thus providing a passage for the flow of combustion products. A partial deck support 18 is associated with the top volute 12. A burner top plate 20 encloses the top volute 12.

[0033] Burner assembly 10 is provided with a main burner 22 incorporating a water supply and a spray nozzle, which will be described in further detail later. Fig. 1B shows a cross-sectional view of a distal end portion of the main burner 22. It includes a spray nozzle 26 as will be described in detail below.

[0034] Referring now to Fig. 2, components of the assembly of the main burner 22 are illustrated in a cross-sectional elevation view. Main burner 22 generally includes an air nozzle subassembly, a gas nozzle subassembly, and a water spray subassembly. Specifically, main burner 22 includes a main burner air nozzle and

cooling coil 24. The main burner air nozzle and cooling coil 24 is coupled to receive a supply of air that generally flows upwardly through the main burner air nozzle and cooling coil 24.

[0035] Main burner 22 also includes a gas nozzle assembly 28 and a water nozzle assembly 30 that is positioned at least partially within the gas nozzle assembly 28. The gas nozzle assembly 28 is attached via a coupling 32 to a fuel gas pipe 34. In turn, fuel gas pipe 34 is coupled via a tee 36 to a fuel gas pipe 38. The fuel gas pipe 38 is in turn coupled via an elbow 40 to provide a fuel gas inlet 42. The inlet 42 is connected to a source of fuel gas (not shown).

[0036] The water nozzle assembly 30 is coupled to a source of water via a water pipe 44. The water pipe 44 is coupled via an elbow 46 to a water pipe 48, which is in turn coupled via an elbow 50 to provide a water inlet 52. The inlet 52 is connected to a source of water or other coolant (not shown).

[0037] As is generally indicated by the arrows in Fig. 2, a passageway is defined for fuel gas flow 54 in a general direction toward the distal end portion of the main burner 22. Concurrently, a passage is defined for water flow 58 toward the distal end portion of the main burner 22 such that the water flow 58 generally flows in a passage or conduit disposed within the fuel gas flow 54. A passageway is defined between the cooling coil 24 and the fuel gas pipe 34 for air flow 56, also in the general direction toward the distal end portion 23 of the main burner 22.

[0038] As will be understood, main burner 22 is configured for combustion of the mixture of fuel and air including the fuel of fuel gas flow 54, the air of air flow 56, and air in the base of volute 14. This combustion generates a flame shown generally at 25 in FIG. 2, extending in a direction along the axis of the main burner 22, which is oriented along a vertical axis A in the embodiment illustrated in Fig. 2. The base of the flame will generally be positioned a short distance beyond the distal end of the main burner 22 along axis A. Referring back to Fig. 1A, the flame will extend toward or into the cone assembly 16.

[0039] Referring to Figs. 3A and 3B, the distal end portion of main burner 22 is illustrated in top and side views, respectively. The main burner 22 includes the water spray nozzle 26 that extends above a top plate 62 of the main burner 22. A pair of lugs 64, offset by 180° in this embodiment, extend radially outward from the

axis A of the main burner 22 for purposes of providing anchorage for an installation tool. Main burner 22 also includes a pipe 66 having a wall with a plurality of ports 68 or holes formed therein through which fuel gas flow 54 from within the pipe 66 can be directed.

[0040] Referring now to Fig. 4, the distal end portion of the main burner 22 is shown in a cross-sectional view in order to illustrate the general directions of fuel gas flow 54 and water flow 58. These flows are directed generally in the same direction along the axis of the main burner 22 (e.g., in a direction parallel or approximately parallel to the axis A). The water flow 58 moves through the water pipe 44 of the water spray subassembly. The fuel gas flow 54 moves in the annular passage defined between the inner surface of the fuel gas pipe 34 and the outer surface of the water pipe 44.

[0041] Referring now to Figs. 4, 5A and 5B, features of the water spray subassembly are illustrated in side elevation and top views, respectively. The water spray subassembly includes a water pipe portion 70 of water pipe 44 extending from a pipe coupling 72. Upper centering members 74 (three being illustrated by way of example only as spokes in this embodiment) extend radially outward from the water pipe portion 70 and is generally located a distance D from the distal end of the pipe coupling 72. The upper centering plate 74 has a thickness T and is configured to provide a centering function such that water pipe portion 70 of water pipe 44 can be centered within the fuel gas pipe 34 of the main burner 22. A lower centering plate 76 is also provided for this purpose.

[0042] The components of the water spray subassembly are shown in Fig. 5A. It has a length L selected depending upon the size of the main burner 22. As is illustrated in Fig. 5B, the upper centering spokes 74 extend outwardly to a distance similar to a diameter of the lower centering plate 76, and such spokes are spaced from one another at an angle A1 (e.g., 120°).

[0043] Referring now to Fig. 6, details of the distal end portion of the main burner 22 are illustrated according to one exemplary embodiment. The water spray nozzle 26 in this embodiment is a solid cone spray nozzle having a water spray cone angle A2. Accordingly, water flow 58 moves through the water pipe portion 70, through the coupling 72, and through a nozzle opening of water spray nozzle 26 to be

directed upwardly from the distal end of the main burner 22 in a solid cone. The water spray cone angle A2 is the included angle of the solid spray cone generated by the water spray nozzle 26.

[0044] The main burner 22 also includes, at its distal end portion, a mounting ring 78, which provides a support for one or more gaskets 80 or seals. The mounting ring 78 and gaskets 80 provide a means for sealing against the plate 62 of the main burner 22, thereby reducing or preventing the flow of fuel gas through the space between the coupling 72 and an aperture 73 in the end plate 62. The seal is shown in Fig. 6 in broken lines, such that the position of the mounting ring 78 and gasket 80 would be adjusted such that the gasket 80 contacts a bottom surface 63 of the end plate 62, thereby providing the seal. This position of the gasket 80 is shown in broken lines in Fig. 6. Thus, substantially all of the fuel gas flow 54 is discharged through the gas nozzle assembly 28 through the ports 68 in the pipe forming the gas nozzle assembly 28.

[0045] Fig. 7 shows another exemplary embodiment of this invention illustrated in a cross-sectional, enlarged view of the distal end portion of a main burner 22. Elements illustrated in FIG. 7 which correspond to the elements described above with respect to FIGS. 1A-6 have been designated by corresponding reference numbers increased by one hundred. The nozzle 90 structure illustrated in Fig. 7 differs somewhat from the nozzle 26 illustrated in Fig. 6. For example, the water spray nozzle 90 provides a hollow cone spray instead of a solid cone water spray.

[0046] More specifically, the nozzle 90 redirects water flow 158 so that it will be discharged in a hollow cone radially outward from the axis A of the main burner. In this way, the water is redirected radially outward and away from the base of the flame that will form at a location beyond the distal end of the main burner along axis A. By using a hollow cone spray shape at the distal end of the burner, it is possible to redirect water flow in a spray shape away from the flame. Also, such a spray shape makes it possible to redirect the water spray toward or into the path of air flow upstream of the combustion zone. Although various nozzle configurations may be used, one suitable nozzle embodiment is a hollow cone spray nozzle such as a Type PJ nozzle available from Delavan Spray Technologies of Delavan Ltd, which is a wholly owned subsidiary of Goodrich Corporation. Such a nozzle is designed to produce a hollow cone spray pattern using an external 'pintle' deflector.

[0047] The water spray nozzle 90 is configured to form a water spray hollow cone angle A3 as illustrated in Fig. 7. Although a wide variety of water spray cone angles A3 may be selected, a spray angle A3 greater than 180° is used for reasons explained later. When the water spray angle A3 is greater than 180°, the angle A4 between the axis of the main burner and a spray direction of the water is less than 90°. The spray angle A3 is in a range from 190° to 230° such that an angle A4 between the axis and the spray direction of the water is from 65 to 85°. For example, in one embodiment the spray angle A3 is about 210° such that an angle A4 between the axis and the spray direction of the water is about 75°.

[0048] The water is introduced into the angular passage 29 that extends between the inner surface of main burner air nozzle and cooling coil 24 and the outer surface of the fuel gas pipe 34 or the outer surface of the gas nozzle assembly 28. In other words, water is directed into the air flow 56 as it passes through the main burner air nozzle and cooling coil 24.

[0049] This direction of the water spray entrains the water into the air flow 56 prior to and upstream of the combustion zone, thus further reducing NOx emissions generated by the flame of the burner. Additionally, the water spray encourages mixing with air upstream of the combustion zone rather than directing water along the axis A into the base of the flame.

[0050] Although the water is introduced into the air using a water spray nozzle at the distal end portion of the burner assembly in the illustrated embodiments, it is contemplated that the water could be introduced at any location in the air upstream from the location of the flame, preferably within the passageway through which air flow 56 is introduced into the area of combustion. For example, water can be introduced at any location along the path of water flow 58, including at the base in the area of the elbow 46 or anywhere else along the path of water flow 58.

[0051] Alternatively, water flow can be introduced into the air flow 56 radially inwardly from the structure of the main burner air nozzle and cooling coil 24. For example, water can be introduced from the cooling coil into the air flow 56 by placing one or more nozzles in the cooling coil facing radially inward toward the fuel gas pipe 34 or gas nozzle assembly 28. In other words, a portion of the water flowing through the cooling coil can be utilized for the reduction of NOx emissions by

directing it radially inward to be entrained within the air flow 56 upstream of the combustion zone.

Examples

[0052] Data was taken for NO_x reduction in a water injection nozzle test. Stack emissions data points were recorded on an LNG vaporizer. Readings were taken with a system incorporating the water injection nozzle shown in FIG. 6 (~92° solid cone spray pattern A2). Test readings were also taken with the water injection nozzle shown in FIG. 7 (210° hollow cone spray pattern A3).

[0053] The test readings are reported in the following table:

Nozzle Type	LNG Flow (MMSCFD)	CO Reading	NO _x Reading
solid cone spray pattern	100	2.8 PPM	30.4 PPM
solid cone spray pattern	145	4.0 PPM	23.5 PPM
solid cone spray pattern	190	2.9 PPM	25.8 PPM
hollow cone spray pattern	100	1.3 PPM	24.4 PPM
hollow cone spray pattern	145	2.3 PPM	17.7 PPM
hollow cone spray pattern	190	1.2 PPM	21.1 PPM

Abbreviations used:

MMSCFD – Million Standard Cubic Feet per Day

CO – Carbon Monoxide

NO_x – Generic term for the mono-nitrogen oxides NO and NO₂ (nitric oxide and nitrogen dioxide)

PPM – Parts per Million

[0054] The foregoing test illustrates that a further reduction of NO_x occurs when the water spray nozzle 26 of Fig. 6 is replaced with the water spray nozzle 90 with a hollow cone spray instead of a solid cone water spray. More specifically, water spray nozzle 90 redirects water flow 158 so that it will extend in a hollow cone radially outwardly from the axis A of the main burner. In this way, the water is redirected radially outward and away from the base of the flame that will form at a location beyond the distal end of the main burner along axis A. This facilitates entrainment of water into the air upstream of the point where the air enters the combustion zone, thus reducing NO_x emissions.

[0055] While embodiments of the invention have been shown and described herein, it will be understood that such embodiments are provided by way of example only. Numerous variations, changes and substitutions will occur to those skilled in the art without departing from the spirit and scope of the invention. Accordingly, it is intended that the disclosure herein covers all such variations and modifications as fall within the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. A burner assembly for combusting fuel in a combustion zone to reduce NOx emissions, comprising:

an air nozzle subassembly including an air nozzle conduit extending along an axis toward a distal end portion of the burner assembly, the air nozzle conduit having an interior region to accommodate air flow;

a gas nozzle subassembly including a fuel gas conduit positioned at least partially within the interior region of the air nozzle conduit, the fuel gas conduit configured to direct fuel in a direction generally along the axis for delivery to the combustion zone;

a passage arranged between the air nozzle conduit and the fuel gas conduit, the passage configured to direct air in a direction generally along the axis for delivery to the combustion zone; and

a water spray subassembly including a water outlet configured to direct water at an angle with respect to the axis, the water outlet further configured to direct the water in a direction toward the passage for mixing with the air upstream of the combustion zone.

2. The burner assembly of claim 1, wherein the water outlet comprises a spray nozzle.
3. The burner assembly of claim 2, wherein the spray nozzle is configured to direct the water in a direction radially outward with respect to the axis.
4. The burner assembly of claim 3, wherein the spray nozzle is configured to direct the water radially outward at a spray angle greater than 180 degrees such that an angle between the axis and a spray direction of the water is less than 90 degrees.
5. The burner assembly of claim 4, wherein the spray nozzle is configured to direct the water radially outward at a spray angle from 190 to 230 degrees such that an angle between the axis and a spray direction of the water is less than 85 degrees.
6. The burner assembly of claim 5, wherein the spray nozzle is configured to direct the water radially outward at a spray angle of about 210 degrees such that an angle between the axis and a spray direction of the water is about 75 degrees.

7. The burner assembly of claim 3, wherein the spray nozzle is configured to direct water radially outward in a hollow cone such that the water is not directed outward from the spray nozzle along the axis.
8. The burner assembly of claim 3, wherein the water spray subassembly further comprises a water conduit extending within the fuel gas conduit, and the spray nozzle is connected to a distal end of the water conduit.
9. The burner assembly of claim 8, further comprising an inner annular passage disposed between the water conduit and the fuel gas conduit, the inner annular passage configured to direct the fuel in a direction generally along the axis for delivery to the combustion zone.
10. The burner assembly of claim 1, wherein the air nozzle conduit comprises cooling coils through which the water can be circulated.
11. A method for combusting fuel in a combustion zone to reduce NO_x emissions, comprising:

providing fuel through a fuel gas conduit in a direction generally along an axis for delivery to the combustion zone;

providing air toward the combustion zone in a direction generally along the axis through an annular passage disposed between an air nozzle conduit and the fuel gas conduit; and

providing water at an angle with respect to the axis and in a direction toward the annular passage for mixing with air upstream of the combustion zone.
12. The method of claim 11, wherein the providing water comprises directing the water in a direction radially outward with respect to the axis.
13. The method of claim 12, wherein the providing water comprises directing the water radially outward at a spray angle greater than 180 degrees such that an angle between the axis and a spray direction of the water is less than 90 degrees.
14. The method of claim 13, wherein the providing water comprises directing the water radially outward at a spray angle from 190 to 230 degrees such that an angle between the axis and a spray direction of the water is less than 85 degrees.

15. The method of claim 14, wherein the providing water comprises directing the water radially outward at a spray angle of about 210 degrees such that an angle between the axis and a spray direction of the water is about 75 degrees.

16. The method of claim 11, wherein the providing water comprises directing water radially outward in a hollow cone from a water spray nozzle such that the water is not directed outward from the water spray nozzle along the axis.