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(54) **FUEL INJECTOR FOR LOW NOX FURNACE**

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(57) **ABSTRACT**

A fuel injector for use in a furnace causes a primary stream of a carrier gas and fuel to be mixed with heated air, oxygen or a mixture of oxygen and CO₂ or re-circulated flue gas, within the injector by a secondary stream of heated air, before the primary stream exits the injector as a fuel stream and flows into a combustion zone of the furnace. The interaction of the primary stream with the heated air of the secondary stream increases stoichiometry at the center of the fuel stream exiting the injector, so as to minimize NO_x creation and maximize combustion of fuel in the furnace.

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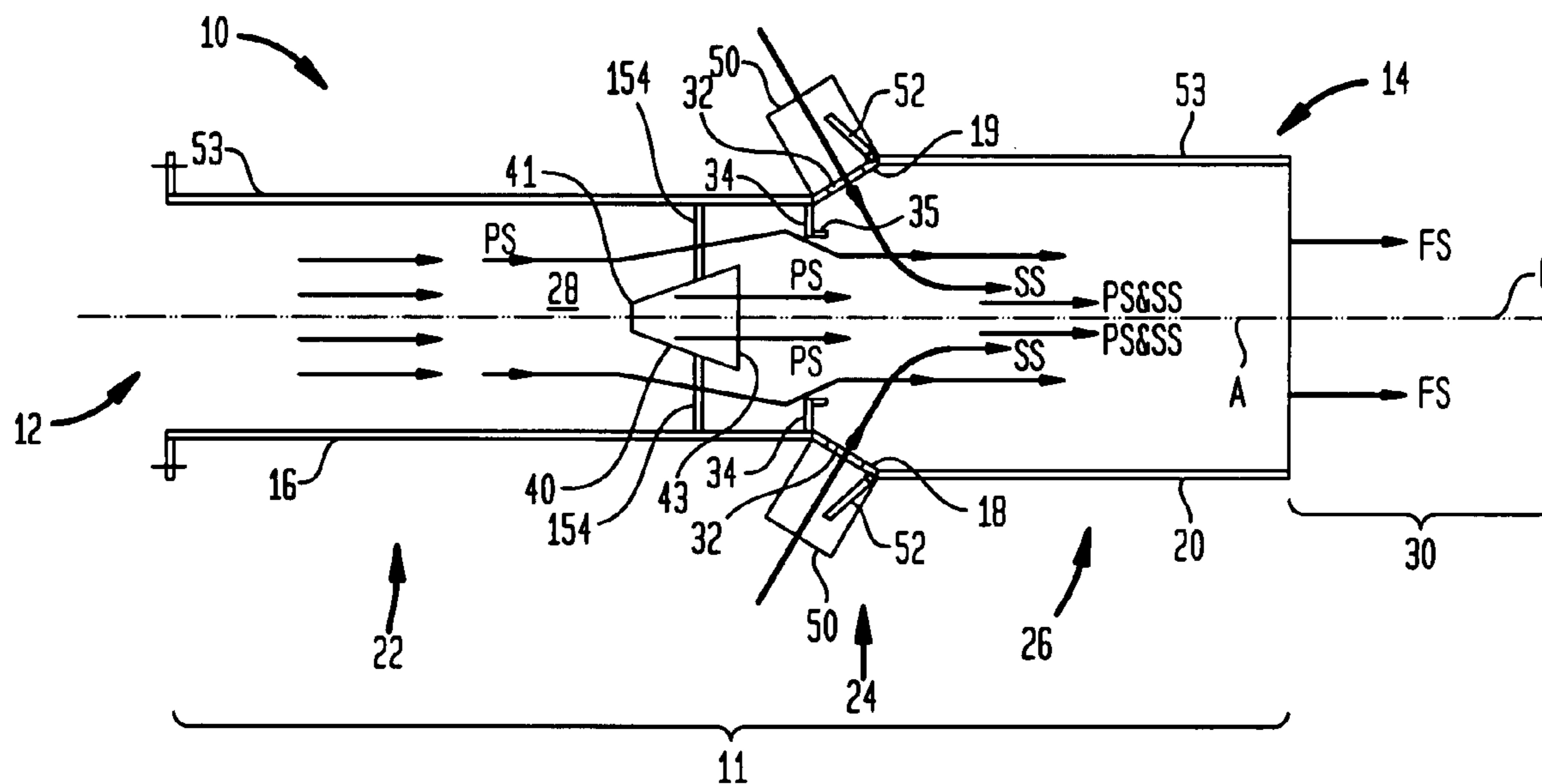
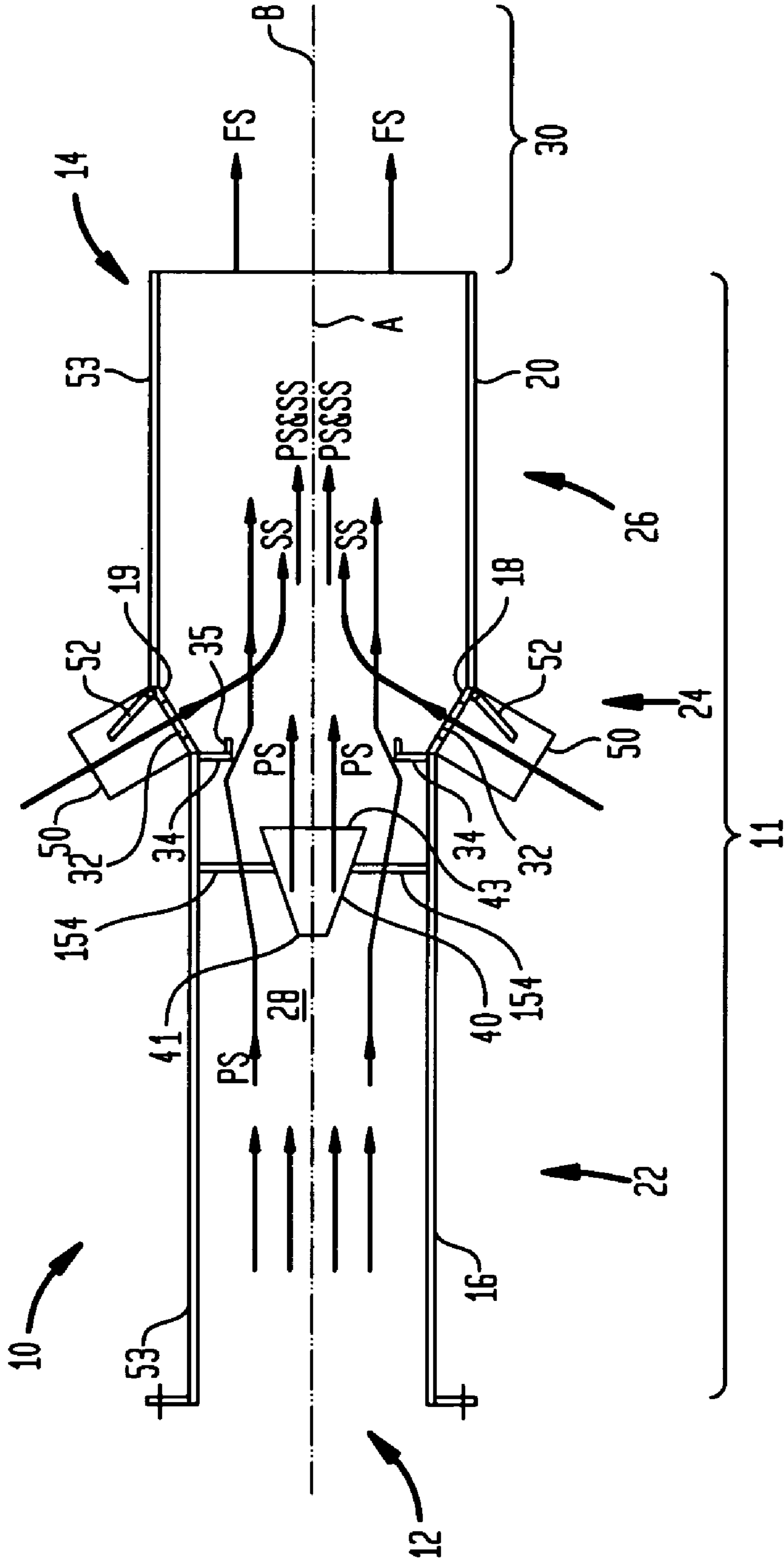


FIG. 1



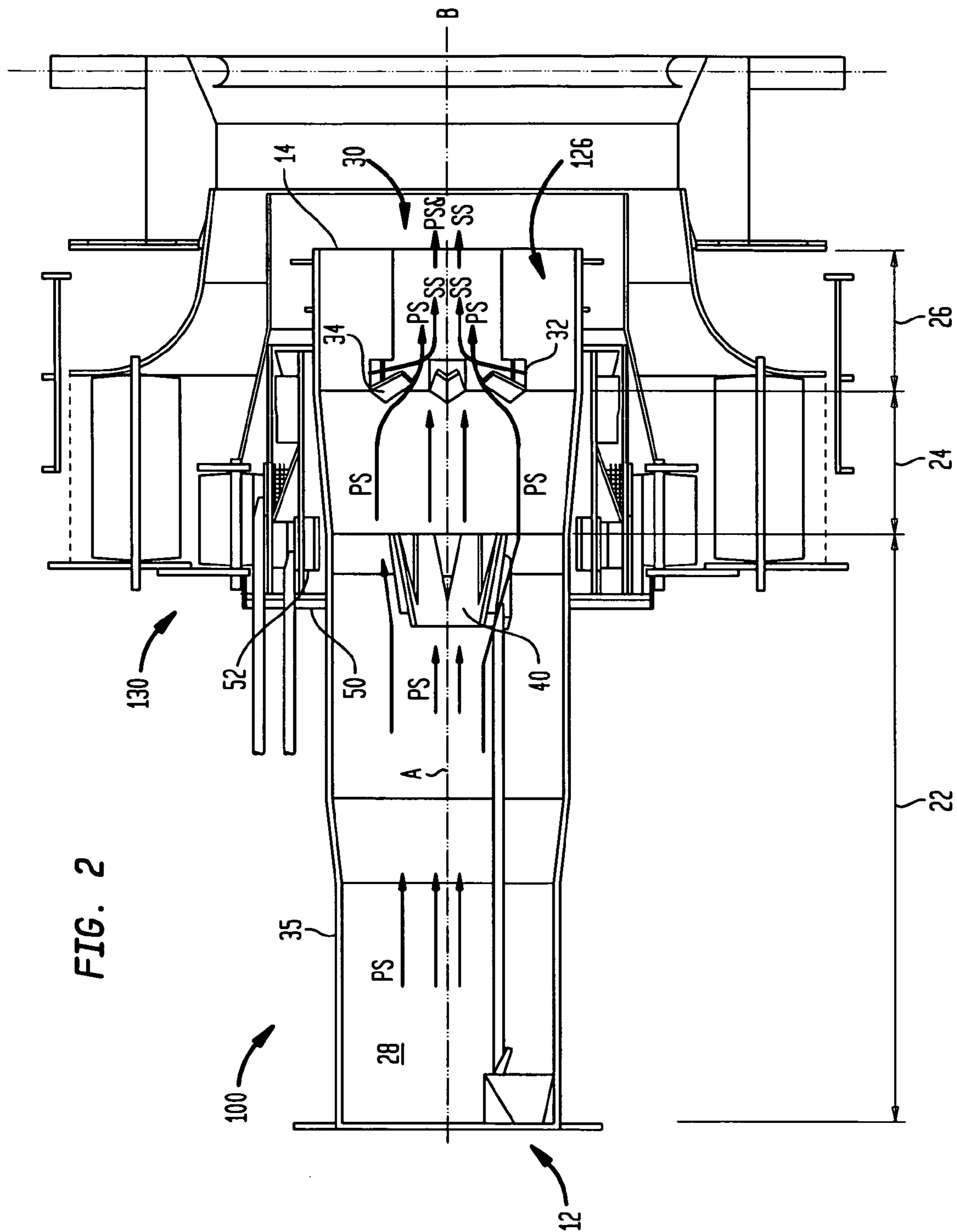


FIG. 3A

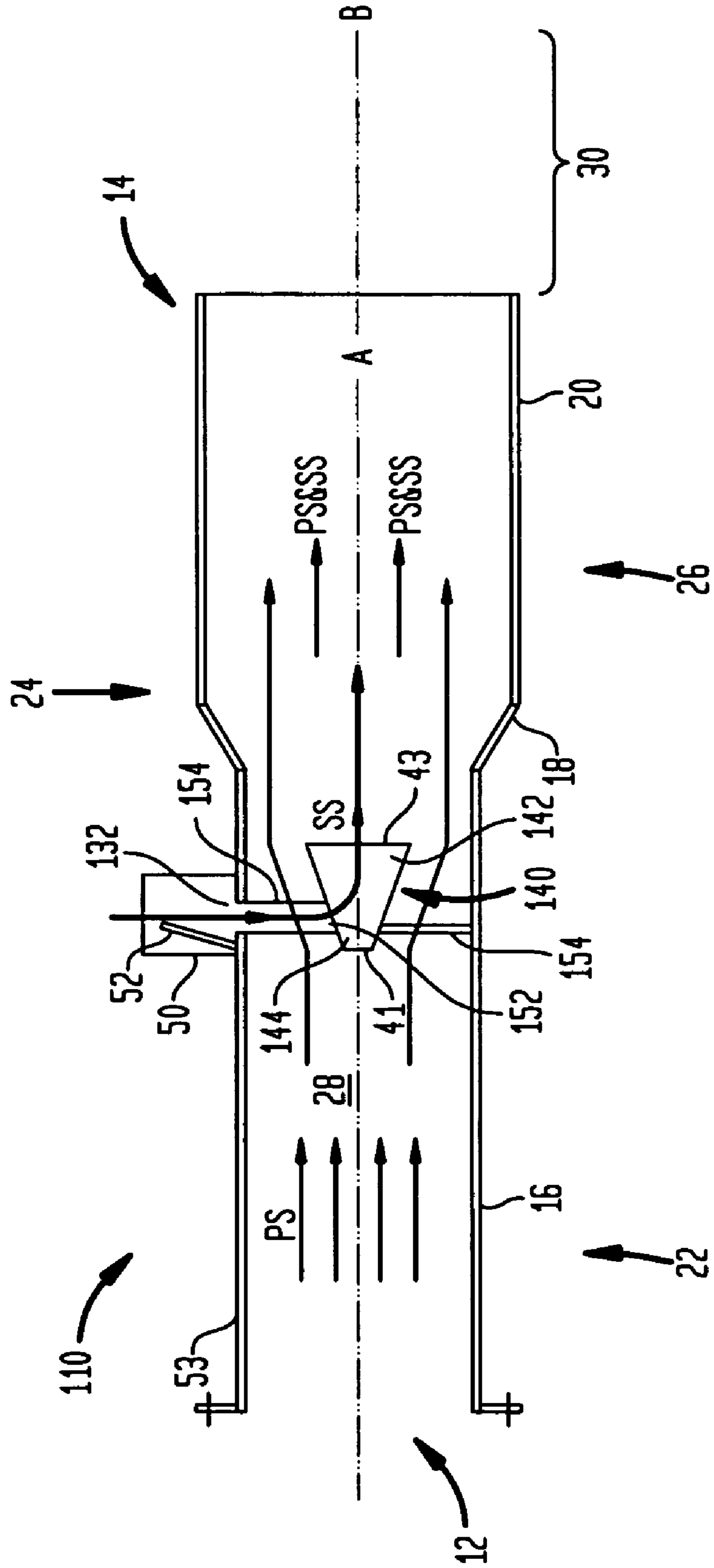


FIG. 3B

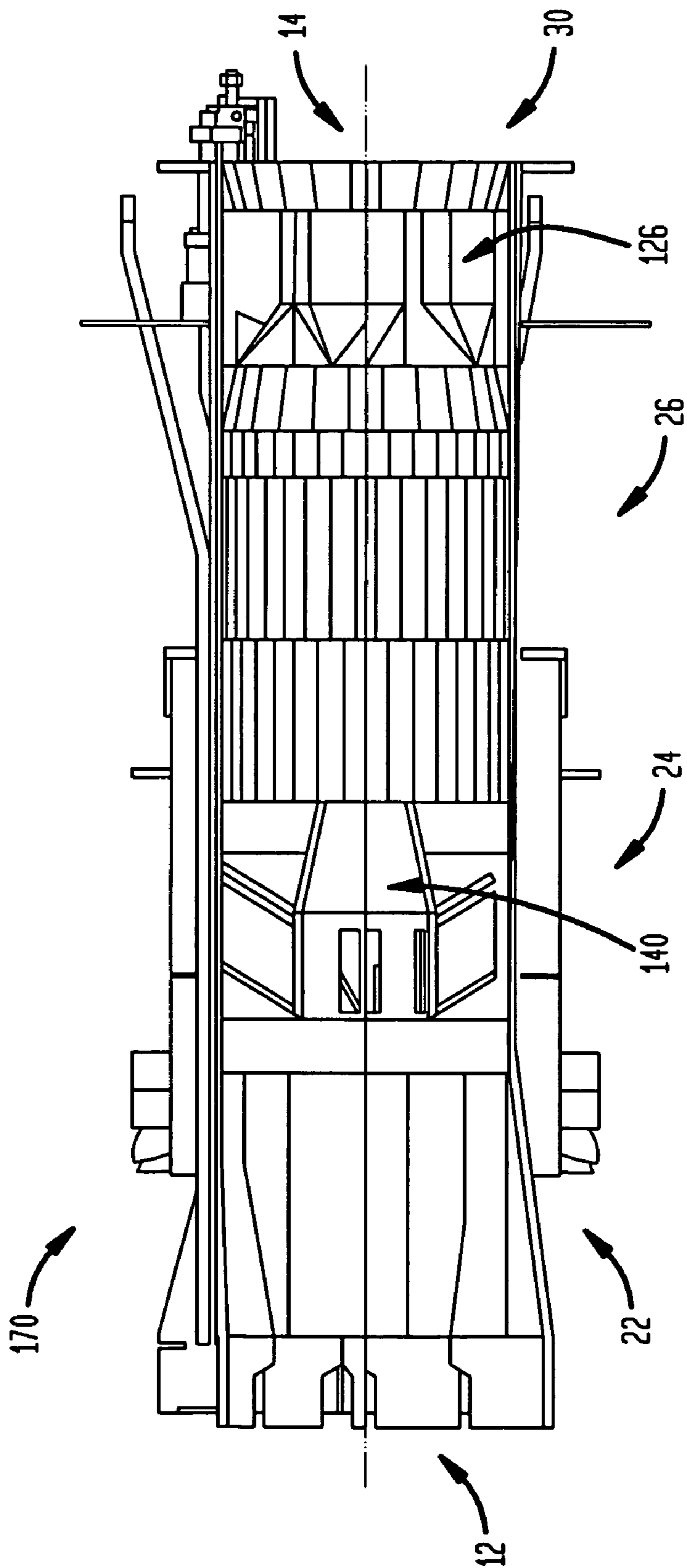
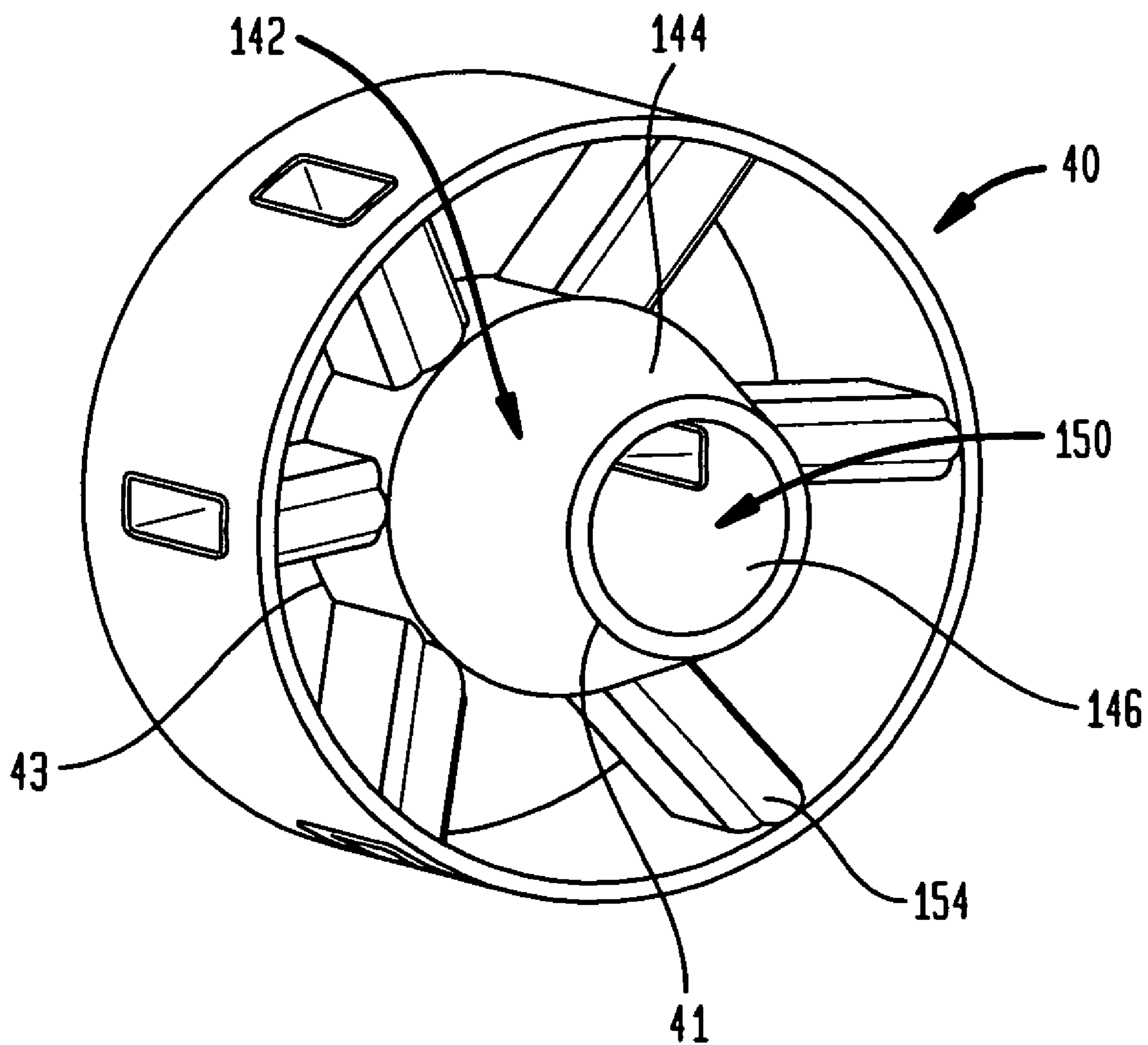


FIG. 4



FUEL INJECTOR FOR LOW NOX FURNACE

FIELD OF THE INVENTION

[0001] The present invention relates generally to a fuel injector for use with a furnace and, more particularly, to a fuel injector for lowering the concentration of nitrogen oxides (“NO_x”) and Unburned Carbon (“UBC”) produced by combustion in an associated furnace.

BACKGROUND OF THE INVENTION

[0002] Great efforts have been exerted by prior art inventors to provide that pulverized coal is transported by a fuel injector for combustion in an associated furnace, where the quantity of nitrogen oxides, which are pollutants produced as by-products, is minimized; and where UBC, a product of incomplete combustion, is also minimized. However, a general relationship between NO_x control and UBC levels is that as NO_x is lowered UBC tends to increase. Prior art furnaces that produce small amounts of nitrogen oxides as by-products are typically known as low NO_x furnaces.

[0003] Nitrous oxide emissions are formed from two primary sources: nitrogen, which is chemically bound in the fuel, such as coal, which is known as “fuel NO_x”; and high temperature fixation of atmospheric nitrogen contained in the combustion air, which is known as “thermal NO_x”. The formation of both fuel and thermal NO_x is governed by the availability of oxygen in the early phase of combustion. In this regard, when too much oxygen is available in the early combustion phases, a high NO_x output will result. Thermal NO_x is directly and exponentially dependent on temperature. As the combustion temperature increases, the NO_x output exponentially increases. Adjusting the distribution of air and fuel at the nozzle of a fuel injector, i.e., at the entrance to a combustion zone of a furnace, such that the initial combustion occurs under very rich fuel conditions, will significantly decrease the conversion of fuel-based nitrogen to nitrous oxide and generally increases the formation of unwanted UBC thereby decreasing the combustion efficiency of the overall system.

[0004] As well known in the art, to achieve low NO_x combustion, the combustion of pulverized coal in a furnace is commenced in an oxygen deficient zone, such that the nitrogen in the coal cannot combine with atmospheric oxygen to produce NO_x. In such oxygen deficient zone, the nitrogen released from the coal combines with other nitrogen atoms to form N₂ molecules, which are harmless in air.

[0005] In the prior art, low NO_x furnaces typically include a central fuel injector, which provides a primary stream of air entrained with fuel, such as pulverized coal, to a combustion zone in the furnace. In addition, these furnaces introduce a secondary stream of heated air into the combustion zone. For example, the furnace includes a multiple stage, secondary air register that provides for flow of a secondary stream of heated air outside of the fuel injector. The secondary air register creates a staged fuel and air flow, such that the central portion of the fuel flow entering the combustion zone is fuel rich. Alternatively, other prior art low NO_x pulverized coal furnaces include a fuel injector that creates several segregated primary streams containing the pulverized coal which are surrounded by streams of secondary heated air.

[0006] In the above-described prior art furnaces, the pulverized coal of the primary stream is highly concentrated in the center of the combustion zone. The high concentration of

the pulverized coal at the center of the combustion zone results in a very low air-to-coal concentration ratio, or low stoichiometry, at the central portion of the combustion zone. Although the outer portion of the combustion zone has a stoichiometry sufficient to support combustion, the stoichiometry of the fuel stream at the central portion of the combustion zone does not have sufficient air to support combustion, which results in the production of unwanted NO_x and UBC.

[0007] In other prior art low NO_x pulverized coal furnaces, a secondary stream of air is mixed with the primary air and coal stream at the exit of the fuel injector to expand the NO_x reducing zone, such that NO_x occurring within the combustion zone can be decreased. In the prior art furnace configuration where the secondary air stream is supplied at the exit of the fuel injector at the central portion of the fuel flow entering the combustion zone, a region of combustion air is created at the central portion of the combustion zone. This region of combustion air creates an internal interface between the primary air/coal stream and the central, secondary stream air stream, thereby forming a high stoichiometric flame surface within the volume of the flame, such that only a small portion of the primary air/coal stream is affected. Because the internal flame surface thus formed is supported by a volume of 100% air, the coal particles that combust within this internal flame surface are at conditions that are at least stoichiometric. Consequently, the resultant NO_x level is not significantly lower than that of a furnace without this feature. Under certain conditions, the internal flame surface may provide some additional NO_x reduction.

[0008] Therefore, there exists a need for a fuel injector for use with an associated furnace which maximizes combustion of fuel while minimizing the generation of NO_x.

SUMMARY OF THE INVENTION

[0009] In accordance with the present invention, a fuel injector for a furnace, such as a pulverized coal burning furnace, is adapted for conveying a primary stream containing a mixture of a carrier gas, such as air, and fuel, such as pulverized coal, along an interior passageway of the injector towards a combustion zone of the furnace, and for introducing a secondary stream of a heated gas, preferably air, into the passageway, such that the secondary stream mixes with and heats, and increases the oxygen concentration of, a portion of the primary stream along and around a central axis of the passageway, before the primary stream exits the injector and is delivered by the injector into a combustion zone of the furnace in the form of a fuel stream. The fuel injector includes a housing that defines the interior passageway, and the passageway extends the length of the fuel injector from an inlet end to an outlet end. Increasing the oxygen concentration of a portion of the primary stream with the heated air of the secondary stream within the fuel injector increases the stoichiometry of the fuel stream on and around a burner axis within the combustion zone, the burner axis being coaxial with the central axis of the injector, such that there is a sufficient quantity of oxygen within the heated air to support combustion on and around the burner axis, but the amount of heated oxygen on and around the burner axis in the combustion zone is not sufficient to create NO_x or provides for creation of only a minimal amount of NO_x.

[0010] Thus, the purpose of the heated secondary air stream is to mix thoroughly with a portion of the primary stream within the fuel injector on and around the central axis. The

stoichiometry at and around the central axis is increased sufficiently such that, with the addition of furnace heat or other ignition source, the fuel stream at and around the burner axis will be partially gasified. Since the fuel, such as coal, contains carbon, hydrogen, nitrogen, oxygen and sulfur and other species that are chemically bound, the partial combustion, or gasification, produces a mixture of partially combusted carbon, carbon monoxide, H₂O, SO₂, and unreacted nitrogen in the form of harmless N₂ rather than the harmful NO_x.

[0011] In one embodiment, the secondary stream is supplied to the passageway of the injector through an aperture in the housing of the injector disposed between the inlet and outlet ends of the passageway. In a further embodiment, an air register controls the supply of the secondary stream through the aperture.

[0012] In a further embodiment of the injector including an aperture in the housing disposed between the inlet and outlet ends of the passageway for supplying the secondary stream to the passageway, the injector includes a baffle extending from the housing inwardly toward the central axis of the passageway and disposed upstream of the aperture. The baffle extends into and is positioned within the passageway for interrupting the flow of the primary stream, so as to facilitate penetration of the secondary stream supplied at the aperture toward the central axis.

[0013] In another embodiment of the injector including an aperture in the housing disposed between the inlet and outlet ends of the passageway for supplying the secondary stream to the passageway, the injector includes a diverging cone extending along and centered about the central axis of the injector, upstream of the aperture, for reducing the amount of fuel of the primary stream flowing along the central axis.

[0014] In a further embodiment, the injector includes an air distributor, preferably in the form of a diverging cone, extending along and centered about the central axis of the injector. The distributor distributes the secondary stream along and around the central axis of the injector. In one embodiment, the secondary stream is supplied to the distributor through a hollow conduit extending to the distributor from the inlet end of the passageway. In another embodiment, the secondary stream is supplied to the injector through a hollow conduit extending from an aperture in the housing to the distributor. In a further preferred embodiment, the distributor defines a hollow interior portion to which the secondary stream is supplied. The hollow interior portion is configured to direct the secondary stream along and around the central axis toward the combustion zone.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Other objects and advantages of the present invention will be apparent from the following detailed description of the presently preferred embodiments, which description should be considered in conjunction with the accompanying drawings in which like references indicate similar elements and in which:

[0016] FIG. 1 is a sectional view of an exemplary embodiment of a fuel injector for a pulverized coal furnace, in accordance with the present invention.

[0017] FIG. 2 is a sectional view of another exemplary embodiment of a fuel injector with a segmented nozzle for a pulverized coal furnace, in accordance with the present invention.

[0018] FIG. 3A is a sectional view of another exemplary embodiment of a fuel injector for a pulverized coal furnace, in accordance with the present invention.

[0019] FIG. 3B is a sectional view of another exemplary embodiment of a fuel injector for a pulverized coal furnace, in accordance with the present invention.

[0020] FIG. 4 is a perspective view of an exemplary embodiment of a diverging cone coupled to a plurality of hollow tubes for use in connection with a fuel injector, in accordance with the present invention.

[0021] FIG. 5 is a sectional view of another exemplary embodiment of a fuel injector for a pulverized coal furnace, in accordance with the present invention.

DETAILED DESCRIPTION

[0022] FIG. 1 illustrates an exemplary fuel injector 10, in accordance with one embodiment of the present invention. The injector 10 is for use in association with a furnace, such as a pulverized coal furnace, and provides for heating a primary stream ("PS") of a carrier gas, preferably air, entrained with fuel, preferably pulverized coal, with a secondary stream ("SS") of a heated gas, preferably air, within the injector 10, prior to the primary stream exiting the injector 10 and entering a combustion zone of the furnace in the form of a fuel stream ("FS"). In alternative embodiments, the secondary stream may be 100% oxygen, a mixture of air and oxygen, a mixture of CO₂ and oxygen, or a mixture of re-circulated flue gas and oxygen.

[0023] As used herein, the term "fuel injector" is intended to cover devices used to transport pulverized fuel and a carrier gas to be burned within an associated furnace. It should be appreciated that the term "pulverized fuel" is intended to cover various types of fuel, such as pulverized coal and the like. The term "pulverized coal" is used below for convenience and is intended to encompass various types of pulverized fuels other than coal. Further, the term "carrier gas" includes gases other than air.

[0024] Referring to FIG. 1, the fuel injector 10 includes an elongated housing 11 having an inlet end 12 and an outlet end 14. The materials of which the fuel injector 10 can be made are conventional and may include various materials capable of withstanding extreme heat, such as iron, various other metals such as carbon steel and stainless steel, ceramic and the like. The housing 11 includes an elongated annular wall 16 extending from the inlet end 12 to an outwardly tapering annular wall 18. In addition, the housing 11 includes an elongated annular wall 20 extending between the outlet end 14 and end 19 of the wall 18, which opposes the outlet end 14 of the fuel injector 10. For convenience and ease of reference, the portions of the injector 10 defined by the walls 16, 18 and 20 are referred to below, respectively, as the entry region 22, the transition region 24 and the nozzle region 26.

[0025] The walls 16, 18 and 20 of the housing 11 form a substantially annular, elongated passageway 28 extending between the inlet and outlet ends 12, 14 of the injector 10. For ease of reference and highlighting the features of the present invention, an axial line extending between the inlet and outlet ends 12, 14 and through the center of the passageway 28 is defined as a central axis A. The passageway 28 functions as a flow path extending from the inlet end 12, at which the primary stream containing pulverized fuel, such as pulverized coal, and the carrier gas, preferably air, is supplied to the injector 10, to the outlet end 14, at which point a fuel stream exits the injector 10. The outlet end 14 of the injector 10

adjoins a combustion zone **30** of an associated furnace (not shown). The central axis **A** of the injector **10** is coaxial with a burner axis **B** extending through the center of the combustion zone **30**, and about which a flame of a fuel core (not shown) in the furnace is disposed. When a primary stream is supplied to the passageway **28** at the inlet end **12**, the primary stream flows along the passageway **28**, through the entry, transition and nozzle regions **22**, **24**, **26**, and then exits the injector **10** from the nozzle region **26** in the form of the fuel stream which is delivered to the combustion zone **30** adjoining the outlet end **14** of the injector **10**. At the combustion zone **30**, the fuel in the fuel stream is consumed by the flame located within the combustion zone **30**.

[0026] As discussed above, in prior art low NO_x furnaces, heated air has been supplied to a combustion zone of a furnace to further heat the primary stream of pulverized coal and air that exits the outlet end of the fuel injector. However, in such prior art furnaces, the center of the fuel stream supplied by an injector to the combustion zone typically has a high concentration of fuel. Although the heated air stream may surround the concentrated fuel in the combustion zone, the heated air stream oftentimes does not sufficiently penetrate the fuel stream (primary stream) to support combustion of the fuel at the center of the fuel stream. Consequently, the uncombusted fuel particles in the center of the fuel stream do not begin to combust until they reach a zone, a considerable distance into the furnace from the fuel injector, where there is sufficient air to support combustion. Under these conditions, where the fuel is being combusted with a much higher oxygen concentration than exists in the early part of the flame, the result is formation of an undesirable amount of NO_x .

[0027] In accordance with the present invention, the fuel injector **10** provides for the introduction of a secondary stream of heated air into the passageway **28**, and the heating of and mixing a portion of the primary stream with the secondary stream, prior to the primary stream exiting the fuel injector **10** at the outlet end **14** in the form of a fuel stream that is delivered to the combustion zone **30** of the associated furnace. By introducing the secondary stream into the fuel injector **10** at a point in the passageway **28** upstream of the outlet end **14**, the stoichiometry at the central portion of the primary stream is sufficiently increased so as to enhance the gasification of the fuel at the center of the fuel stream in the combustion zone **30** of the furnace. Advantageously, the secondary stream increases the oxygen concentration and heats the primary stream within the injector **10** to create an increased stoichiometry in the primary stream on and around the central axis **A** of the passageway **28**, which in turn increases the stoichiometry of the fuel stream on and around the burner axis within the combustion zone **30**. Further, by raising the temperature of the fuel stream due to the mixing of the high temperature secondary air with the primary stream, the resultant fuel/air mixture on and around the burner axis will more easily gasify or combust once sufficient energy is supplied to initiate the combustion process. In addition to low NO_x and UBC, a further benefit is a shorter flame length.

[0028] In a preferred embodiment, the amount and temperature of the air supplied in the secondary stream are selected so as to increase the stoichiometry of the fuel stream on and around the burner axis to a level sufficient to support combustion, and where the amount of air preferably does not exceed a level where NO_x can be created. In other words, air from the secondary stream is caused to heat and mix with the primary stream within the injector **10**, such that, on and

around the burner axis within the combustion zone **30**, the amount of oxygen is sufficiently deficient to support combustion and results in a low heating value gas, which can be expressed in British thermal units (“BTUs”). As is well known, a low heating value gas is very low in fuel bound nitrogen, because substantially all of the fuel bound nitrogen has been converted to harmless N_2 molecules.

[0029] By increasing the stoichiometry of the fuel stream exiting the injector in accordance with the present invention, the further advantage of increased combustion of fuel around and along the burner axis in the combustion zone of the furnace is achieved. Consequently, when the fuel in the primary stream is pulverized coal, the total amount of uncombusted coal of the primary stream, which is typically expressed as unburned carbon (“UBC”), is reduced below the levels typical for conventional low NO_x pulverized coal furnaces.

[0030] In a preferred embodiment, the temperature of the air in the secondary stream when supplied to the injector **10** is between about 400°F . and 1000°F ., and most preferably between about 500°F . and 700°F .

[0031] Referring again to FIG. **1**, in the exemplary illustrated embodiment of the fuel injector **10**, the tapered annular wall **18** defines an annular aperture **32** through which the secondary stream is directly supplied to the passageway **28** at the transition region **24** of the injector **10**. Upstream of the aperture **32**, an annular baffle **34** extends from the junction of the walls **16**, **18**, radially inwardly into the passageway **28**, orthogonal to the central axis **A**, and terminates at a lip **35**, which is parallel to the central axis **A**. In an alternative embodiment, the baffle **34** extends from the housing **11** inwardly into the passageway **28** and towards the outlet end **14**.

[0032] Further, an air register **50** including a flow regulator **52** is mounted to an exterior surface **53** of the housing **11**, about the aperture **32**. The flow regulator **52** can be positioned to cover the aperture **32** at least partially or completely, in other words, adjust the effective size of the aperture **32**, and, thus, control the flow of the secondary stream into the passageway **28** through the aperture **32**.

[0033] In operation of the injector **10** including the baffle **34**, the primary stream flows downstream from the inlet end **12**, through the passageway **28**, to the outlet end **14**. In addition, the secondary stream is supplied to the passageway **28** through the aperture **32** in the wall **18**. Upstream side of the transition region **24**, and substantially adjacent to the junction of the walls **16**, **18**, the baffle **34** with the lip **35** interrupts the flow of the primary stream in the passageway **28**, to facilitate penetration of the secondary stream into the primary stream as the primary stream flows towards the outlet end **14**. Beginning in the transition region **24**, and continuing into the nozzle region **26**, the heated air in the secondary stream interacts with the fuel of the primary stream flowing around and along the axis **A**, thereby increasing the stoichiometry along and around the axis **A**, and also heats the fuel of the primary stream flowing along and around the axis **A**. Consequently, the fuel stream exiting the nozzle region **26** and delivered to the combustion zone **30** has been heated by the secondary stream and has a suitable, desired stoichiometry on and around the burner axis in the combustion zone **30**.

[0034] It is to be understood that the angle of taper of the wall **18** in the transition region **24**; the diameters of the walls **16** and **20** within the entry and nozzle regions **22** and **26**, respectively; the angle that the baffle **34** extends from the

housing 11 inwardly into the passageway 28 and towards the direction of the outlet end 14, in relation to the central axis A; the angle of the lip 35 in relation to the baffle 34; the lengths of the baffle 34 and the lip 35; and the flow rate of the secondary stream through the aperture 32 are suitably selected according to the requirements of the furnace to which the injector 10 delivers the fuel stream, to provide a desired stoichiometry on and around the burner axis in the combustion zone 30. For example, the taper and the diameters are selected to maintain the speed of the primary stream constant throughout the passageway 28, or alternatively obtain a selected speed for the fuel stream exiting at the outlet end 14 of the injector 10 which is different than the speed of the primary stream entering at the inlet end 12 of the injector 10.

[0035] Referring again to FIG. 1, in a further embodiment the injector 10 includes an optional internal diverging cone 40 disposed within the entry region 22. Also referring to FIG. 4, which illustrates a perspective view of a preferred embodiment of the cone 40, the cone has an upstream ring-shaped end wall 41 facing the inlet end 12 of the injector 10, which has an outer diameter less than an outer diameter of a ring-shaped downstream end wall 43 of the cone 40 facing the outlet end 14. In addition, the cone 40 includes a wall 142 having outer and inner surfaces 144, 146. The inner surface 146 defines a conically-shaped hollow interior 150. The cone 40 may be suitably supported in the passageway 28 by at least two legs 154 and can be axially adjustable via rods (not shown) attached to one or more of the legs 154 and extending to the inlet end 12. The cone 40 extends along and is centered about the axis A, and the distance between the upstream end wall 41 and the transition region 24 is less than the distance between the upstream end wall 41 and the inlet end 12.

[0036] In operation of the injector 10 as illustrated in FIG. 1 and including the optional cone 40, a primary stream flows from the inlet end 12, along the passageway 28, through the entry region 22 and in the direction of the outlet end 14. When the primary stream encounters the cone 40 in the passageway 28, the cone 40 diverts a portion of the flow of the primary stream towards the outer radial portions of the passageway 28 within the entry region 22. This diverted primary stream continues to flow past the cone 40 and toward the transition region 24. The baffle 34 interrupts the flow of the primary stream at or near the transition region 24, so that the secondary stream supplied at the aperture 32 can penetrate toward the central axis A, as discussed above. The distance between the upstream end wall 41 of the cone 40 and the junction of the walls 16, 18 is suitably selected to provide that the primary stream is diverted in a desired manner towards the outer radial portions of the passageway 28, before the primary stream reaches the transition 24.

[0037] In a preferred embodiment, the cone 40 in the injector 10 directs a predetermined amount of the fuel in the primary stream toward the outer radial portions in the entry region 26, which reduces the concentration of fuel, for example, pulverized coal, of the primary stream entering the transition region 24 on and around the central axis A, to a predetermined amount, such that the fuel stream exiting the outlet end 14 and flowing on and surrounding the burner axis of the combustion zone 30 has a desired stoichiometry.

[0038] It is to be understood that the effective size of the aperture 32, as regulated by the flow regulator 52 of the air register 50, the geometry of the cone 40, the position of the cone 40 in relation to the transition region 24 and the position,

size and orientation of the baffle 34 are design parameters selectable based on the characteristics of the fuel in the primary stream, the concentration of fuel in the primary stream and the like, for purposes of obtaining a desired stoichiometry for the fuel stream delivered from the injector 10 to the combustion zone 30.

[0039] In a further embodiment of the injector 10, the injector 10 includes the cone 40 and the aperture 32 for supplying the secondary stream, and the baffle 34 is omitted.

[0040] FIG. 2 illustrates another embodiment of a fuel injector 100, in accordance with the present invention. Like reference numerals are used to designate elements of the fuel injector 100 that are identical to, or substantially similar in construction and operation as, those elements described in connection with the injector 10. Referring to FIG. 2, the injector 100 includes entry, transition and nozzle regions 22, 24 and 26, and the portion of the nozzle region 26 adjacent to the transition region 24 includes an aperture 32 adjacent to a baffle 34, where the effective size of the aperture 32 is controllable by a flow regulator 52 of an air register 50. In addition, the injector 100 includes a segmented nozzle region 126, such as of the type described in U.S. Pat. No. 5,762,007, incorporated by reference herein, extending between the nozzle region 22 and the outlet end 14. Further, a secondary air register 130 is provided in conjunction with the injector 100 for supplying a supplemental stream of heated air at the outer radial portions of the fuel stream exiting the injector 10 and being delivered to the combustion zone 30. The segmented nozzle region 126 creates a larger outer surface area of the primary stream, which has interacted with and been heated by the secondary stream within the passageway 28 of the injector 100, as the primary stream exits the injector 100 and enters the combustion zone 30 in the form of a fuel stream, such that more of the fuel in the fuel stream can combust within the oxygen deficient region on and surrounding the burner axis in the combustion zone 30. The supplemental stream of heated air provided by the register 130 interacts with and heats the fuel stream in the combustion zone 30, to achieve a desired increase in the stoichiometry at and around the burner axis within the combustion zone 30.

[0041] FIG. 3A illustrates a further alternative embodiment of an injector 110, in accordance with the present invention. Like reference numerals are used to designate elements of the fuel injector 110 that are identical to, or substantially similar in construction and operation as, those elements described in connection with the injector 10. Referring to FIG. 3A, the injector 110 includes entry, transition and nozzle regions 22, 24 and 26 defined by walls 16, 18 and 20, respectively, of the housing 11. The injector 110 includes an air distributor 140, preferably having the same construction as the diverging cone 40 described above, except that the end wall 41 seals the inlet end of the interior 150 and the wall 142 further defines an aperture 152 in communication with the interior 150. In addition, the wall 16 of the entry region 22 includes an aperture 132, preferably radially aligned with the aperture 152 of the distributor 140. An air register 50 with a flow regulator 52 is mounted to exterior surface 53 of the housing 11, such that the regulator 52 is operable for controlling flow through the aperture 132. A hollow tube 154 extends between the aligned apertures 132 and 152. In one embodiment of the distributor 140, a plurality of hollow tubes 154 extends, respectively, between a plurality of apertures 132 spaced circumferentially about the wall 16 and a plurality of corresponding apertures 152 spaced circumferentially about the wall 142.

[0042] In operation of the injector 110, the secondary stream is supplied to the injector 110 through the aperture 132, and then flows from the aperture 132 through the hollow tube 154 and into the interior 150 of the distributor 140. The conical shape of the interior 150 directs the secondary stream substantially on and around the central axis A of the passageway 28. The secondary stream, upon exiting the interior 150, interacts with and heats the primary stream, which the distributor 140 has diverted in a manner similar to that described above for the cone 40 of the injector 10, beginning in the entry region 22, and then in the transition and the nozzle regions 24, 26 of the injector 10. The temperature and amount of the heated air supplied as the secondary stream to the distributor 140 are selected, in accordance with the present invention, to provide that the stoichiometry of the primary stream around and along the central axis A is suitably modified to obtain low NO_x and low UBC combustion of the fuel stream delivered by the injector 10 to the combustion zone 30 at and surrounding the burner axis.

[0043] FIG. 3B illustrates another alternative embodiment of an injector 170, in accordance with the present invention. Like reference numerals are used to designate elements of the fuel injector 170 that are identical to, or substantially similar in construction and operation as, those elements described in connection with the injector 110. Referring to FIG. 3B, the injector 170 includes entry, transition and nozzle regions 22, 24 and 26, and the distributor 140 within the entry region 22. Further, the injector 170 includes a segmented nozzle region 126 extending between the nozzle region 22 and the outlet end 14.

[0044] FIG. 5 illustrates a further embodiment of an injector 200, in accordance with the present invention. Like reference numerals are used to designate elements of the fuel injector 200 that are identical to, or substantially similar in construction and operation as, those elements described in connection with the injector 10. Referring to FIG. 5, the injector 200 includes entry, transition and nozzle regions 22, 24 and 26 defined by walls 16, 18 and 20, respectively, of a housing 11. The injector 200 further includes an air distributor 240, preferably having the same outer surface configuration as the diverging cone 40 described above. The distributor 240 includes a wall 142 having outer and inner surfaces 144, 146, similar to the distributor 140. The inner surface 146 and a ring-shaped upstream end wall 41 define a conically-shaped hollow interior 150. The upstream end wall 41 defines an aperture 241, which is in communication with the interior 150. A hollow tube 154 extends from the inlet end 12 to the aperture 241. The tube 154 also extends upstream of the inlet end 12, and is coupled to an air register (not shown).

[0045] In operation of the injector 200, the secondary stream flows through the tube 154, into the distributor 240 through the aperture 241 and then exits from the interior 150 of the distributor 240 into the passageway 28 in the entry region 22. The conical shape of the interior 150 directs the secondary stream substantially along and surrounding the central axis A of the passageway 28. The secondary stream, upon exiting the interior 150 of the distributor 240, interacts with and heats a portion of the primary stream flowing along and around the central axis of the passageway 28 as the primary stream flows from the entry region into the transition region 24 and then into the nozzle region 26 of the injector 10.

[0046] In a preferred embodiment of the inventive injector, the nozzle region 26 is fabricated from stainless steel, and the entry region 22 is fabricated from carbon steel.

[0047] Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims.

1. A fuel injector for use in a furnace comprising:
 - a housing having an inlet end and an outlet end, wherein the housing defines a passageway extending between the inlet and outlet ends, wherein the inlet end is for receiving a primary stream of a carrier gas and fuel, wherein a central axis extends along the length and through the center of the passageway;
 - means for introducing a secondary stream of a heated gas into the passageway; and
 - wherein, when the primary stream is supplied to the passageway at the inlet end and the secondary stream is introduced into the passageway by the introducing means, the primary stream flows through the passageway towards the outlet end and the secondary stream mixes with and heats, and increases oxygen concentration of, a portion of the primary stream along and around the central axis of the passageway, before the primary stream exits the passageway at the outlet end.
2. The fuel injector of claim 1, wherein the gas of the secondary stream is air and the fuel is pulverized coal.
3. The fuel injector of claim 2, wherein the air in the secondary stream is between about 400° F. and 1000° F.
4. The fuel injector of claim 1, wherein the introducing means defines at least one aperture for introducing the secondary stream into the passageway, wherein the aperture is between the inlet end and the outlet end.
5. The fuel injector of claim 4, wherein the aperture is defined by an adjustable air register.
6. The fuel injector of claim 4 further comprising:
 - a baffle extending from the housing into the passageway and towards the central axis, wherein the baffle is disposed upstream of the aperture to facilitate penetration of the secondary stream toward the central axis.
7. The fuel injector of claim 6, wherein the baffle is substantially adjacent to the aperture.
8. The fuel injector of claim 6, wherein the baffle extends in the direction of the outlet end.
9. The fuel injector of claim 4 further comprising:
 - a diverging cone disposed along the central axis upstream of the aperture, wherein the cone diverges in the direction of the outlet end.
10. The fuel injector of claim 9 further comprising:
 - a baffle extending from the housing into the passageway and towards the central axis and disposed downstream of the cone, wherein the baffle is disposed upstream of the aperture to facilitate penetration of the secondary stream toward the central axis.
11. The fuel injector of claim 1 further comprising:
 - a segmented nozzle at the outlet end for receiving from the passageway the primary stream in combination with the secondary stream, wherein the segmented nozzle separates the combination of the primary and secondary streams into a plurality of substantially elliptically shaped fuel streams for delivery from the injector at the outlet end.

12. The fuel injector of claim **1**, wherein the secondary stream is 100% oxygen, a mixture of air and oxygen, a mixture of CO₂ and oxygen, or a mixture of re-circulated flue gas and oxygen.

13. A fuel injector for use in a furnace comprising:
a housing having an inlet end and an outlet end, wherein the housing defines a passageway extending between the inlet and outlet ends, wherein a central axis extends along the length and through the center of the passageway and wherein the inlet end is for receiving a primary stream of a carrier gas and fuel;

an air distributor for distributing the secondary stream substantially along and around the central axis upstream of the outlet end; and

wherein, when the primary stream is supplied to the passageway at the inlet end and flows through the passageway towards the outlet end and the secondary stream is distributed by the air distributor, the secondary stream exiting the distributor mixes with and heats, and increases oxygen concentration of, a portion of the primary stream along and around the axis before the primary stream exits the passageway at the outlet end.

14. The fuel injector of claim **13** further comprising:
a hollow conduit for supplying the secondary stream to the distributor, wherein the distributor is a divergent cone defining a hollow interior in communication with the hollow conduit.

15. The fuel injector of claim **14**, wherein the hollow conduit extends from the inlet end to the distributor.

16. The fuel injector of claim **14**, wherein the housing defines at least one aperture between the inlet end and the outlet end and the hollow conduit extends from the aperture to the distributor.

17. The fuel injector of claim **13**, wherein the gas of the secondary stream is air and fuel is pulverized coal.

18. The fuel injector of claim **17**, wherein the air in the secondary stream is between about 400° F. and 1000° F.

19. The fuel injector of claim **13** further comprising:
a segmented nozzle at the outlet end for receiving the from the passageway the primary stream in combination with the secondary stream, wherein the segmented nozzle separates the combination of the primary and secondary streams into a plurality of substantially elliptically shaped fuel streams for delivery from the injector at the outlet end.

20. The fuel injector of claim **13**, wherein the secondary stream is 100% oxygen, a mixture of air and oxygen, a mixture of CO₂ and oxygen, or a mixture of re-circulated flue gas and oxygen.

21. A method for delivering fuel from a fuel injector to a combustion zone of a furnace comprising:

providing a fuel injector, wherein the fuel injector comprises a housing having an inlet end and an outlet end, wherein the housing defines a passageway extending between the inlet and outlet ends, wherein a central axis extends along the length and through the center of the passageway;

supplying a primary stream of a carrier gas and fuel to the passageway at the inlet end, wherein the primary stream flows through the passageway towards the outlet end; and

supplying a secondary stream of a heated gas into the passageway, wherein the secondary stream mixes with and heats, and increases oxygen concentration of, a portion of the primary stream along and around the axis, before the primary stream exits the passageway at the outlet end.

22. The method of claim **21**, wherein the gas of the secondary stream is air and the fuel is pulverized coal.

23. The method of claim **22**, wherein the air in the secondary stream is between about 400° F. and 1000° F.

24. The method of claim **21** further comprising:

supplying the secondary stream into the passageway through at least one aperture in the housing disposed between the inlet end and the outlet end.

25. The method of claim **24**, wherein the aperture is defined by an adjustable air register.

26. The method of claim **24** further comprising:

interrupting the flow of the primary stream upstream of the aperture to facilitate penetration of the secondary stream toward the central axis.

27. The method of claim **26**, wherein the flow is interrupted substantially adjacent to the aperture.

28. The method of claim **24** further comprising:

diverting flow of the primary stream away from the central axis upstream of the aperture.

29. The method of claim **21** further comprising:

separating the primary stream as heated by the secondary stream into a plurality of substantially elliptically shaped fuel streams for delivery from the injector at the outlet end.

30. The method of claim **21** further comprising:

supplying the secondary stream to generate a fuel stream exiting the outlet end having a predetermined stoichiometry on and surrounding the central axis of the passageway.

31. The method of claim **21** further comprising:

supplying the secondary stream along and around the central axis.

32. The method of claim **31**, wherein the secondary stream is supplied from a hollow conduit extending from the inlet end.

33. The method of claim **31**, wherein the secondary stream is supplied from an aperture in the housing, through a hollow conduit and to an air distributor for distributing the secondary stream along and around the central axis

34. The method of claim **21**, wherein the secondary stream is 100% oxygen, a mixture of air and oxygen, a mixture of CO₂ and oxygen, or a mixture of re-circulated flue gas and oxygen.

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