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(54) **LOW CONSUMPTION ASSISTED FLARE APPARATUS AND METHOD**

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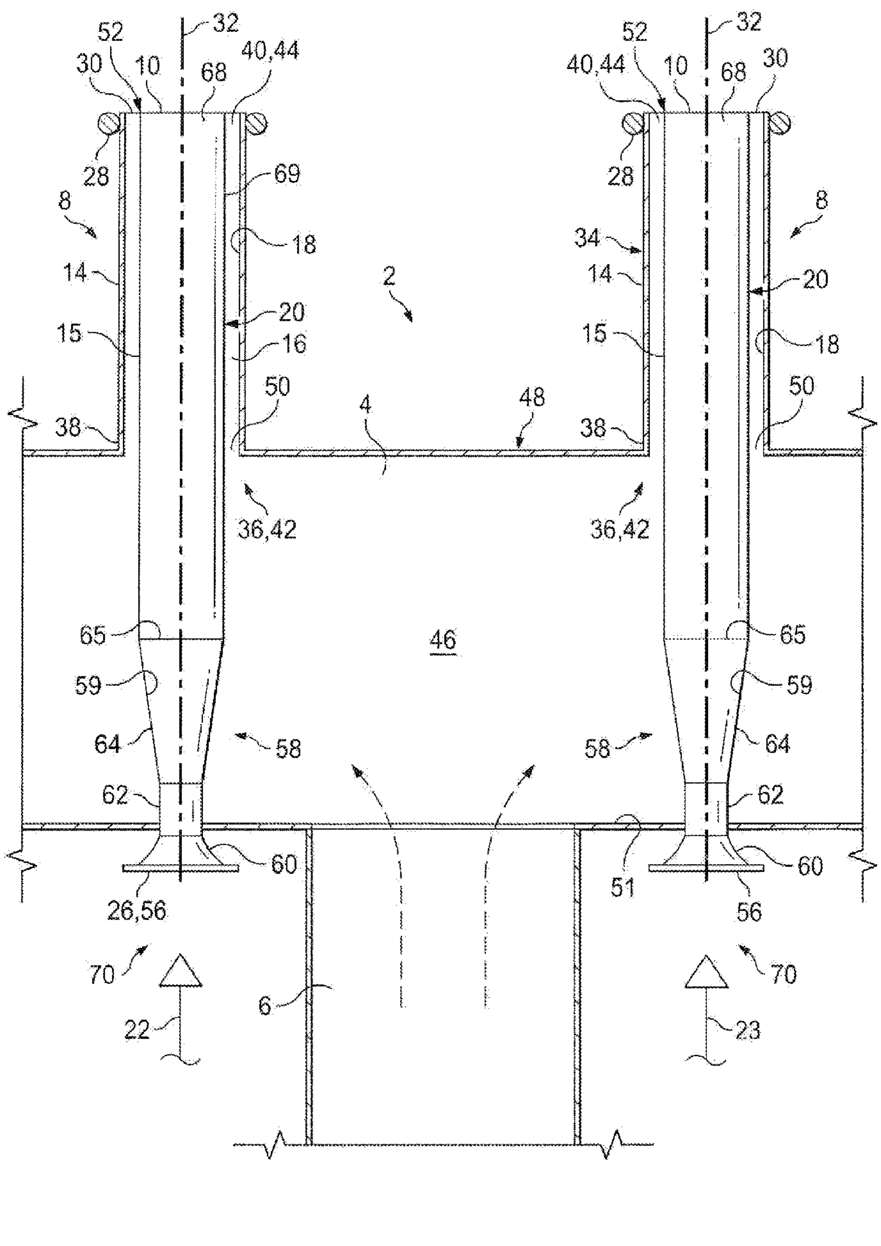
(57) **ABSTRACT**

An assisted flare apparatus and method which increase the amount of air which is inducted into each of the flare combustion tip assemblies used in the apparatus by injecting the steam or other assist media used in each tip assembly into an inner conduit of the tip assembly which is configured such that at least a lower portion of the inner conduit is in the form of a venturi flow structure in which a straight venturi flow section is followed by a diverging venturi bell outlet section.



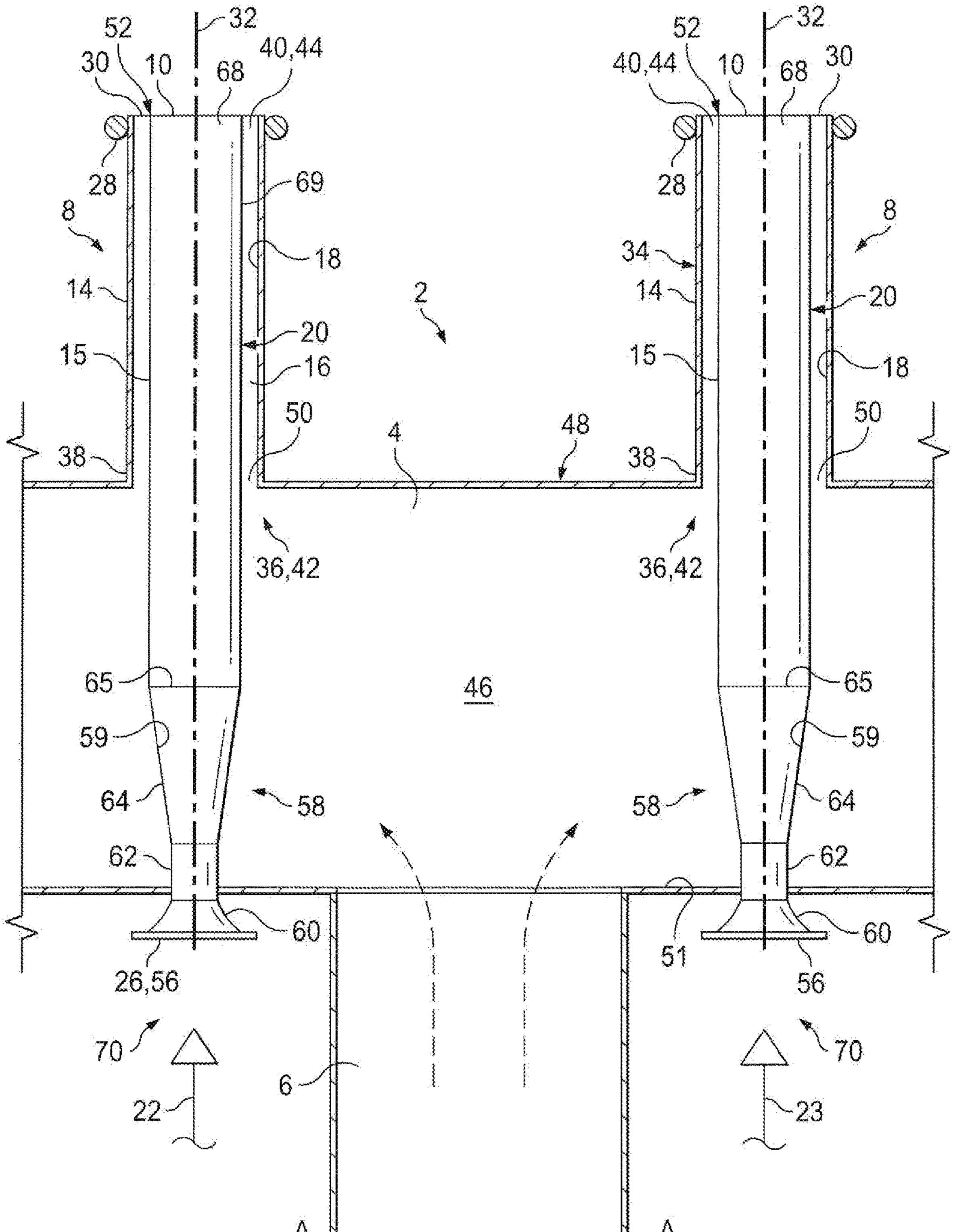

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FIG. 1

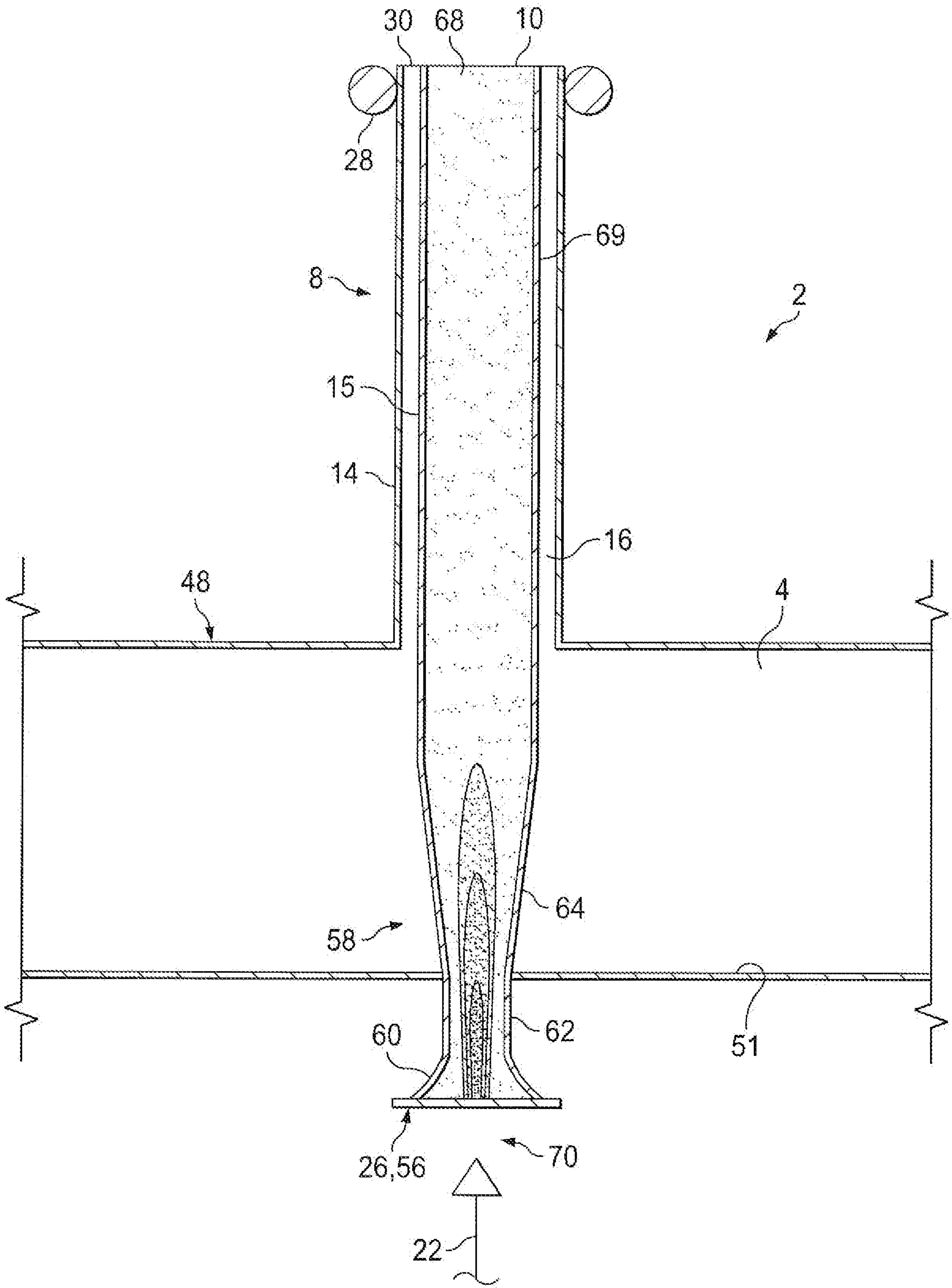

FIG. 2

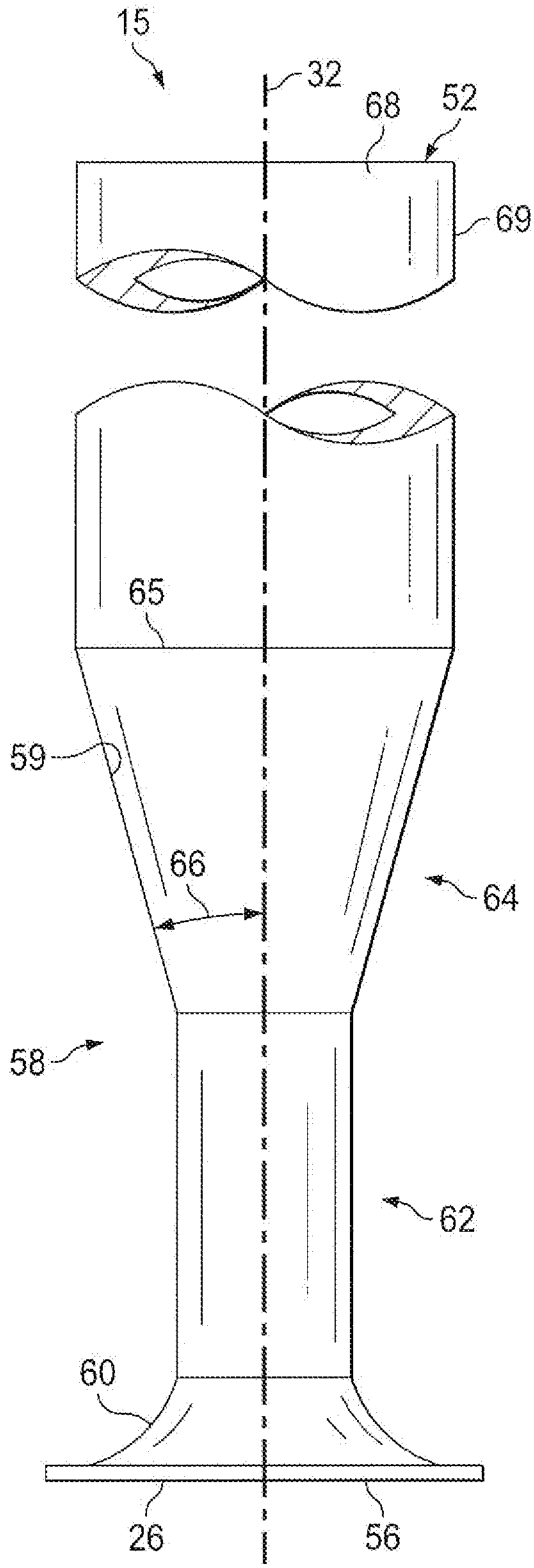

FIG. 3

LOW CONSUMPTION ASSISTED FLARE APPARATUS AND METHOD

FIELD OF THE INVENTION

[0001] The present invention relates to flare apparatuses and methods in which steam or other entrainment media is injected to (i) induce additional air into the flare combustion zone, (ii) create turbulence which enhances mixing and improves combustion efficiency, (iii) inhibit smoke generation, and (iv) provide reduced emissions.

BACKGROUND OF THE INVENTION

[0002] Flare systems are used in many applications to burn off fuels, waste gases, and other gases that can be harmful if vented to the atmosphere without burning. Flare systems are widely used in the refining, chemical, petrochemical, petroleum production, and other industries for burning flammable and/or toxic materials which are released due to upset or startup conditions, or which are released simply as a result of the process itself.

[0003] Most utility-type flares are comprised of a pipe with a flame stabilization device at the top thereof. Flare gas flows through the pipe and burns at the stabilization device. However, when the flow of flare gas becomes too great for the amount of air that will naturally mix with the flare gas at the combustion zone, the combustion of the flare gas occurs under sub-stoichiometric conditions. When the flare gas is burned under sub-stoichiometric conditions, smoke will typically be produced. Smoke produced by flare systems contributes to smog. In addition, the combustion of the flare gas under sub-stoichiometric conditions produces atmospheric emissions such as: nitrogen oxides (NO_x); carbon monoxide (CO); unburned hydrocarbon emissions (UHC's); and particulates (PM10).

[0004] To reduce smoke production, as well as the production of harmful emissions, steam-assisted flare assemblies have been used in which steam is injected (i) into the flare gas stream flowing upwardly through the flare stack, (ii) around the upper end of the stack, and/or (iii) into one or more tubes within the flare stack. Depending upon the type and location of the injection system, the injected steam can operate to: induce additional air into the combustion mixture; create increased turbulence for better mixing; lower the combustion flame temperature for reduced NO_x emissions and less thermal cracking; shape the combustion flame; cool the flare tip; and/or reduce noise.

[0005] However, although the benefits provided by steam-assisted flare systems can be significant, the fuel costs and other costs incurred for producing and delivering the amount of high pressure steam which these systems require can also be substantial. In addition, due to the offsetting emissions which are produced as a result of the combustion of gas or liquid fuels for generating the steam used in the steam-assisted flare systems, the benefits provided by these systems for the flare combustion process are somewhat nullified.

[0006] Consequently, a need exists for an improved assisted flare apparatus and method in which the amount of steam or other entrainment media required for inducing a desired amount of air into the flare combustion mixture to provide a smokeless operation is significantly reduced.

SUMMARY OF THE INVENTION

[0007] The present invention satisfies the needs and alleviates the problems discussed above. In the inventive apparatus and method, venturi structures are used in one or more flare tip nozzle assemblies to increase the amount of air which is inducted into the flare combustion zone. The inventive apparatus and method are well suited for use in elevated flares, but can also be used in enclosed flares and other types of flare systems.

[0008] In one aspect, there is provided an apparatus for combusting a flare gas comprising one or more flare nozzle assemblies. Each of the flare nozzle assemblies preferably comprises: (i) an outer conduit having a longitudinal axis, a rearward longitudinal end, and a forward longitudinal end and (ii) an inner conduit for a flow of an entrainment media and air. The inner conduit preferably comprises: an inlet opening at a rearward longitudinal end of the inner conduit; a discharge opening at a forward longitudinal end of the inner conduit; a longitudinally extending straight venturi section having a substantially constant interior cross-sectional area; and a longitudinally extending diverging venturi section which increases in interior cross-sectional area as the diverging venturi section extends forwardly from a forward longitudinal end of the straight venturi section. Each flare nozzle assembly also preferably comprises an injection structure positioned outside of the inlet opening of the inner conduit for injecting the entrainment media into the inlet opening of the inner conduit.

[0009] The inner conduit of each nozzle assembly preferably extends into the rearward longitudinal end of the outer conduit such that (i) the rearward longitudinal end of the inner conduit is positioned outside of the rearward longitudinal end of the outer conduit and (ii) the discharge opening of the inner conduit is positioned substantially at the forward longitudinal end of the outer conduit. In addition, a longitudinally extending flow annulus for the flare gas is formed in the outer conduit between the interior surface of the outer conduit the exterior of the inner conduit. The longitudinally extending flow annulus (i) laterally surrounds the longitudinal axis of the outer conduit, (ii) has an inlet opening at the rearward longitudinal end of the outer conduit for receiving the flare gas, and (iii) has a discharge opening for the flare gas at the forward longitudinal end of the outer conduit.

[0010] In another aspect, there is provided a method of combusting a flare gas which preferably comprises the steps of: (a) delivering the flare gas upwardly through an annulus between an inner surface of an outer conduit and an exterior of an inner conduit, the inner conduit extending upwardly into a lower end of the outer conduit, the annulus having a discharge opening at an upper end of the outer conduit, the inner conduit having a discharge opening substantially at the upper end of the outer conduit, and the inner conduit having an inlet opening at a lower end of the inner conduit which is positioned outside of and spaced downwardly from the lower end of the outer conduit; (b) injecting an entrainment media into the inlet opening of the inner conduit from an injection structure which is spaced downwardly from the inlet opening of the inner conduit so that the entrainment media inducts an amount of air into the inner conduit as the entrainment media travels through a gap between the injection structure and the inlet opening of the inner conduit; and (c) increasing the amount of air inducted into the inner conduit by the entrainment media in step (b) by delivering the entrainment media upwardly through a venturi structure, which forms at least a lower portion of the inner conduit, and out of the discharge opening of the inner conduit substantially at the upper end of the outer conduit. The venturi structure comprises (i) an upwardly extending straight venturi section of the inner conduit having a substantially constant interior cross-sectional area followed by (ii) a diverging venturi section of the inner conduit which increases in interior cross-sectional area as it extends upwardly from the straight venturi section.

[0011] Further aspects, features, and advantages of the present invention will be apparent to those in the art upon examining the accompanying drawings and upon reading the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** is an elevational side view illustrating an embodiment **2** of the flare apparatus provided by the present invention.

[0013] FIG. **2** is an elevational side view of a portion of the inventive flare apparatus **2** illustrating a flare tip nozzle assembly **8** used in the inventive flare apparatus **2**.

[0014] FIG. **3** is an elevational view of an inner conduit **15** used in the inventive flare apparatus **2**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0015] An embodiment **2** of the flare apparatus provided by the present invention is illustrated in FIGS. **1**-**3**. The inventive flare apparatus **2** comprises a plenum **4** on the upper end of a flare stack **6**. A flare gas is delivered to the plenum **4** through the flare stack **6**. The inventive flare apparatus **2** further comprises one or more (preferably a plurality) of flare tip nozzle assemblies **8** which receive the flare gas from the plenum **4** and discharge the flare gas from the upper (or forward) ends **10** of the nozzle assemblies **8** for combustion. As used herein and in the claims, the term "flare gas" can refer to any type of single or two phase fuel, waste gas, or other stream from a plant, refinery, oil or gas production site, or other source which is suitable for combustion in a flare system.

[0016] Each of the one or more flare tip nozzle assemblies **8** of the inventive apparatus **2** preferably comprises: an outer conduit **14**; an inner conduit **15**; a flow annulus **16** for the flare gas which is formed between the inner surface **18** of the outer conduit **14** and the exterior surface **20** of the inner conduit **15**; an injection structure **22** for injecting steam or other entrainment media into the lower (or rearward) longitudinal end **26** of the inner conduit **15**; and an exterior clean-up ring or assembly **28** positioned around the upper (or forward) longitudinal end **30** of the outer conduit **14**.

[0017] The outer conduit **14** of each nozzle assembly **2** comprises; a longitudinal axis **32**; a longitudinally extending outer wall **34** which surrounds the longitudinal axis **32**; an inlet opening **36** at the lower (or rearward) longitudinal end **38** of the outer conduit **14**; and a discharge opening **40** at the upper (or forward) longitudinal end **30** of the outer conduit **14**. The flow annulus **16** formed between the inner surface **18** of the outer conduit **14** and the exterior **20** of the inner conduit **15** also surrounds the longitudinal axis **32** of the outer conduit and extends longitudinally from the lower longitudinal end **38** to the upper longitudinal end **30** of the outer conduit **14**. The flow annulus **16** has an inlet opening **42** at the lower longitudinal end **38** of the outer conduit **14** and a discharge opening **44** at the upper longitudinal end **30** of the outer conduit **14**.

[0018] The outer conduit **14** is preferably cylindrical but can alternatively have an elliptical, oval, rectangular, square, triangular or other cross-sectional shape. In addition, although the interior of the outer conduit **14** will preferably have a substantial constant interior cross-sectional area along its entire length, it will be understood that the entire length or any portion of the longitudinal length of the interior surface **18** of the outer conduit **14** can alternatively have a converging or diverging shape.

[0019] The outer conduit **14** of each nozzle assembly **8** is connected to the plenum **4** in a manner which places the inlet opening **42** of the nozzle flow annulus **16** in fluid communication with the interior **46** of the plenum **4**. In the embodiment **2** of the inventive flare apparatus illustrated in FIGS. **1** and **2**, the lower end **38** of the outer conduit **14** is connected to the upper wall **48** of the plenum **4** such that the inlet opening **42** of the flow annulus **16** is positioned over a flow opening **50** formed through the upper wall **48**. Alternatively, a lower portion of the outer conduit **14** can extend through an opening in the upper wall **48** of the plenum **4** such that the lower end **38** of the outer conduit **14** and the inlet opening **42** of the flow annulus **16** would be located inside the interior **46** of the plenum **4**.

[0020] The upper wall **48** of the plenum **4** can be flat, outwardly dished, or have any other shape.

[0021] The inner conduit **15** of each nozzle assembly **8** extends upwardly (or forwardly) through the lower wall **51** of the plenum **4** and into the lower end **38** of the outer conduit **14** such that (a) the upper (or forward) longitudinal end **52** of the inner conduit **14** is located substantially at (i.e., preferably within ±40 inches of, more preferably within ±30 inches of, more preferably within ±20 inches of, more preferably within 10 inches of, more preferably within ±5 inches of, more preferably within ±2.5 inches of, more preferably within ±+1 inch of, and most preferably at) the upper longitudinal end **30** of the outer conduit **14**, (b) the lower (or rearward) longitudinal end **26** of the inner conduit **15** is located outside of and spaced downwardly (or rearwardly) from the lower longitudinal end **38** of the outer conduit **14**, and (c) the inlet opening **56** at the lower end **26** of the inner conduit **15** is located outside of the plenum **4**. The lower wall **51** of the plenum can be flat, outwardly dished, or have any other desired shape.

[0022] The inner conduit **15** of each nozzle assembly **8** is configured such that at least a lower portion of the inner conduit **15** is in the form of a venturi flow structure **58** for the steam or other entrainment media which is injected into the lower end **26** of the inner conduit **15**. The flow of the steam or other entrainment media through the venturi flow structure **58** of the inner conduit **15** operates to further reduce the pressure at the lower inlet opening **56** of the inner conduit **15** so that, as compared to an entirely straight inner conduit design with no venturi flow, significantly more air is inducted by the entrainment media into the inner conduit **15**.

[0023] The venturi flow structure **58** of the inner conduit **15** preferably comprises: a venturi inlet bell structure **60** at the lower (or rearward) end **26** of the inner conduit **15**; a straight venturi section **62** which extends upwardly (or forwardly) from the inlet bell structure **60**; and a diverging venturi bell outlet section **64** which extends upwardly (or forwardly) from the upper or forward end of the straight section **62**. The interior cross-sectional flow area of the straight venturi section **62** is substantial constant along the entire length of the straight section **62**. The interior cross-sectional flow area of the diverging bell outlet section **64** increases as the bell outlet section **64** extends upwardly or forwardly from the straight venturi section **62**. The interior surface of the bell outlet section **64** preferably diverges at an angle **66** in the range of from about 5° to about 60°, more preferably from about 5° to about 45° and more preferably from about 5' to about 30° with respect to the longitudinal axis **32** of the outer and inner conduits **14** and **15**.

[0024] The diverging bell outlet section **64** of the venturi structure **58** can extend all of the way to the discharge opening **68** at the upper (or forward) longitudinal end **52** of the inner conduit **15**. Alternatively, the inner conduit **15** can further comprise an upper or forward discharge section **69** of substantially constant internal cross-sectional flow area which extends from the upper or forward end **65** of the diverging venturi bell outlet section **64** to the discharge opening **68** of the inner conduit **15**. If the inner conduit **15** includes an upper or forward discharge section **69** as just described, the upper or forward end **65** of the diverging bell outlet section **64** of the venturi structure **58** can be located prior to or inside the outer conduit **14**.

[0025] The longitudinal length of the venturi flow structure **58** will preferably be at least 10%, more preferably at least 20% and more preferably at least 25%, of the entire longitudinal length of the inner conduit **15**. The longitudinal length of the straight venturi section **62** of the venturi flow structure **58** will preferably be at least 5%, more preferably at least 10%, of the entire length of the venturi structure **58**. The longitudinal length of the diverging bell outlet section **64** of the venturi structure **58** will preferably be at least 10%, more preferably at least 20% and more preferably at least 30%, of the entire length of the venturi structure **58**.

[0026] The inner conduit **15** and each section of the venturi flow structure **58** of the inner conduit **15** will preferably have a circular cross-sectional shape such that, at least in the interior thereof, the interior surface of the straight venturi section **62** is cylindrical and the interior surface of the diverging venturi bell section **64** has a conical shape. However, the cross-section of the inner conduit **15** and of each section of the venturi structure **58** can alternatively be elliptical, oval, rectangular, square, triangular or other non-circular shape. Also, the interior surface **59** of the venturi flow structure **58** can be smooth or roughened.

[0027] The entrainment media used in the inventive apparatus and method will preferably be steam. However, examples of other types of entrainment media suitable for use in the inventive apparatus and method include, but are not limited to, carbon dioxide, air, nitrogen, or argon.

[0028] The injection structure **22** for the entrainment media is located outside of the plenum **4** and is spaced downwardly or rearwardly apart from the inlet bell opening **56** at the lower end **26** of the inner conduit **15** so that a gap **70** is formed between the injection structure **22** and the inlet bell opening **56** of the inner conduit **15**. The injection structures **22** for the entrainment media can be single port tips, multi-port spiders, or other types of ejectors for supersonic, sonic, or subsonic ejection flow.

[0029] In the method of the present invention, the flare gas delivered to the plenum **4** flows upwardly or forwardly through the flow annulus **16** of each flare tip nozzle assembly **8** and is discharged for combustion from the discharge opening **44** of the flow annulus **16** at the upper or forward longitudinal end **30** of the outer conduit **14**. At the same time, steam or other entrainment media is ejected from the injection structure **22** toward the inlet bell opening **56** at the lower or rearward end **26** of the inner conduit **15**. As the ejected entrainment media travels through the gap **70** between the injection structure **22** and the inlet bell opening **56**, atmospheric air is entrained by the media and pulled into the inner conduit **15**.

[0030] In accordance with the present invention, by causing the injected entrainment media to flow through the venturi flow structure **58** which forms at least a lower or rearward portion of the inner conduit **15**, the pressure at the inlet bell opening **56** is further reduced, thus resulting in significantly more air being induced by the flow of the entrainment media into the inner conduit **15**. As compared to a nozzle tip using an entirely straight inner conduit design, the venturi flow structure **58** incorporated in the inner conduit **15** of the inventive flare tip nozzle assembly **8** increases the amount of air delivered by the entrainment media into the inner conduit **15** by an amount of at least 5% (more preferably at least 10%, at least 15%, at least 20%, or at least 25%).

[0031] The air inducted into the inner conduit **15** mixes with the entrainment media and is discharged from the discharge opening **68** of the inner conduit **15** for combustion of the inducted air with the flare gas discharged from the discharge opening **44** of the flow annulus **16**. Because the discharge opening **68** of the inner conduit **15** is located substantially at the upper or forward longitudinal end **30** of the outer conduit **14**, rather than inside the outer conduit **14**, substantially no mixing of the flare gas with the entrainment media and inducted air occurs within the outer conduit **14**, thus further reducing the pressure at the inlet opening **56** of the inner conduit **15** and causing even more air to be inducted into the inner conduit **15**.

[0032] The exterior clean-up ring or apparatus **28** at the upper (or forward) longitudinal end **30** of the outer conduit **14** comprises a series of ejection ports, nozzles or other ejection structures which eject steam into the combustion mixture discharged from the flare tip nozzle assemble **8**. The steam ejected from the clean-up ring **28** operates to induct additional air into the combustion mixture and can also be used to shape the combustion flame or assist in maintaining the shape of the flame in high wind conditions.

[0033] Thus, the present invention is well adapted to carry out the objectives and attain the ends and advantages mentioned above as well as those inherent therein. While presently preferred embodiments have been described for purposes of this disclosure, numerous changes and modifications will be apparent to those in the art. Such changes and modifications are encompassed within the invention as defined by the claims.

What is claimed is:

1. An apparatus for combusting a flare gas comprising one or more flare nozzle assemblies, each of the flare nozzle assemblies comprising:

an outer conduit having a longitudinal axis, a rearward longitudinal end, and a forward longitudinal end;

an inner conduit for a flow of an entrainment media and air, the inner conduit comprising

an inlet opening at a rearward longitudinal end of the inner conduit, a discharge opening at a forward longitudinal end of the inner conduit,

a longitudinally extending straight venturi section of substantially constant interior cross-sectional area, and

a longitudinally extending diverging venturi section which increases in interior cross-sectional area as the diverging venturi section extends forwardly from a forward longitudinal end of the straight venturi section;

an injection structure positioned outside of the inlet opening of the inner conduit for injecting the entrainment media into the inlet opening of the inner conduit;

the inner conduit extending into the rearward longitudinal end of the outer conduit such that (i) the rearward longitudinal end of the inner conduit is positioned outside of the rearward longitudinal end of the outer conduit and (ii) the discharge opening of the inner conduit is positioned substantially at the forward longitudinal end of the outer conduit; and

a longitudinally extending flow annulus for the flare gas which is formed in the outer conduit between an interior surface of the outer conduit an exterior of the inner conduit, wherein the longitudinally extending flow annulus (i) laterally surrounds the longitudinal axis of the outer conduit and (ii) has an inlet opening at the rearward longitudinal end of the outer conduit for receiving the flare gas.

2. The apparatus of claim **1** wherein:

the inner conduit further comprises a venturi inlet bell structure at the rearward longitudinal end of the inner conduit and

the longitudinally extending straight venturi section of the inner conduit extends forwardly from the venturi inlet bell structure.

3. The apparatus of claim **1** wherein the inner conduit further comprises a longitudinal discharge section of substantially constant internal cross-sectional area which extends forwardly from a forward longitudinal end of the longitudinally extending diverging venturi section of the inner conduit to the discharge opening of the inner conduit.

4. The apparatus of claim **3** wherein the forward longitudinal end of the longitudinally extending diverging venturi section of the inner conduit is located outside of the rearward longitudinal end of the outer conduit.

5. The apparatus of claim **3** wherein the forward longitudinal end of the longitudinally extending diverging venturi section of the inner conduit is located inside of the outer conduit.

6. The apparatus of claim **1** further comprising a plenum for the flare gas, the plenum having an interior, an upper wall, and a lower wall and, wherein for each of the one or more flare nozzle assemblies:

the rearward longitudinal end of the outer conduit of the flare nozzle assembly is located inside the interior of the plenum or at the upper wall of the plenum such that the inlet opening of the flow annulus of the flare nozzle assembly is in fluid communication with the interior of the plenum;

the forward longitudinal end of the outer conduit of the flare nozzle assembly is located outside of plenum;

the inner conduit of the flare nozzle assembly extends through the lower wall of the plenum; and

the inlet opening of the inner conduit of the flare nozzle assembly is located outside of the plenum.

7. The apparatus of claim **6** comprising a plurality of the flare nozzle assemblies.

8. The apparatus of claim **6** further comprising a flare stack having an upper end on which the plenum is located.

9. The apparatus of claim **1** wherein

the longitudinally extending straight venturi section of the inner conduit has a cylindrical interior surface and

the longitudinally extending diverging venturi section of the inner conduit comprises an interior surface having a conical shape.

10. The apparatus of claim **1** further comprising an upper steam injection ring or assembly positioned outside of and around the forward longitudinal end of the outer conduit.

11. A method of combusting a flare gas comprising the steps of:

a) delivering the flare gas upwardly through an annulus between an inner surface of an outer conduit and an exterior of an inner conduit, the inner conduit extending upwardly into a lower end of the outer conduit, the inner conduit having a discharge opening substantially at the upper end of the outer conduit, and the inner conduit having an inlet opening at a lower end of the inner conduit which is positioned outside of and spaced downwardly from the lower end of the outer conduit;

b) injecting an entrainment media into the inlet opening of the inner conduit from an injection structure which is spaced downwardly from the inlet opening of the inner conduit so that the entrainment media inducts an amount of air into the inner conduit as the entrainment media travels through a gap between the injection structure and the inlet opening of the inner conduit; and

c) increasing the amount of air inducted into the inner conduit by the entrainment media in step (b) by delivering the entrainment media upwardly through a venturi structure, which forms at least a lower portion of the inner conduit, and out of the discharge opening of the inner conduit substantially at the upper end of the outer conduit,

wherein the venturi structure comprises (i) an upwardly extending straight venturi section of the inner conduit having a substantially constant interior cross-sectional area followed by (ii) a diverging venturi section of the inner conduit which increases in interior cross-sectional area as it extends upwardly from the straight venturi section.

12. The method of claim **11** wherein the entrainment media is steam.

13. The method of claim **11** wherein the inner conduit further comprises a venturi inlet bell structure at the lower end of the inner conduit.

14. The method of claim **11** wherein the inner conduit further comprises an upper discharge section having a substantially constant internal cross-sectional area which extends upwardly from the diverging venturi section of the inner conduit to the discharge opening of the inner conduit.

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