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(54) **Improved fuel staging process for low NOx operations**

Verbesserte gestuffte Brennstoffversorgung für Betrieb mit niedrigem NOx-Ausstoss

Alimentation en carburant étagée pour utilisations à faibles émissions de NOx

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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to fuel staging processes and systems for reducing nitrogen oxide (NOx) emissions, and in particular to such processes and systems using fuel dilution tips in low NOx burners.

[0002] One of the challenges confronting the Chemical Process Industry (CPI) is the combustion of waste fuels for economic reasons and at the same time meeting low NOx and CO emissions requirements. The waste fuels contain a cocktail of higher C/H ratio gases which combust with very luminous flames due to carbon oxidation and also produce soot particles or carbon depending on the combustion process. Typical refinery fuel composition contains varying amounts of fuels and inert gases (*e.g.*, C1, C2, C3,...Cn, olefins, hydrogen, nitrogen, CO2, water vapor). If carbon or soot particles are formed on the fuel tips, the soot structure generally grows under favorable pressure and temperature conditions existing near the tip exit. This could result in fuel jet blockage, fuel jet deflection, and overheating of tips and furnace parts, such as process tubes and refractory walls, and the potential shutdown of the burners and furnace operation. The shutdown of a furnace could result in significant financial penalties, including liability arising from downstream process interruption.

[0003] Dirty refinery fuels consisting of higher carbon and containing gases such as acetylene, ethane, propane, butane and olefins (*e.g.*, ethylene and propylene) generally produce soot particles if fuel tips are subjected to:

- ■ inadequate mixing in the furnace (depending on the number of jets, jet geometry, injection angles and injection velocities not being optimum) (generally classified as a burner design issue);
- ■ lack of combustion air or oxidant availability in the vicinity of fuel jets (generally classified as a burner flow configuration issue);
- ■ inadequate cooling of fuel tips (exposure to furnace radiation on regular basis) (generally classified as a fuel tip configuration and burner design issue);
- ■ interruption of fuel flows (upstream fuel equipment reliability) (generally classified as a process issue);
- ■ lower firing operation (lower fuel flow rates due to process turndown) (generally classified as a process issue); or
- ■fluctuation of refinery fuel composition in terms of carbon containing species (generally classified as a process requirement issue).

[0004] The burner or tip design significantly affect tip overheating, soot production, tip plugging, and resulting frequent maintenance for the burner equipment. These problems are compounded by changing process conditions, such as low end of process turndown and/or interruption of fuel flows, which affect required cooling needed on the fuel tips. Changing process conditions and fuel composition changes are common in refinery operation.

[0005] Another challenge confronting the CPI is the requirement of low NOx emissions to meet emission regulations. There are various areas in the United States where NOx regulations (under the 1990 Clean Air Act) require less than 10 ppm NOx emissions from process heaters, boilers, gas turbines, and other stationary combustion equipment. The most common or BACT (Best Available Control Technology) solution in the CPI is to use a SCR (Selective Catalytic Reactor) for post cleanup of flue gas for reduction of NOx contained in the flue stream (by converting NOx into N2) using ammonia injection inside a large catalytic reactor. This process is very capital intensive and requires significant quantities of ammonia, hot air, and electricity for ID fan operation.

[0006] Most refineries would like to avoid SCR installation and instead use low NOx burners to meet their NOx compliance requirements. However, low NOx burners have not consistently produced less than 10 ppm NOx in various process heating applications, such as steam methane reformers (SMR), crude heaters, ethylene crackers, or boilers. For this reason, the use of low NOx burners has not been certified by regulating agencies as the BACT. In other words, SCR currently is the only commercially viable solution for meeting stringent NOx levels in ozone attainment regions where ground level ozone concentration exceeds legal limits.

[0007] Typically, operators in the CPI utilize clean natural gas or an optimum blend of natural gas and dirty refinery fuels to reduce penalties on maintenance issues. However, due to natural gas shortages and the high cost of fuels, it is not always possible for process industries to utilize clean natural gas for combustion. The refineries that can combust waste fuels typically have higher productivity and a relatively favorable competitive status compared to other refineries which are under utilizing the waste fuel potential.

[0008] With regard to NOx reduction, the common NOx control methods include utilization of low NOx burners equipped with higher levels of fuel staging and dilution of air/fuel with flue gas recirculation (FGR). By injecting non-reactive or inert chemical species in the fuel/oxidant mixture, the average flame temperature is reduced and thus, NOx emissions are reduced. However, these methods require additional piping and energy costs associated with the transport of flue gas. In addition, there is an energy penalty due to required heating of the gases from ambient temperature to the process temperature. In addition, the field data published in the literature do not indicate that these methods achieve less than

10 ppm NOx performance.

[0009] Various devices and methods using fuel staging have been developed with the goal of reducing NOx emissions. Several of these are discussed below.

[0010] U.S. Patent Application No. 2003/0148236 (Joshi, et al.) discloses an ultra low NOx burner using staged fuel nozzles. The burner has eight fuel staging lances located around the main burner body. The center part of the burner is used for supplying 100% of the combustion air and a very small amount of fuel (~10%) is injected for overall flame stability. The rest of the fuel (- 90%) is injected using multiple fuel staging lances. The fuel staging lances have special fuel nozzle tips with two circular holes. As shown in Figures 1A-1C, these lances have axial and radial divergence angles for delayed mixing with the combustion air and entraining furnace gases due to a relatively high jet velocity (152 to 305 m/s (500 to 1,000 feet/sec) or 34500 to 103000 N/m^2 (5 to 15 psig) fuel supply pressure depending on the firing rate).

[0011] U.S. Pat. No. 6,383,462 (Lang) discloses a method and an apparatus which has a mixing chamber outside of the "burner and furnace" for mixing flue gases from the furnace with the fuel gas, as shown in Figure 2. A converging diverging venturi mixer is utilized to further dilute the fuel gas with additional flow motivating gas. The resulting mixture (diluted fuel with flue gas) is then sent to the burner wherein the mixture is combined with the combustion air and burned in the furnace. Depending on the flue gas dilution level, a NOx emission reduction from 26 ppm to 14 ppm may be obtained. This apparatus and method do not reduce NOx emissions below 10 ppm and the results are not comparable to those typically achieved with SCR technology.

[0012] U.S. Pat. No. 6,481,209 (Johnson, et al.) discloses a fuel staging system suitable for gas turbine engines. Efficient combustion with air is achieved with lower NOx and CO emissions by splitting fuel injection in two stages: 1) injectors installed in swirl mixers, and 2) injectors installed in the trapped vortex region of the combustor. However, this injection scheme is not suitable for large furnaces where trapped vortex zones are not possible due to furnace and load geometry.

[0013] U.S. Pat. No. 6,558,154 (Eroglu, etal.) discloses a control based fuel staging strategy for an aero engine in which two separate instrumented fuel staging nozzles are used. A set of emission and pulsation sensors are installed downstream of each staging zone. These sensors measure the quality of combustion products issued from each staging zone and then a control unit varies relative amounts of fuels injected in each zone depending on changing operating and environmental conditions.

[0014] U.S. Pat. No. 5,601,424 (Bernstein, et al.) discloses a method for reducing NOx using atomizing steam injection control. The NOx levels are lowered by adding to the burner flame atomizing steam, which is available for fuel oil atomization. For 30% NOx reduction, approximately 0,227 kg steam/0,454 kg of fuel flow (0.5 lb steam/lb of fuel flow) is necessary. A large amount of steam is necessary to reduce flame temperature and obtain a required NOx reduction. In addition, if a large amount of steam is used for flame quenching, there is a possibility of flame instability and sputtering. Thus, there is an upper limit for steam injection on flame stability grounds.

[0015] The gas turbine industry also uses a similar steam injection technique for NOx control. However, due to an inefficient steam injection mode, a large economic penalty is paid in order to reduce NOx emissions. The steam consumption is very large, and the technique is relatively inefficient and not cost effective for NOx control.

[0016] It is desired to have a cost effective, retrofit apparatus and method for NOx emission reduction, which provide the ability to combust refinery waste gases without excessive NOx emissions.

[0017] It is further desired to have an apparatus and method which reduce equipment maintenance due to problems such as plugging of burner tips and over-heating of process tubes, and which will provide additional benefits of improved fuel efficiency and furnace productivity.

[0018] It is still further desired to have an apparatus and method which will allow current low NOx burners to meet SCR level NOx performance and allow refiners to comply with NOx regulations without using the capital-intensive SCR technology.

[0019] It is still further desired to have an apparatus and method which will enable process industries to consume cheaper waste fuel without incurring penalties on maintenance issues such as tips plugging, equipment overheating, process interruptions, *etc.*, while at the same time meeting NOx regulations by producing less than 10 ppm NOx emissions.

[0020] It is also desired to have an apparatus and method for combusting a fuel which afford better performance than the prior art, and which also overcome many of the difficulties and disadvantages of the prior art to provide better and more advantageous results.

BRIEF SUMMARY OF THE INVENTION

[0021] The present invention is a method and a system for diluting a fuel to reduce nitrogen oxide emissions through fuel staging. The invention also includes a fuel dilution device that may be used in the method or the system.

[0022] There are multiple steps in a first embodiment of the method for diluting a fuel to reduce nitrogen oxide emissions through fuel staging. The first step is to provide a fuel dilution device, which includes: a first conduit having an inlet and an outlet spaced apart from the inlet, the first conduit adapted to transmit a stream of the fuel entering the inlet and exiting the outlet at a first thermodynamic state and a first fuel index; and a second conduit having an intake and an outtake spaced apart from the intake, the second conduit adapted to transmit a stream of a fluid entering the intake and exiting the outtake at a second thermodynamic state and a second fuel index, the second fuel index being different from the first fuel index by at least about 0.1 and the second thermodynamic state being different from the first thermodynamic state, whereby a potential for mixing exists between the stream of the fuel exiting the outlet of the first conduit and the stream of the fluid exiting the outtake of the second conduit. The second step is to feed the stream of the fuel to the inlet of the first conduit, said stream of the fuel exiting the outlet of the first conduit at the first thermodynamic state and the first fuel index. The third step is to feed the stream of the fluid to the intake of the second conduit, said stream of the fluid exiting the outtake of the second conduit at the second thermodynamic state and the second fuel index, whereby at least a portion of the stream of the fuel exiting the outlet of the first conduit mixes with at least a portion of the stream of the fluid exiting the outtake of the second conduit at a location proximate both the outlet and the outtake, thereby generating at least one diluted fuel stream having an intermediate fuel index between the first fuel index and the second fuel index. The fourth step is to provide a source of an oxidant. The fifth step is to combust a portion of the oxidant with at least a portion of at least one of the stream of the fuel, or the stream of the fluid, or the diluted fuel stream, thereby generating a gas containing a reduced amount of nitrogen oxide, said reduced amount of nitrogen oxide being less than a higher amount of nitrogen oxide that would be generated by combusting the fuel using a means other than the fuel dilution device.

[0023] There are many variations of the first embodiment of the method. In one variation, the fluid is a fuel. In another variation, the fluid is selected from a group consisting of steam, flue gas, carbon dioxide, nitrogen, argon, helium, xenon, krypton, other inert fluids, and mixtures or combinations thereof.

[0024] In another variation of the first embodiment of the method, the first conduit is adjacent the second conduit. In yet another variation, at least a substantial portion of the second conduit is disposed in the first conduit. In still yet another variation, the second conduit has an equivalent diameter (D_c) and the outtake of the second conduit is located at a distance behind the outlet of the first conduit, said distance being in a range of about (2 D_c) to about (20 D_c).

[0025] A second embodiment of the method for diluting a fuel to reduce nitrogen oxide emissions through fuel staging is similar to the first embodiment but includes two additional steps. The first additional step is to provide a swirler disposed in the second conduit. The second additional step is to transmit at least a portion of the stream of the fluid through the swirler, thereby swirling at least a portion of the fluid exiting the second conduit.

[0026] According to the invention a zipper nozzle is provided in fluid communication with the outlet of the first conduit. This enables to transmit through the zipper nozzle at least a portion of a diluted fuel stream.

[0027] Another embodiment of the method is similar to the first embodiment but includes the additional step of placing the fuel dilution device in fluid communication with a furnace containing a quantity of a furnace gas, whereby at least a portion of the quantity of the furnace gas mixes with at least a portion of the diluted fuel stream.

[0028] Another embodiment of a method for diluting a fuel to reduce nitrogen oxide emissions through fuel staging includes multiple steps. The first step is to provide a fuel dilution device, which includes: a first conduit having an inlet and an outlet spaced apart from the inlet, the first conduit adapted to transmit a stream of the fuel entering the inlet and exiting the outlet at a first pressure, a first velocity, and a first fuel index; and a second conduit having an intake and an outtake spaced apart from the intake, the second conduit adapted to transmit a stream of a fluid entering the intake and exiting the outtake at a second pressure, a second velocity, and a second fuel index, the second fuel index being different from the first fuel index by at least about 0.1 and at least one of the second pressure and the second velocity being different from at least one of the first pressure and the first velocity, whereby a potential for mixing exists between the stream of the fuel exiting the outlet of the first conduit and the stream of the fluid exiting the outtake of the second conduit. The second step is to feed the stream of the fuel to the inlet of the first conduit, said stream of the fuel exiting the outlet of the first conduit at the first pressure, the first velocity, and the first fuel index. The third step is to feed the stream of the fluid to the intake of the second conduit, said stream of the fluid exiting the outtake of the second conduit at the second pressure, the second velocity, and the second fuel index, whereby at least a portion of the stream of the fuel exiting the outlet of the first conduit mixes with at least a portion of the stream of the fluid exiting the outtake of the second conduit at a location proximate both the outlet and the outtake, thereby generating at least one diluted fuel stream having an intermediate fuel index between the first fuel index and the second fuel index. The fourth step is to provide a source of an oxidant. The fifth step is to combust a portion of the oxidant with at least a portion of at least one of the stream of the fuel, or the stream of the fluid, or the diluted fuel stream, thereby generating a gas containing a reduced amount of nitrogen oxide, said reduced amount of nitrogen oxide being less than a higher amount of nitrogen oxide that would be generated by combusting the fuel using a means other than the fuel dilution device.

[0029] There are multiple elements in a first embodiment of a fuel dilution device for diluting a fuel to reduce nitrogen oxide emissions through fuel staging. The first element is a first conduit having an inlet and an outlet spaced apart from the inlet, the first conduit adapted to transmit a stream of a fuel entering the inlet and exiting the outlet at a first thermodynamic state and a first fuel index. The second element is a second conduit having an intake and an outtake spaced apart from the intake, the second conduit adapted to transmit a stream of a fluid entering the intake and exiting the outtake at a second thermodynamic state and a second fuel index, the second fuel index being different from the first fuel index by at least about 0.1 and the second thermodynamic state being different from the first thermodynamic state, whereby a potential for mixing exists between the stream of the fuel exiting the outlet of the first conduit and the stream of the fluid exiting the outtake of the second conduit, whereby at least a portion of the stream of the fuel exiting the outlet of the first conduit mixes with at least a portion of the stream of the fluid exiting the outtake of the second conduit at a location proximate both the outlet and the outtake, thereby generating at least one diluted fuel stream having an intermediate fuel index between the first fuel index and the second fuel index. The third element is a source of an oxidant. The fourth element is a means for combusting a portion of the oxidant with at least a portion of at least one of the stream of the fuel, or the stream of the fluid, or the diluted fuel stream, thereby generating a gas containing a reduced amount of nitrogen oxide, said reduced amount of nitrogen oxide being less than a higher amount of nitrogen oxide that would be generated by combusting the fuel using a means other than the fuel dilution device.

[0030] There are many variations of the first embodiment of the fuel dilution device. In one variation, the fluid is a fuel. In another variation, the fluid is selected from a group consisting of steam, flue gas, carbon dioxide, nitrogen, argon, helium, xenon, krypton, other inert fluids, and mixtures or combinations thereof.

[0031] In another variation, the first conduit is adjacent the second conduit. In yet another variation, at least a substantial portion of the second conduit is disposed in the first conduit. In still yet another variation, the second conduit has an equivalent diameter (D_c) and the outtake of the second conduit is located at a distance behind the outlet of the first conduit, said distance being in a range of about (2 x D_c) to about (20 x D_c).

[0032] In another variation of the first embodiment, the fuel dilution device is in fluid communication with a furnace containing a quantity of a furnace gas, whereby at least a portion of the quantity of the furnace gas mixes with at least a portion of the diluted fuel stream.

[0033] A second embodiment of the fuel dilution device is similar to the first embodiment but includes a swirler disposed in the second conduit. According to the invention, the fuel dilution device includes a zipper nozzle in fluid communication with the outlet of the first conduit.

[0034] Another embodiment of the fuel dilution device for diluting a fuel to reduce nitrogen oxide emissions through fuel staging includes multiple elements. The first element is a first conduit having an inlet and an outlet spaced apart from the inlet, the first conduit adapted to transmit a stream of a fuel entering the inlet and exiting the outlet at a first pressure, a first velocity, and a first fuel index. The second element is a second conduit having an intake and an outtake spaced apart from the intake, the second conduit adapted to transmit a stream of a fluid entering the intake and exiting the outtake at a second pressure, a second velocity, and a second fuel index, the second fuel index being different from the first fuel index by at least about 0.1 and at least one of the second pressure and the second velocity being different from at least one of the first pressure and the first velocity, whereby a potential for mixing exists between the stream of the fuel exiting the outlet of the first conduit and the stream of the fluid exiting the outtake of the second conduit, whereby at least a portion of the stream of the fuel exiting the outlet of the first conduit mixes with at least a portion of the stream of the fluid exiting the outtake of the second conduit at a location proximate both the outlet and the outtake, thereby generating at least one diluted fuel stream having an intermediate fuel index between the first fuel index and the second fuel index. The third element is a source of an oxidant. The fourth element is a means for combusting a portion of the oxidant with at least a portion of at least one of the stream of the fuel, or the stream of the fluid, or the diluted fuel stream, thereby generating a gas containing a reduced amount of nitrogen oxide, said reduced amount of nitrogen oxide being less than a higher amount of nitrogen oxide that would be generated by combusting the fuel using a means other than the fuel dilution device.

[0035] Another aspect of the invention is a system for diluting a fuel to reduce nitrogen oxide emissions through fuel staging. The system includes multiple elements. The first element is a fuel dilution device, which includes: a first conduit having an inlet and an outlet spaced apart from the inlet, the first conduit adapted to transmit a stream of the fuel entering the inlet and exiting the outlet at a first thermodynamic state and a first fuel index; and a second conduit having an intake and an outtake spaced apart from the intake, the second conduit adapted to transmit a stream of a fluid entering the intake and exiting the outtake at a second thermodynamic state and a second fuel index, the second fuel index being different from the first fuel index by at least about 0.1 and the second thermodynamic state being different from the first thermodynamic state, whereby a potential for mixing exists between the stream of the fuel exiting the outlet of the first conduit and the stream of the fluid exiting the outtake of the second conduit. The second element is a means for feeding the stream of the fuel to the inlet of the first conduit, said stream of the fuel exiting the outlet of the first conduit at the first thermodynamic state and the first fuel index. The third element is a means for feeding the stream of the fluid to the intake of the second conduit, said stream of the fluid exiting the outtake of the second conduit at the second thermodynamic state and the second fuel index, whereby at least a portion of the stream of the fuel exiting the outlet of the first conduit mixes with at least a portion of the stream of the fluid exiting the outtake of the second conduit at a location proximate both the outlet and the outtake, thereby generating at least one diluted fuel stream having an intermediate fuel index between the first fuel index and the second fuel index. The fourth element is a source of an oxidant. The fifth element is a means for combusting a portion of the oxidant with at least a portion of at least one of the stream of the fuel, or the stream of the fluid, or the diluted fuel stream, thereby generating a gas containing a reduced amount of nitrogen oxide, said reduced amount of nitrogen oxide being less than the high amount of nitrogen oxide that would be generated by combusting the fuel using a means other than the fuel dilution device.

[0036] Another embodiment of the system for diluting a fuel to reduce nitrogen oxide emissions through fuel staging includes multiple elements. The first element is a fuel dilution device, which includes: a first conduit having an inlet and an outlet spaced apart from the inlet, the first conduit adapted to transmit a stream of the fuel entering the inlet and exiting the outlet at a first pressure, a first velocity, and a first fuel index; and a second conduit having an intake and an outtake spaced apart from the intake, the second conduit adapted to transmit a stream of a fluid entering the intake and exiting the outtake at a second pressure, a second velocity, and a second fuel index, the second fuel index being different from the first fuel index by at least about 0.1 and at least one of the second pressure and the second velocity being different from at least one of the first pressure and the first velocity, whereby a potential for mixing exists between the stream of the fuel exiting the outlet of the first conduit and the stream of the fluid exiting the outtake of the second conduit. The second element is a means for feeding the stream of the fuel to the inlet of the first conduit, said stream of the fuel exiting the outlet of the first conduit at the first pressure, the first velocity, and the first fuel index. The third element is a means for feeding the stream of the fluid to the intake of the second conduit, said stream of the fluid exiting the outtake of the second conduit at the second pressure, the second velocity, and the second fuel index, whereby at least a portion of the stream of the fuel exiting the outlet of the first conduit mixes with at least a portion of the stream of the fluid exiting the outtake of the second conduit at a location proximate both the outlet and the outtake, thereby generating at least one diluted fuel stream having an intermediate fuel index between the first fuel index and the second fuel index. The fourth element is a source of an oxidant. The fifth element is a means for combusting a portion of the oxidant with at least a portion of at least one of the stream of the fuel, or the stream of the fluid, or the diluted fuel stream, thereby generating a gas containing a reduced amount of nitrogen oxide, said reduced amount of nitrogen oxide being less than a higher amount of nitrogen oxide that would generated by combusting the fuel using a means other than the fuel dilution device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] The invention will be described by way of example with reference to the accompanying drawings, in which:

[0038] Figure 1A is a cross-sectional plan view of a prior art fuel staging nozzle used in an ultra low-NOx burner;

[0039] Figure 1B is a cross-sectional elevation view of the prior art fuel staging nozzle of Figure 1A;

[0040] Figure 1C is a side view of the prior art fuel staging nozzle of Figure 1 B;

[0041] Figure 2 is a cross-sectional elevation view of a prior art mixing chamber for mixing flue gases from a furnace and a flow motivating gas with a fuel gas;

[0042] Figure 3 is a schematic diagram illustrating a cross-sectional view of one embodiment according to the prior art.

[0043] Figure 4 is a schematic diagram illustrating a cross-sectional view of another embodiment according to the prior art.

[0044] Figure 5A is a schematic diagram illustrating another embodiment according to the prior art which uses strong jet-weak jet entrainment;

[0045] Figure 5B is a schematic diagram illustrating a cross-sectional view of another embodiment according to the prior art; which uses a swirl induced entrainment;

[0046] Figure 6 is a schematic diagram illustrating a cross-sectional view of another embodiment according to the prior art;

[0047] Figure 7 is a schematic diagram illustrating a cross-sectional view of an embodiment of the invention which includes a zipper tip or nozzle;

[0048] Figure 8A is a schematic diagram illustrating a front view of a zipper tip or nozzle;

[0049] Figure 8B is a schematic diagram illustrating a side view of a zipper tip or nozzle attached to a lance, such as that shown in Figure 7;

[0050] Figure 8C is a schematic diagram illustrating a plan view of a zipper tip or nozzle;

[0051] Figure 8D is a schematic diagram illustrating a portion of the front view of the zippertip or nozzle in Figure 8A in detail for dimensioning; and

[0052] Figure 9 is a schematic diagram illustrating a cross-sectional view of another embodiment of the invention which includes a zipper tip or nozzle.

DETAILED DESCRIPTION OF THE INVENTION

[0053] The present invention addresses a number of issues encountered in combustion equipment design, such as burners used for heating reformers, process heaters, boilers, ethylene crackers, or other high temperature furnaces. The invention relates to an improved fuel staging process. In particular, two general approaches that provide for rapid dilution and mixing, depending on the required process objectives, are:

I. Staging Fuel with Another Fuel (F-F): High-pressure refinery waste fuel, atomized liquid fuel, *etc.* are injected in the vicinity of a relatively clean and low-pressure gaseous fuel for clean, maintenance free, low NOx operation; and
II. Staging Fuel with Inert Gas (F-I): High-pressure inert fluids such as steam, nitrogen, CO2, *etc.* are injected in the vicinity of a low-pressure gaseous fuel for NOx reduction.

[0054] As used herein, the term "fuel index" (FI) is defined as the weighted sum of the fuel carbon atom number where molecular H2 is assigned a carbon number 1.3, the weights being the component mole fractions: FI $= \Sigma C_i x_i / \Sigma x_i$ where C_i and x_i are the number of carbon atoms and the mole fraction of component i, respectively. The fuel indices of a number of fuels and inerts are listed in Table I. Generally, a fuel with a higher fuel index cracks more easily and produces more NOx through the prompt NOx mechanism. H2 is a special case in this definition. Although H2 does not have any carbon atoms, it is well known that H2 addition in natural gas increases NOx emissions. The literature suggests that about a 30% higher NOx emission occurs for pure H2 flames as compared to methane flames. The increased NOx emission from H2 flames is attributable to higher flame temperatures via the thermal NOx mechanism. Since the fuel index is used as an indicator for NOx emissions herein, a value of 1.3 is assigned to H2 to be consistent with its NOx emission potential.

Table I: Fuel Indices for Selected Fuels and Inerts

Fuels or Inerts	Fuel Index
H2	1.3
H2O	0
CO2	0
CO	1
N2	0
CH4	1
C3H8	3
ROG (1)	1.434
PSA offgas (2)	0.57
Natural gas (3)	1.08
Natural gas (4)	1.14
(1) ROG: H2 18%, CH4 44%, C2H2 38%. (2) PSA offgas: H2 30%. CH4 18%, CO2 52%. (3) Natural gas: CH4 91 %, C2H6 4%, C3H8 3%, N2 1%, CO2 1%. (4) Natural gas: CH4 84%, C2H6 12%, C3H8 2%, N2 2%.	

[0055] As discussed herein, the term "thermodynamic state" is defined as a state of existence for a matter. This definition is based on the generally known concept of thermodynamics, but with an extension to include not only the usual temperature and pressure but also velocity, concentration, composition, volume fraction, flow rate, electric potential, *etc.*, to completely characterize a stream. This definition is used to precisely define mixing as the result of a difference in the thermodynamic state between two streams.
[0056] The two approaches are discussed in detail below.

I. *Staging Fuel with Another Fuel (F-F):*

[0057] This approach may be used to combust refinery waste fuels at a high supply pressure that contain a blend of hydrogen and higher C/H fuels (ethane, propane, butane, olefins, *etc.*) with a second relatively cleaner, low-pressure fuel gas. Maintenance problems arise with such refinery waste fuel due to thermal cracking of the high C/H fuels and subsequent soot build-up in the burner fuel tips. In addition, combustion of such fuels results in higher than normal NOx emissions.

[0058] To improve combustion of high C/H refinery waste fuels, the dirty fuel is diluted with a relatively cleaner (secondary) fuel stream (*e.g.*, hydrogen, syngas, natural gas, or a low kg (BTU) fuel blend). In one embodiment shown in Figure 3, a high-pressure refinery fuel gas (containing high C/H ratio fuel gases) is injected through a center lance 32 and a relatively clean, low-pressure fuel gas, such as natural gas, syngas, process gas, PSA off gas (recycled fuel gas after removing product hydrogen from PSA adsorbent beds), etc is injected through an annular region 33 between the center lance 32 and an outer lance 34. As shown in Figure 3, the exit 36 of the center lance is recessed a preferred distance from the exit 38 of the outer lance. This distance preferably is 2 to 20 times the equivalent diameter (Dc) of the center lance. Depending on the fuel split between the high-pressure refinery fuel gas and the cleaner low-pressure fuel gas, the distance preferably is 1,59 to 25,4 mm (about 1/16" to 1").

[0059] Persons skilled in the art will recognize that the reference to "high pressure" in Figures 3-7 and 9 also could state "high velocity" or "high pressure or high velocity." Similarly, the reference to "low pressure" in those figures could state "low velocity" or "low pressure or low velocity."

[0060] The arrangement shown in Figure 3 allows the dirty high-pressure refinery fuel gas to mix with the cleaner low-pressure fuel gas due to turbulent jet interaction. The velocity of the high-pressure refinery fuel gas through the center lance 32 preferably is 274 to 427 m/s (about 900 to 1400 feet/sec) (preferably sonic or choked velocity). The velocity of the low-pressure fuel gas through the annular region 33 between the center lance 32 and the outer lance 34 preferably is 30,5 to 274 m/s (about 100 to 900 feet/sec), depending on the available supply pressure of the low-pressure gas. The higher velocity gas stream exiting the exit 36 of the center lance entrains the lower velocity gas stream approaching the exit 38 of the outer lance and provides "first stage" mixing before the streams exit through an orifice(s) 40. The outer lance orifice geometry, angles, *etc.* are designed for optimum "second stage" mixing in the furnace atmosphere. A very large amount of furnace gas 42 is entrained for second stage dilution, thereby lowering the peak flame temperatures and subsequent reduction in NOx emissions.

[0061] Figure 4 illustrates an arrangement for liquid fuel (F-F) staging. In this embodiment, a high-pressure (and high C/H ratio) liquid fuel (*e.g.*, fuel oil, diesel, bunker C, waste liquid fuel, *etc.*) is diluted using a low-pressure fuel gas before being injected into a furnace atmosphere for further dilution. For example, heavy fuel oil can be atomized with an atomizing fluid, such as steam, and then diluted with a low-pressure fuel gas for soot free (clean) combustion inside the furnace. This embodiment also decreases NOx emissions due to lower peak flame temperatures.

[0062] In Figure 4, X is the distance from the exit of the center lance 32 to the back face of the exit for the outer lance 34. D_c is the flow area-equivalent diameter of the exit of the center lance, that is, the total flow areas of the exit of the center lance is the same as a circle of diameter D_c. D_e is the flow area-equivalent diameter of the outer lance, that is, the total flow area of the exit of the lance is the same as a circle of diameter D_e.

[0063] Two other embodiments of (F-F) staging are shown in Figures 5A and 5B. In Figure 5A, a strong jet - weak jet interaction takes place between the high-pressure refinery fuel gas and the low-pressure fuel gas. The high-pressure refinery fuel gas is injected in a high-pressure lance 52 at a high velocity 274 to 427 m/s (about 900 to 1400 feet/sec) in a preferred direction, and a low-pressure fuel gas, which is injected in a low-pressure lance 54, is entrained by the high-pressure refinery fuel gas.

[0064] In Figure 5B, the high-pressure refinery fuel gas is swirled in a center lance 32 using a fuel swirler 56, and the low-pressure fuel gas is entrained in the collapsed region (central region) of the high velocity swirl. This allows good mixing of the high-pressure refinery fuel gas and the low-pressure fuel gas before they exit the outer lance 34 and enter the furnace (not shown), where additional dilution takes place with the furnace gases 42. This approach is beneficial for applications requiring a short flame profile or a smaller combustion space.

[0065] An application for (F-F) staging is found in steam methane reformers (SMR) where the high-pressure fuel gas is generally a supply of natural gas or a refinery off-gas which is generally classified as a trim fuel. Referring to Figure 6, the high-pressure fuel gas is injected in the center lance 32. The low-pressure fuel gas injected in the annular region 33 between the center lance 32 and the outer lance 34 is generally PSA (pressure swing adsorption) off-gas or clean vent stream from PSA that contains CO_2 (~45%), hydrogen (~30%), methane (~15%), and CO (~10%) with a fuel index of about 0.64. The PSA off-gas is permeate out of the adsorption bed after hydrogen product is separated. The high-pressure trim fuel accounts for between 10% to 30% of a total energy for typical reformers having PSA for hydrogen separation.

[0066] A secondary advantage of this staging application is to improve PSA recovery by increasing the range of PSA pressure cycle, particularly at the low end. Referring to Figure 7, this is achieved by creating a low-pressure region inside the outer lance 34. The high velocity central jet 72 shown in Figure 7 creates a low-pressure region around the jet body where the slower moving low-pressure fuel gas is entrained by the faster moving central jet. Due to an active entrainment process, the supply pressure for the low-pressure fuel gas is reduced for the same fuel flow rate.

[0067] In one laboratory firing experiment, the supply pressure of low-pressure PSA off-gas was reduced from 13800 to 11000 N/m^2 (2 psig to 1.6 psig) (20% reduction). This was achieved by injecting the high- pressure fuel gas at 172000 N/m^2/396 m/s (25 psig) (1300 feet/sec velocity). The combustion energy split between the high-pressure fuel gas and the low-pressure fuel gas was 30:70 respectively.

[0068] To further quantify details of the (F-F) staging process, laboratory test results were considered using a low NOx burner. The burner had 10 fuel lances distributed around a circle of 457 mm (18")diameter. Of the 10 fuel lances, two lances were reserved for the (F-F) type staging configuration. The lances had special fuel tips and multiple diverging slots (zipper tips 74) to improve passive mixing. A schematic diagram of the (F-F) fuel staging configuration using zipper tips 74 is shown in Figure 7. The burner was rated at $8{,}44 \cdot 10^6$ kg/h (8 MM Btu/hr) firing rate utilizing 340°C (644°F) air preheat and it was designed to utilize two types of fuels. The details of the two fuels are provided below:

- High-pressure refinery fuel gas: H_2 (18%), natural gas (44%) and ethylene (38%). This fuel has a fuel index of 1.43 and accounts for 30% of the total energy input.
- Low-pressure fuel gas: CO_2 (52%), natural gas (18%) and H_2 (30). It has a fuel index of 0.57, and accounts for about 70% of the total energy input.

[0069] Referring to the arrangement illustrated in Figure 7, the high-pressure fuel gas was injected in a center lance 32 made of standard tubing having a 9,53 mm (3/8'')diameter x 0,88 mm (0.035") wall thickness, which was placed concentrically in an outer lance 34 made of pipe of 19,1 mm (¾") sch 40. A zipper tip 74 was attached to the end of the pipe. The zipper tip was sized for 13 mm (0.51") equivalent diameter and, as shown in Figures 8A-8D, had four vertical slots and one horizontal slot. The divergence angles ($\alpha 1$ and $\alpha 2$) for the vertical slots were 18° and 6° respectively for the axial zipper nozzle tip geometry as follows: 1) a series of vertical structures at intersecting planes between adjacent primary shapes; 2) flow induced downstream instabilities; and 3) a high level of molecular (small-scale) mixing between the first fluid (fuels) and the second fluid (furnace gases). The above mixing also was achieved in the shortest axial distance. The low NOx burner laboratory experiments conducted with the lance-in-lance configuration of Figure 7 (including zipper tips), indicate a rapid axial mixing, higher furnace gas entrainment with the divergence angle β at 7°.

[0070] The overall fluid processes according to the arrangement of Figure 7 resulted in more uniform heat transfer to the load and ultra low (< 15 ppmv) NOx and CO emissions at a fuel pressure less than 13800 N/m^2 (2 psig). It was also noticed that without the lance-in-lance process, the combustion of high pressure and high C/H ratio fuel produces a visible soot rich flame. Also, the NOx emissions were as high as 25 to 30 ppm. This experiment demonstrated that the F-F staging process could lower NOx emissions dramatically. The F-I staging process could reduce the emissions even more with inerts.

[0071] The visual proof of enhanced mixing was observed in a furnace in a laboratory whenever the lance-in-lance (F-F) fuel staging configuration was used for refinery fuels consisting of butane (C_4H_{10}) as high as 50%. The individual flames were found to mix much more quickly with furnace gases and created a spacious or flameless combustion. On the other hand, simple lances with cylindrical nozzle lances created a rather visible (bluish) and relatively longer flame, indicating less furnace gas dilution and mixing, and at the same time produced relatively higher NOx and CO emission levels at given fuel supply pressure.

[0072] Table II provides a preferred firing range, dimensions, dimensionless ratios and injection angles for a proposed lance-in-lance configuration. Simple circular tubing was used for high-pressure refinery fuel whereas a zipper tip was used for the low-pressure PSA off-gas fuel. These lances are critical components of a low NOx burner because the reliability of burner performance directly affects steam methane reformer on stream performance.

Table II: Dimensional parameters for Lance-in-Lance fuel staging tips

	Low pressure zipper tip							High Prs. Cyl. Tip	
	(H)	(W)	(R_o/R_1)	(H/Ro)	($\alpha 1$, $\alpha 2$)	(β)	L/D_e	D_c	X/D_c
Burner Firing Capacity (MM Btu/Hr)	Slot Height (In) mm	SlotWidth (In) mm	Slot end radius to center radius ratio	Slot height to corner radius ratio	Axial div. Angle (°)	Radial div. Angle (°)	Zipper tip thickness to equiv. diameter ratio	Tube Dia (inch) mm	Dist. back zipper tip inlet
8	(1/32-1) 0,79-25,4	(1/4 -2) 0,25-50,8	1.6 (1-3)	3.7 (2-6)	15 (0 - 30)	7 (0- 30)	0.625 (0.05-3)	(0.305) (1/16-2) 7,75 1,59-50,8	4 (2-20)

(continued)

	Low pressure zipper tip							High Prs. Cyl. Tip	
	(H)	(W)	(R_o/R_1)	(H/Ro)	(α1, α2)	(β)	L/D_e	D_c	X/D_c
5.2	(1/32-1) 0,79-25,4	(1/4-2) 0,25-50,8	1.6 (1-3)	3.7 (2-6)	15 (0 - 30)	7 (0 -30)	0.625 (0.05-3)	(0.277) (1/16-2) 7,04 1,59-50,8	4 (2-10)

[0073] The above dimensional ranges are valid for a variety of fuels, such as natural gas, propane, refinery off gases, low kg (BTU) fuels, *etc.* The nozzles are optimally sized depending on fuel composition, flow rate (or firing rate) and supply pressure available at the burner inlet In Table II, the dimensions, ratios and ranges are estimated for a $2{,}11 \cdot 10^6$ to $10{,}6 \cdot 10^6$ kg/h (2 to 10 MM Btu/Hr) burner firing rate. However, these dimensions and ranges can be scaled up for higher firing rate burners $>10{,}6 \cdot 10^6$ kg/h (> 10 MM Btu/Hr) using standard engineering practice of keeping similar flow velocity ranges. II. *Staging Fuel with Inert* Gas *(F-I)*:

[0074] The improved fuel staging with high-pressure inert gases, such as steam (dry or saturated, CO2, flue gas, nitrogen, or other inert gases, is performed with low-pressure fuel gases to reduce NOx emissions. The staging fuels that may be used include but are not limited to natural gas; low kg (BTU) process gas (consisting of hydrogen and other refinery fuels); and PSA off-gas. The injection tip configurations are similar to those shown in Figures 3-7. The main objective is to further reduce NOx emissions. A preferred embodiment is illustrated in Figure 9.

[0075] Referring to Figure 9, a high pressure 207000 to 689000 N/m^2 (30 to 100 psig) saturated or dry steam is sent through the center lance 32 at about 274 to 427 m/s (900 to 1400 feet/sec) and low-pressure fuel gas is sent through the annular region 33 between the center lance 32 and the outer lance 34. A high velocity steam jet 92 entrains the fuel gas for first stage dilution (and mixing) inside the annular region. The resulting mixture then exits through a zipper tip 74 at a high velocity of about 183 to 427 m/s (about 600 to 1400 feet/sec) for second stage dilution in the furnace (not shown) using furnace gases (not shown). The second stage dilution is very effective due to high steam velocities and entrainment loops set up by individual flames formed by the zipper tip. Due to the zipper tip geometry and steam-assist, improved fuel dilution is obtained. The peak flame temperatures are further reduced and ultra low NOx emissions are obtained. Table III provides estimated steam consumption numbers for a large steam methane reformer furnace.

Table III: Steam Consumption Economics with Proposed (F-I) Staging Process

steam injection rate kg stm/kg fuel	(lb_stm/lb_fuel)	0.02	0.05
firing rate kg/h	(mmbtu/hr LHV)	$89 \cdot 10^8$, (850)	89.10^8, (850)
fuel heating value mg/Nm^3	(btu/scf, LHV)	37,2 (1000)	37,2 (1000)
fuel cost \$/$1{,}06 \cdot 10^6$ kg	(\$/mmbtu, LHV)	6	6
fuel molecular weight		18	18
steam needed kg/h m^3	(lb/hr) (mmscfd)	366 (806) (0.408)	0,9 (2.016) (1.02)
		11600	28900
energy required to generate steam at 689000 N/m^2 (100 psia) and 204,4°C (400 F) from water at 15,5°C (60 F)	(btu/scf) mg/Nm^3 (btu/lb) kg/kg	2,12(57.1) 2798,6 (1203.2)	2,12 (57.1) 2798,6 (1203.2)
steam cost	\$/day \$/year	140 50,992	349 127,480

[0076] As shown in Table III, due to the unique method of fuel staging with an inert gas such as steam, the amount of steam required for fuel dilution is extremely low. The amount of steam needed for (F-I) staging is from about 2% to 10% on a kg per kg (lb per lb) basis when compared to the low-pressure fuel. The high velocity of steam is used for a two-stage dilution process: 1) inside the lance tube using steam and low-pressure fuel gas, and 2) in the furnace space using high velocity fuel-steam mixture and furnace gases.

[0077] The laboratory experiments using an inert gas, such as nitrogen, have shown that NOx reductions of about

30% to 40% are possible based on a comparison between the simple prior art lance configuration (zipper or circular tips alone without lance-in-lance arrangement) and the lance-in-lance configuration of Figure 9. For example, using a low NOx burner, at $5{,}28 \cdot 10^6$ kg/h (5 MM btu/Hr) firing rate, using ambient combustion air, a furnace operating at an average temperature of 871,1°C (1600°F), exhaust gas at 1093,3°C (2000°F), using a nitrogen flow rate of 10% on a weight basis, the NOx emission is reduced from about 10 ppm (corrected at 3% O2) for no inert gas in the center to about 7 ppm (corrected at 3% O2) with nitrogen gas in the center.

[0078] In each of the embodiments discussed above, the favorable results achieved by the present invention are driven by two differences in the streams exiting the two conduits. The first difference is a difference in the thermodynamic states of the respective streams, and the second difference is a difference in the fuel indices of the respective streams. Specifically, in order for there to be a potential for mixing between the two streams exiting the two conduits, there must be a difference in the thermodynamic states of the two streams, and a difference of at least 0.1, and preferably at least 0.2, between the fuel indices of the two streams must exist for meaningful NOx reduction.

[0079] In the embodiments illustrated in the figures and discussed above, the difference between the thermodynamic states of the two streams is expressed in terms of the pressure differential (*i.e.*, a "high pressure" fluid in one conduit, and a "low pressure" fluid in the other conduit). However, persons skilled in the art will recognize that the differential in thermodynamic states may also be expressed in terms of, and achieved as a result of, differences in velocity, temperature, concentration, composition, volume fraction, flow rate, electric potential, *etc.*

[0080] Therefore, the present invention includes many other embodiments and variations thereof which are not illustrated in the figures or discussed in the Detailed Description of The Invention. Those embodiments and variations, however, do fall within the scope of the appended claims and equivalents thereof.

[0081] Those skilled in the art also will recognize that the embodiments and variations illustrated in the drawings and discussed in the Detailed Description of The Invention do not disclose all of the possible arrangements of the present invention, and that other arrangements are possible. Accordingly, all such other arrangements are contemplated by the present invention and are within the scope of the present invention. For example, in each of the embodiments illustrated in Figures 7 and 9, the arrangement of the low pressure and high pressure streams may be reversed (*i.e.*, the low pressure lance may be the inner lance, and the high pressure lance may be the outer lance).

[0082] In addition to reduced NOx emissions, there are other advantages and benefits of the present invention, some of which are discussed below:

- ■ The proposed fuel staging method enables active tip cooling due to either (F-F) staging or (F-I) staging. For fuel tips having relatively large tip exit area, the nozzle tips are actively cooled by exiting high velocity fuel gas or inert stream. This is a significant improvement over conventional circular nozzles.
- ■ Due to relatively poor entrainment efficiency and higher operating temperature, conventional tips have serious maintenance issues and soot plugging problems using high C/H fuels. In comparison the present invention has the following advantages:
  - reduced tendency to coke while using higher carbon content fuels
  - ability to use smaller flow rates or higher heating value fuels
  - ability to use cheaper fuel nozzle material (Stainless steel 304 or 310 is adequate)

[0083] Thermal cracking is a main concern for many refinery furnaces where fuel compositions contain hydrocarbons ranging from C1 to C4. The cracked carbon is found to plug burner nozzles and create over heating of burner parts, reduced productivity and poor thermal efficiency. Thus, having maintenance free operation (using F-F or F-I staging) is a critical advantage for the refinery operator.

[0084] Although illustrated and described herein with reference to certain specific embodiments, the present invention is nevertheless 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.

Claims

1. A fuel dilution device for diluting a fuel to reduce nitrogen oxide emissions through fuel staging, comprising:

a first conduit (32) having an inlet and an outlet spaced apart from the inlet, the first conduit (32) adapted to transmit a stream of a fuel entering the inlet and exiting the outlet and

a second conduit (34) having an intake and an outtake spaced apart from the intake, the second conduit (34) adapted to transmit a stream of a fluid entering the intake and exiting the outtake, the outlet of the first conduit (32) and the outtake of the second conduit (34) defining a mixing location proximate both the outlet and the

outtake, **characterized in that** the device further comprises
a zipper nozzle (74) in downstream fluid communication with the outlet of the first conduit (34) and the mixing location.

2. A fuel dilution device as in claim 1, wherein the first conduit (32) is adjacent the second conduit (34),

3. A fuel dilution device as in claim 1, wherein the second conduit (34) is disposed in the first conduit (32).

4. A fuel dilution device as in any one of claims 1 to 3, further comprising a swirler (54) disposed in the second conduit (34).

5. A fuel dilution device as in any one of claims 1 to 4, wherein the second conduit (34) has an equivalent diameter (D_c) and the outtake of the second conduit (34) is located at a distance behind the outlet of the first conduit (32), said distance being in a range of about (2 x D_c) to about (20 x D_c), and/or
wherein the fuel dilution device is in fluid communication with a furnace containing a quantity of a furnace gas,

6. A method for diluting a fuel to reduce nitrogen oxide emissions through fuel staging utilizing a fuel dilution device according to any one of claims 1 to 5, comprising the steps of:

a) feeding a stream of the fuel to the inlet of the first conduit (32), transmitting the stream of the fuel entering the inlet through the first conduit (32); said stream of the fuel exiting the outlet of the first conduit (32) at a first thermodynamic state and a first fuel index;
b) feeding a stream of a fluid to the intake of a second conduit (34); transmitting the stream of the fluid entering the intake through the second conduit (34), said stream of the fluid exiting the outtake of the second conduit (34) at a second thermodynamic state and a second fuel index, the second fuel index being different from the first fuel index by at least about 0.1 and the second thermodynamic state being different from the first thermodynamic state;
c) thereby providing a potential for mixing between the stream of the fuel exiting the outlet of the first conduit (32) and the stream of the fluid exiting the outtake of the second conduit (34);
d) mixing at least a portion of the stream of the fuel exiting the outlet of the first conduit (32) with at least a portion of the stream of the fluid exiting the outtake of the second conduit (34) at a location proximate both the outlet and the outtake
e) thereby generating at least one diluted fuel stream having an intermediate fuel index between the first fuel index and the second fuel index;
f) transmitting through the zipper nozzle at least a portion of the diluted fuel stream;
g) providing a source of an oxidant; and
h) combusting a portion of the oxidant with at least a portion of the diluted fuel stream.

7. A method as in claim 6, wherein the fluid is a fuel,
or wherein the fluid is selected from a group consisting of steam, flue gas, carbon dioxide, nitrogen, argon, helium, xenon, krypton, other inert fluids, and mixtures or combinations thereof.

8. A method as in claim 6 or 7 utilizing a device as defined in claim 4, comprising the further step of:

transmitting at least a portion of the stream of the fluid through the swirler (56), thereby swirling at least a portion of the fluid exiting the second conduit.

9. A method as in any one of claims 6 to 8, utilizing a fuel dilution device as defined in claim 5,
comprising the further step of placing the fuel dilution device in fluid communication with a furnace containing a quantity of a furnace gas, thereby mixing at least a portion of the quantity of the furnace gas with at least a portion of the diluted fuel stream.

Patentansprüche

1. Brennstoffverdünnungsvorrichtung zum Verdünnen eines Brennstoffs, um Stickstoffoxid-Emissionen durch Brennstoffstufung zu verringern, umfassend:

eine erste Leitung (32), welche einen Einlass und einen vom Einlass beabstandeten Auslass aufweist, wobei die erste Leitung (32) angepasst ist einen Brennstoffstrom zu übertragen, welcher in den Einlass eintritt und aus dem Auslass austritt, und

eine zweite Leitung (34), welche einen Einlass und einen vom Einlass beabstandeten Auslass aufweist, wobei die zweite Leitung (34) angepasst ist einen Fluidstrom zu übertragen, welcher in den Einlass eintritt und aus dem Auslass austritt, wobei der Auslass der ersten Leitung (32) und der Auslass der zweiten Leitung (34) eine Mischstelle nahe beider Auslässe definiert, **dadurch gekennzeichnet, dass**

die Vorrichtung weiter eine Reißverschluss-Düse (74) in Fluidkommunikation stromabwärts mit dem Auslass der ersten Leitung (34) und der Mischstelle umfasst.

2. Brennstoffverdünnungsvorrichtung nach Anspruch 1, wobei die erste Leitung (32) benachbart zur zweiten Leitung (34) ist.

3. Brennstoffverdünnungsvorrichtung nach Anspruch 1, wobei die zweite Leitung (34) in der ersten Leitung (32) angeordnet ist.

4. Brennstoffverdünnungsvornchtung nach einem der Ansprüche 1 bis 3, weiter umfassend einen in der zweiten Leitung (34) angeordneten Drallkörper (54).

5. Brennstoffverdünnungsvorrichtung nach einem der Ansprüche 1 bis 4, wobei die zweite Leitung (34) einen Äquivalenzdurchmesser (D_c) aufweist und der Auslass der zweiten Leitung (34) mit einem Abstand hinter dem Auslass der ersten Leitung (32) angeordnet ist, wobei der Abstand im Bereich von ungefähr (2 x D_c) bis ungefähr (20 x D_c) ist, und/oder

wobei die Brennstoffverdünnungsvorrichtung in Fluidkommunikation mit einem Ofen ist, welcher eine Menge an Ofengas enthält.

6. Verfahren zum Verdünnen eines Brennstoffes, um Stickstoffoxid-Emissionen durch Brennstoffstufung zu verringern, welches eine Brennstoffverdünnungsvorrichtung nach einem der Ansprüche 1 bis 5 verwendet, umfassend die Schritte:

a) Zuführen eines Brennstoffstroms zu dem Einlass der ersten Leitung (32), Übertragen des in den Einlass eintretenden Brennstoffstroms durch die erste Leitung (32); wobei der Brennstoffstrom den Auslass der ersten Leitung (32) in einem ersten thermodynamischen Zustand und einem ersten Brennstoffindex verlässt;
b) Zufuhr eines Fluidstroms zu dem Einlass einer zweiten Leitung (34); Übertragen des in den Einlass eintretenden Fluidstroms durch die zweite Leitung (34), wobei der Fluidstrom den Auslass der zweiten Leitung (34) in einem zweiten thermodynamischen Zustand und einem zweiten Brennstoffindex verlässt, wobei der zweite Brennstoffindex sich um mindestens ungefähr 0.1 vom ersten Brennstoffindex unterscheidet und sich der zweite thermodynamische Zustand vom ersten thermodynamischen Zustand unterscheidet;
c) dabei ein Potenzial zum Mischen zwischen dem aus dem Auslass der ersten Leitung (32) austretenden Brennstoffstrom und dem aus dem Auslass der zweiten Leitung (34) austretenden Fluidstrom bereitstellend;
d) Mischen zumindest eines Teils des aus dem Auslass der ersten Leitung (32) austretenden Brennstoffstroms mit zumindest eines Teils aus dem Auslass der zweiten Leitung (34) austretenden Fluidstroms an einer Stelle nahe beider Auslässe;
e) dabei zumindest einen verdünnten Brennstoffstrom erzeugend, welcher einen zwischen dem ersten Brennstoffindex und dem zweiten Brennstoffindex dazwischen liegenden Brennstoffindex aufweist;
f) Übertragen zumindest eines Teils des verdünnten Brennstoffstroms durch die Reißverschluss-Düse;
g) Bereitstellen einer Quelle eines Oxidationsmittels; und
h) Verbrennen eines Teils des Oxidationsmittels mit zumindest eines Teils des verdünnten Brennstoffstroms.

7. Verfahren nach Anspruch 6, wobei das Fluid ein Brennstoff ist, oder wobei das Fluid ausgewählt ist aus der Gruppe bestehend aus Dampf, Abgas, Kohlenstoffdioxid, Stickstoff, Argon, Helium, Xenon, Krypton, andere inerte Fluide, und Mischungen oder Kombinationen davon.

8. Verfahren nach Anspruch 6 oder 7, welches eine wie in Anspruch 4 definierte Vorrichtung verwendet, umfassend den weiteren Schritt von:

Übertragen zumindest eines Teils des Fluidstroms durch den Drallkörper (56), dabei Verwirbeln zumindest eines Teils des aus der zweiten Leitung austretenden Fluids.

9. Verfahren nach einem der Ansprüche 6 bis 8, welches eine wie in Anspruch 5 definierte Brennstoffverdünnungsvorrichtung verwendet,
umfassend den weiteren Schritt des Anordnens der Brennstoffverdünnungsvorrichtung in Fluidkommunikation mit einem Ofen, welcher eine Menge an Ofengas enthält, dabei Mischen zumindest eines Teils der Menge an Ofengas mit zumindest einem Teil des verdünnten Brennstoffstroms.

Revendications

1. Dispositif de dilution de carburant pour diluer un carburant dans le but de réduire les émission d'oxydes d'azote par l'intermédiaire d'une alimentation en carburant étagée, comprenant:

un premier conduit (32) qui présente une entrée et une sortie espacée de l'entrée, le premier conduit (32) étant adapté pour transmettre un courant d'un carburant qui entre par l'entrée et qui sort par la sortie; et
un deuxième conduit (34) qui présente une admission et une évacuation espacée de l'admission, le deuxième conduit (34) étant adapté pour transmettre un courant d'un fluide qui entre par l'admission et qui sort par l'évacuation, la sortie du premier conduit (32) et l'évacuation du deuxième conduit (34) définissant un point de mélange qui est situé à proximité à la fois de la sortie et de l'évacuation, **caractérisé en ce que** le dispositif comprend en outre:

une buse avec une ouverture à motif de fermeture éclair (74) en communication fluidique vers l'aval avec la sortie du premier conduit (32) et le point de mélange.

2. Dispositif de dilution de carburant selon la revendication 1, dans lequel le premier conduit (32) est situé à proximité du deuxième conduit (34).

3. Dispositif de dilution de carburant selon la revendication 1, dans lequel le deuxième conduit (34) est disposé dans le premier conduit (32).

4. Dispositif de dilution de carburant selon l'une quelconque des revendications 1 à 3, comprenant en outre un tourbillonneur (54) qui est disposé dans le deuxième conduit (34).

5. Dispositif de dilution de carburant selon l'une quelconque des revendications 1 à 4, dans lequel le deuxième conduit (34) présente un diamètre équivalent (D_c), et l'évacuation du deuxième conduit (34) est située à une certaine distance derrière la sortie du premier conduit (32), ladite distance étant comprise dans la gamme d'environ (2 x D_c) à environ (20 x D_c), et/ou
dans lequel le dispositif de dilution de carburant est en communication fluidique avec un four contenant une quantité de gaz de four.

6. Procédé pour diluer un carburant dans le but de réduire les émissions d'oxydes d'azote par l'intermédiaire d'une alimentation étagée en utilisant un dispositif de dilution de carburant selon l'une quelconque des revendications 1 à 5, comprenant les étapes suivantes:

a) amener un courant de carburant jusqu'à l'entrée du premier conduit (32), faire passer le courant de carburant qui entre dans l'entrée à travers le premier conduit (32); ledit courant du carburant sortant par la sortie du premier conduit (32) dans un premier état thermodynamique et à un premier indice de carburant;
b) amener un courant de fluide jusqu'à l'admission d'un deuxième conduit (34); faire passer le courant de fluide qui entre dans l'admission à travers le deuxième conduit (34), ledit courant de fluide sortant par l'évacuation du deuxième conduit (34) dans un deuxième état thermodynamique et à un deuxième indice de carburant, le deuxième indice de carburant étant différent du premier indice de carburant d'au moins environ 0,1, et le deuxième état thermodynamique étant différent du premier état thermodynamique;
c) établissant ainsi un potentiel pour réaliser un mélange entre le courant de carburant qui sort par la sortie du premier conduit (32) et le courant de fluide qui sort par l'évacuation du deuxième conduit (34);
d) mélanger au moins une partie du courant de carburant qui sort par la sortie du premier conduit (32) avec au moins une partie du courant de fluide qui sort par l'évacuation du deuxième conduit (34) en un point qui est situé à proximité à la fois de la sortie et de l'évacuation;
e) générer ainsi au moins un courant de carburant dilué qui présente un indice de carburant intermédiaire entre le premier indice de carburant et le deuxième indice de carburant;

f) transmettre au moins une partie du courant de carburant dilué à travers la buse avec une ouverture à motif de fermeture éclair;
g) prévoir une source d'oxydant; et
h) brûler une partie de l'oxydant avec au moins une partie du courant de carburant dilué.

7. Procédé selon la revendication 6, dans lequel le fluide est un carburant, ou dans lequel le fluide est sélectionné dans un groupe comprenant de la vapeur, un gaz de fumée, du dioxyde de carbone, de l'azote, de l'argon, de l'hélium, du xénon, du krypton, d'autres fluides inertes et des mélanges ou des combinaisons de ceux-ci.

8. Procédé selon la revendication 6 ou 7, qui utilise un dispositif selon la revendication 4, comprenant l'étape supplémentaire qui consiste à transmettre au moins une partie du courant de fluide à travers le tourbillonneur (56), faisant ainsi tourbillonner au moins une partie du fluide qui sort du deuxième conduit.

9. Procédé selon l'une quelconque des revendications 6 à 8, qui utilise un dispositif de dilution de carburant selon la revendication 5, comprenant l'étape supplémentaire qui consiste à placer le dispositif de dilution de carburant en communication fluidique avec un four contenant une quantité de gaz de four, mélangeant de ce fait au moins une partie de la quantité du gaz de four avec au moins une partie du courant de carburant dilué.

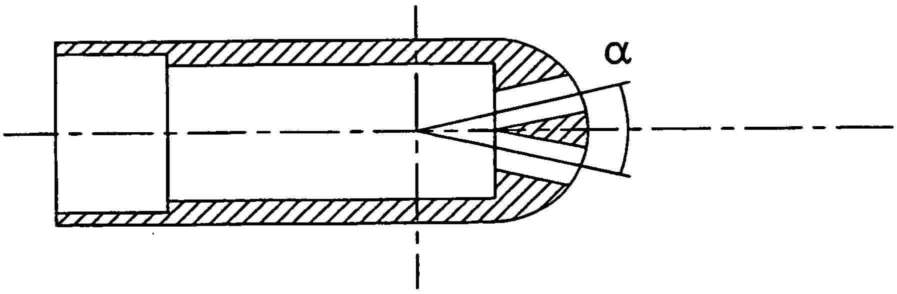

FIG. 1A
(PRIOR ART)

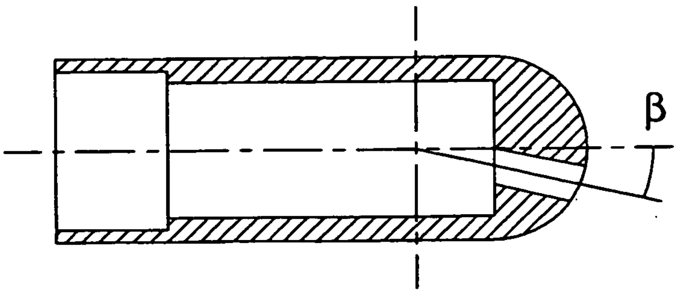

FIG. 1B
(PRIOR ART)

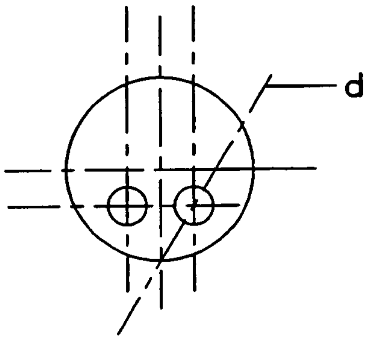

FIG. 1C
(PRIOR ART)

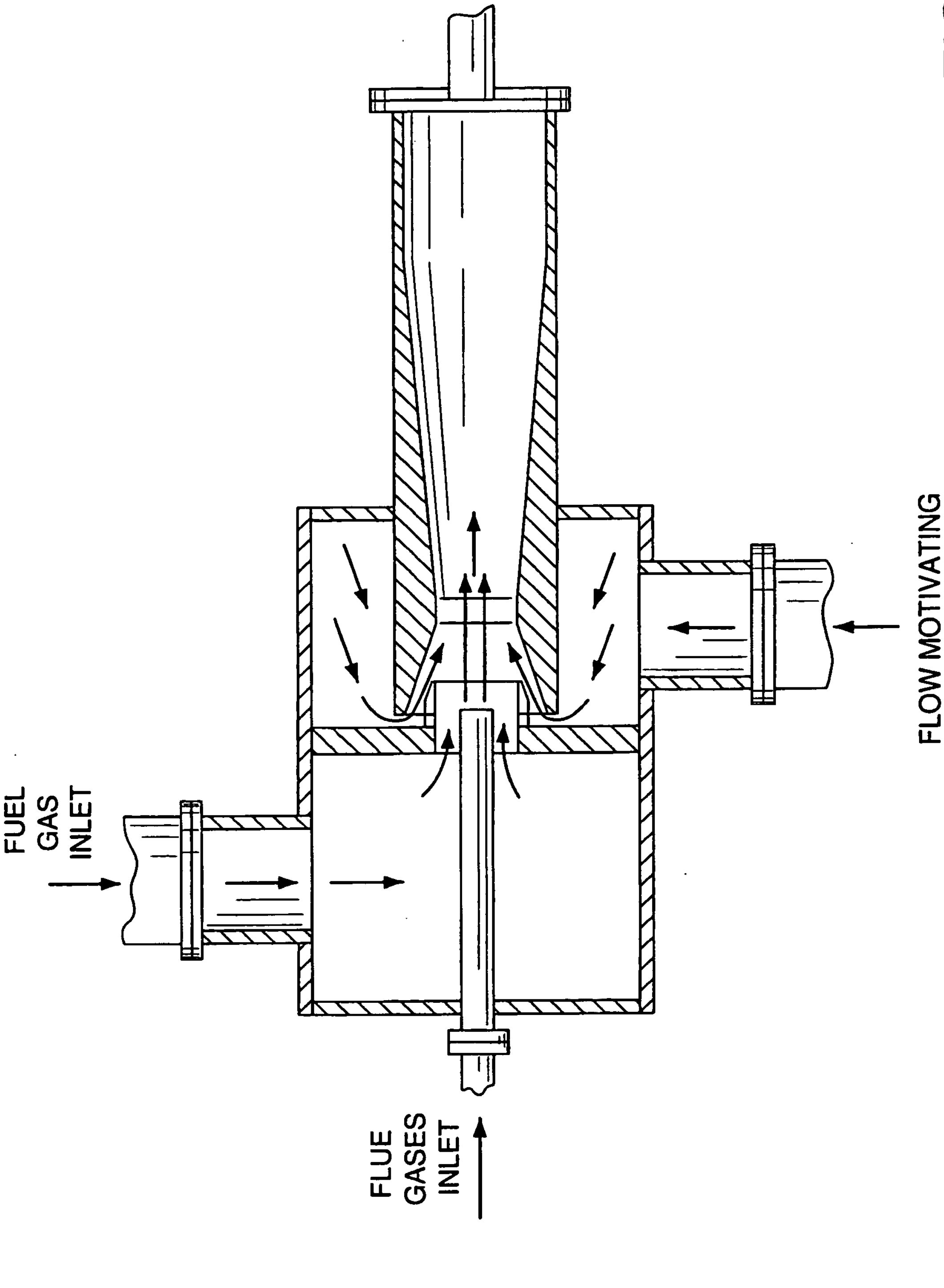

FIG. 2
(PRIOR ART)

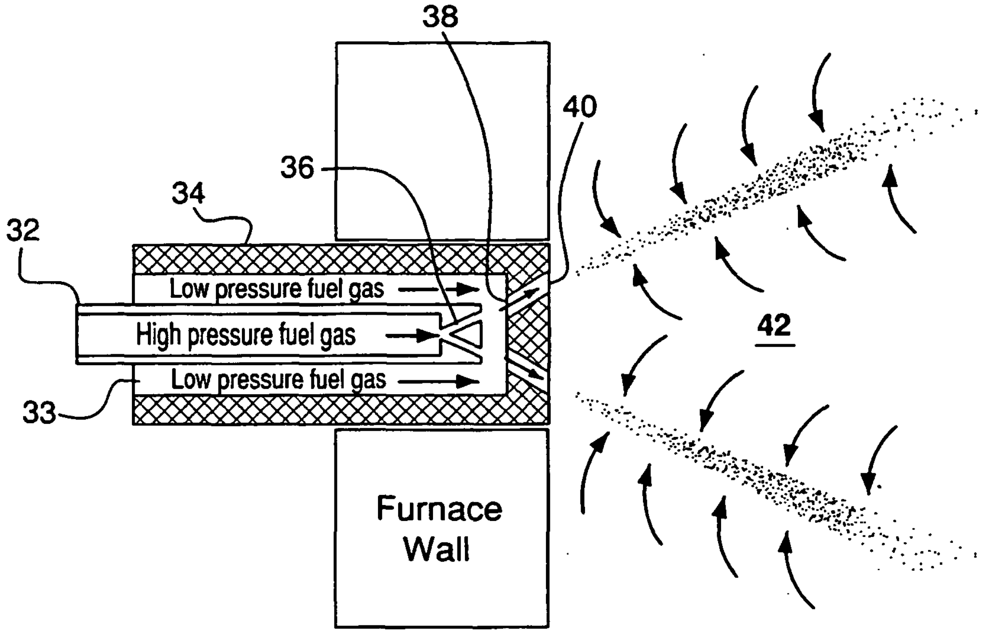

FIG. 3
(PRIOR ART)

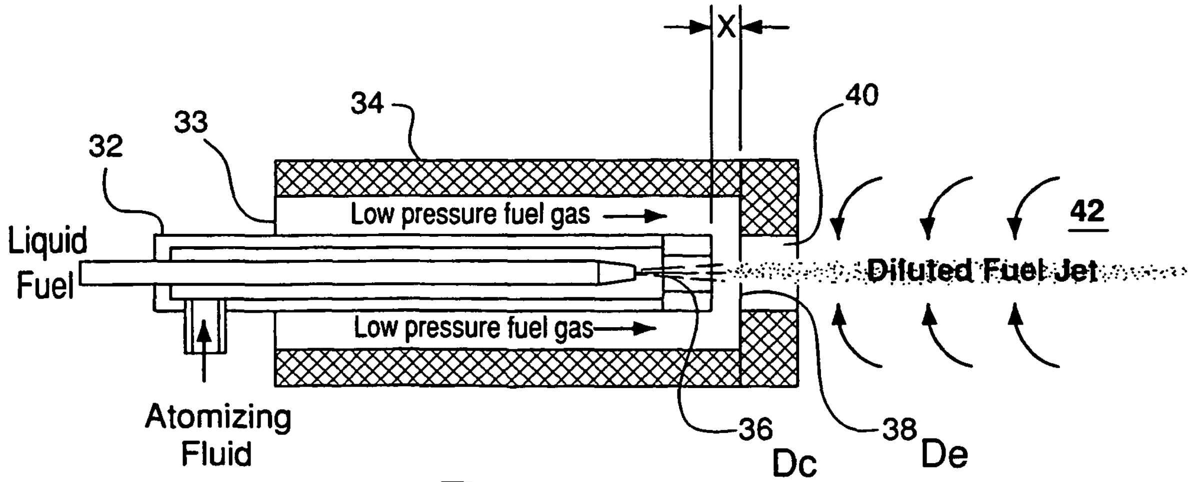

FIG. 4
(PRIOR ART)

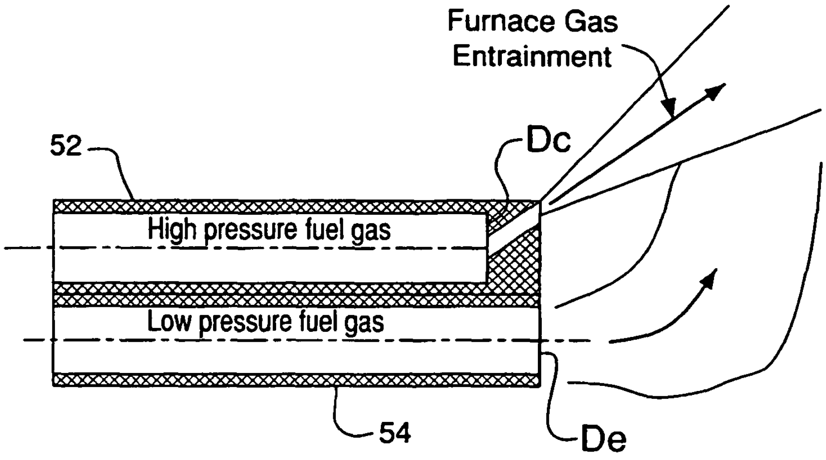

FIG. 5A
(PRIOR ART)

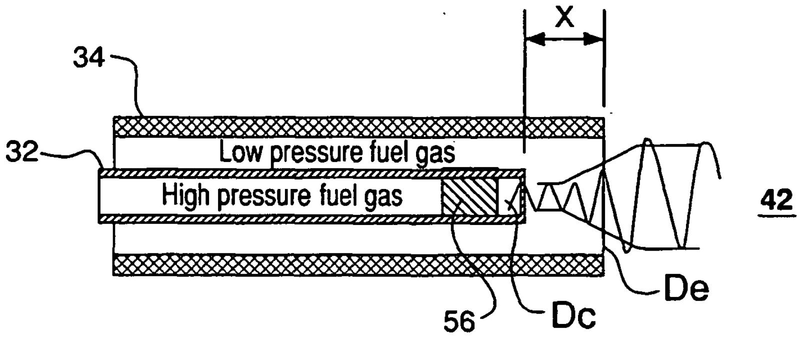

FIG. 5B
(PRIOR ART)

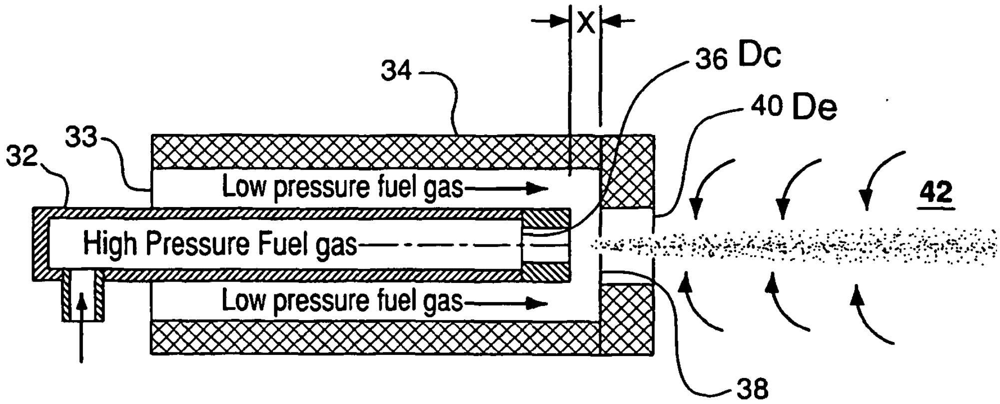

FIG. 6
(PRIOR ART)

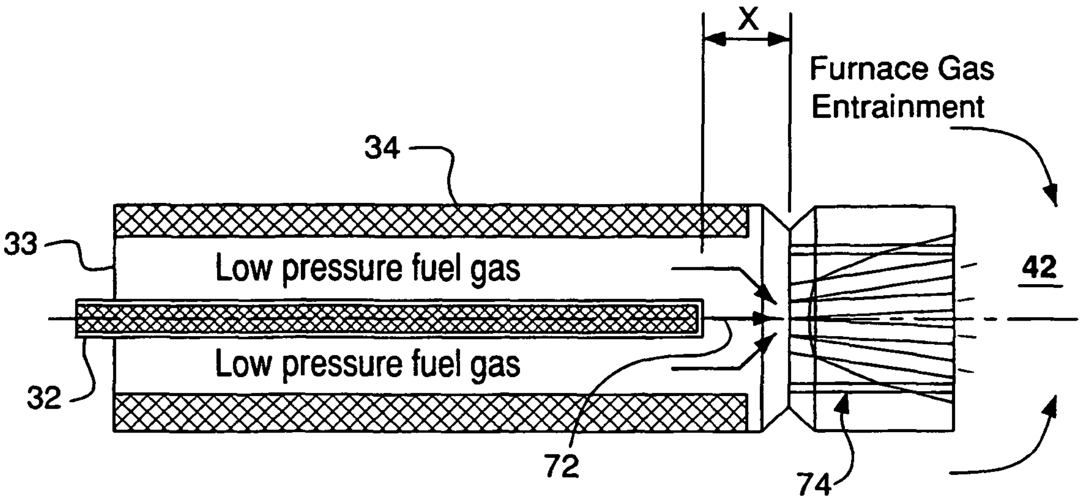

FIG. 7

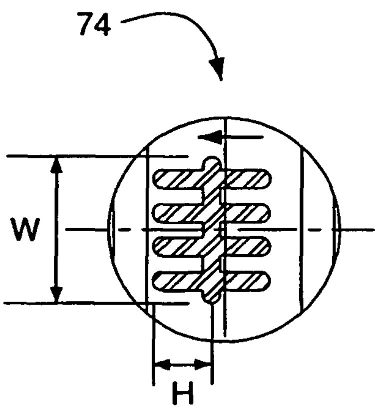

FIG. 8A

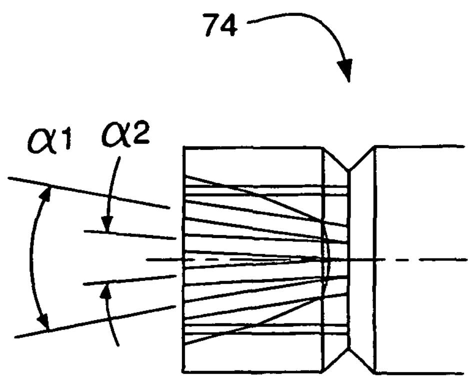

FIG. 8B

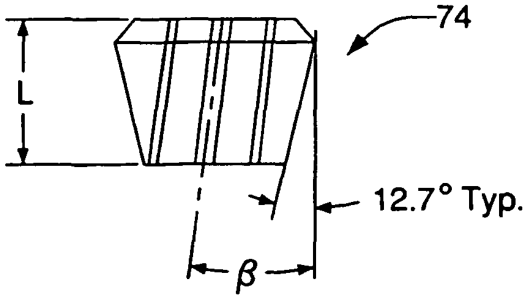

FIG. 8C

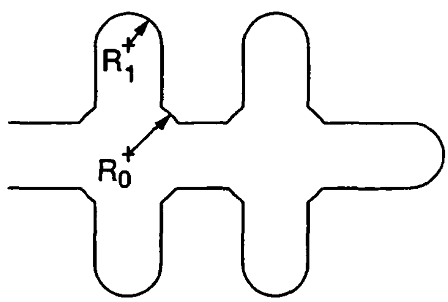

FIG. 8D

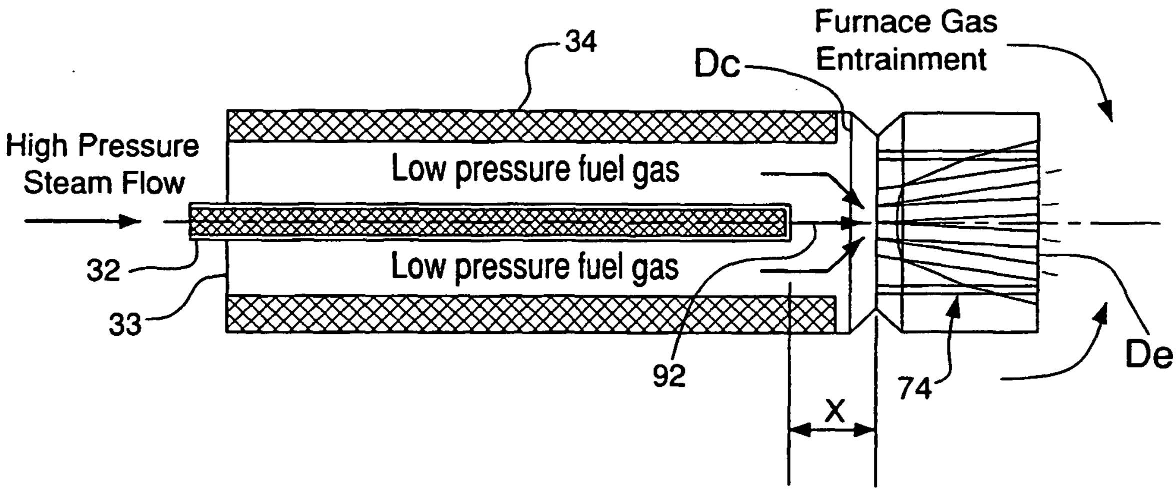
34
Dc
Furnace Gas
Entrainment
High Pressure
Steam Flow
Low pressure fuel gas
Low pressure fuel gas
32
33
92
74
X
De

FIG. 9

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

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