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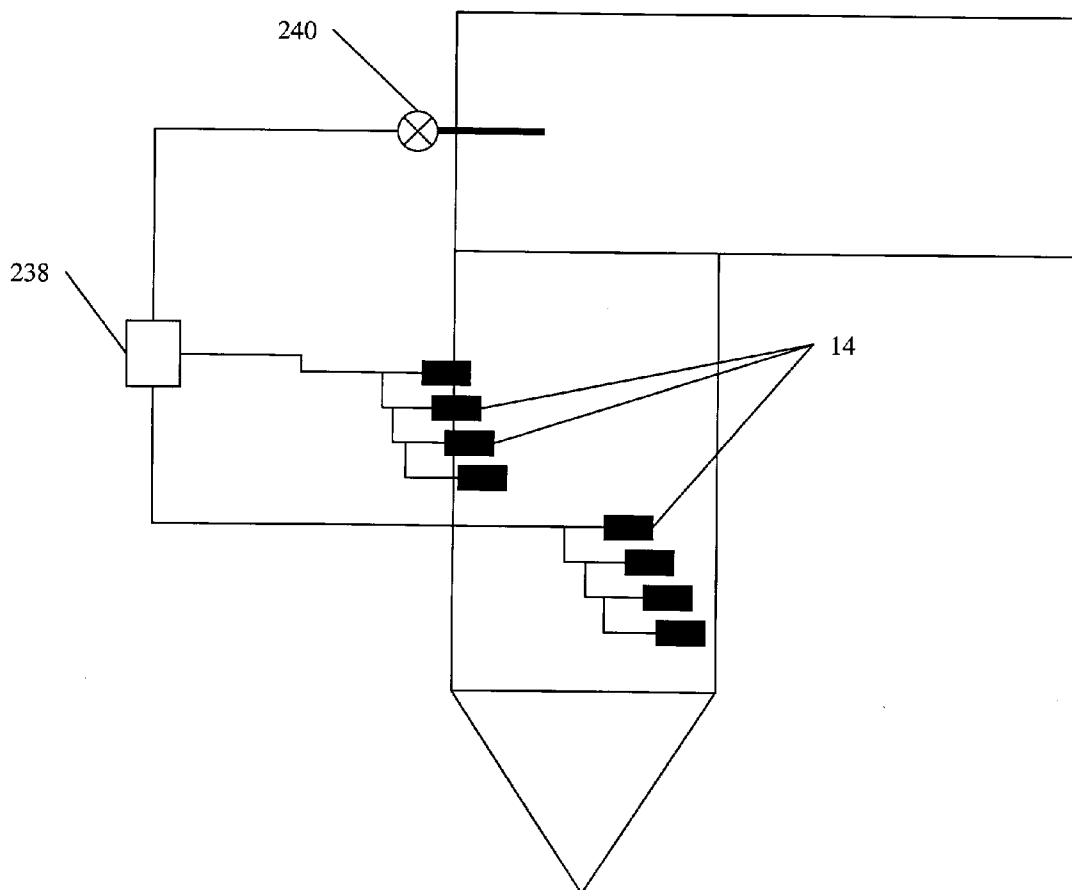
(19) **United States**(12) **Patent Application Publication**
Moberg(10) **Pub. No.: US 2004/0185399 A1**(43) **Pub. Date: Sep. 23, 2004**(54) **UREA-BASED MIXING PROCESS FOR
INCREASING COMBUSTION EFFICIENCY
AND REDUCTION OF NITROGEN OXIDES
(NOX)**(52) **U.S. Cl. 431/4**(57) **ABSTRACT**(76) **Inventor: Goran Moberg, Cary, NC (US)**

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(21) **Appl. No.: 10/461,567**(22) **Filed: Jun. 13, 2003****Related U.S. Application Data**(63) **Continuation-in-part of application No. 10/391,825,
filed on Mar. 19, 2003.****Publication Classification**(51) **Int. Cl.⁷ F23J 7/00**

A method for increasing combustion process and furnace efficiency and for reducing NO_x formation, including the steps of: providing a furnace with a plurality of secondary air injection ducts, asymmetrically positioned in an opposing manner; injecting fuel with primary air through a first stage prior to injection of a second air; injecting secondary air through the plurality of reagent injection ducts; providing a staged combustion system including a furnace with asymmetrical injection ports introducing at least one reagent to the reactor by asymmetrical injection at predetermined, spaced apart locations; controlling the asymmetrical injection to produce a high velocity mass flow and a turbulence resulting in dispersion of the at least one reagent into the reaction system, wherein one of the at least one reagents is an NH₃-producing compound; thereby providing increased reaction efficiency and reduced NO_x formation in the combustion process.

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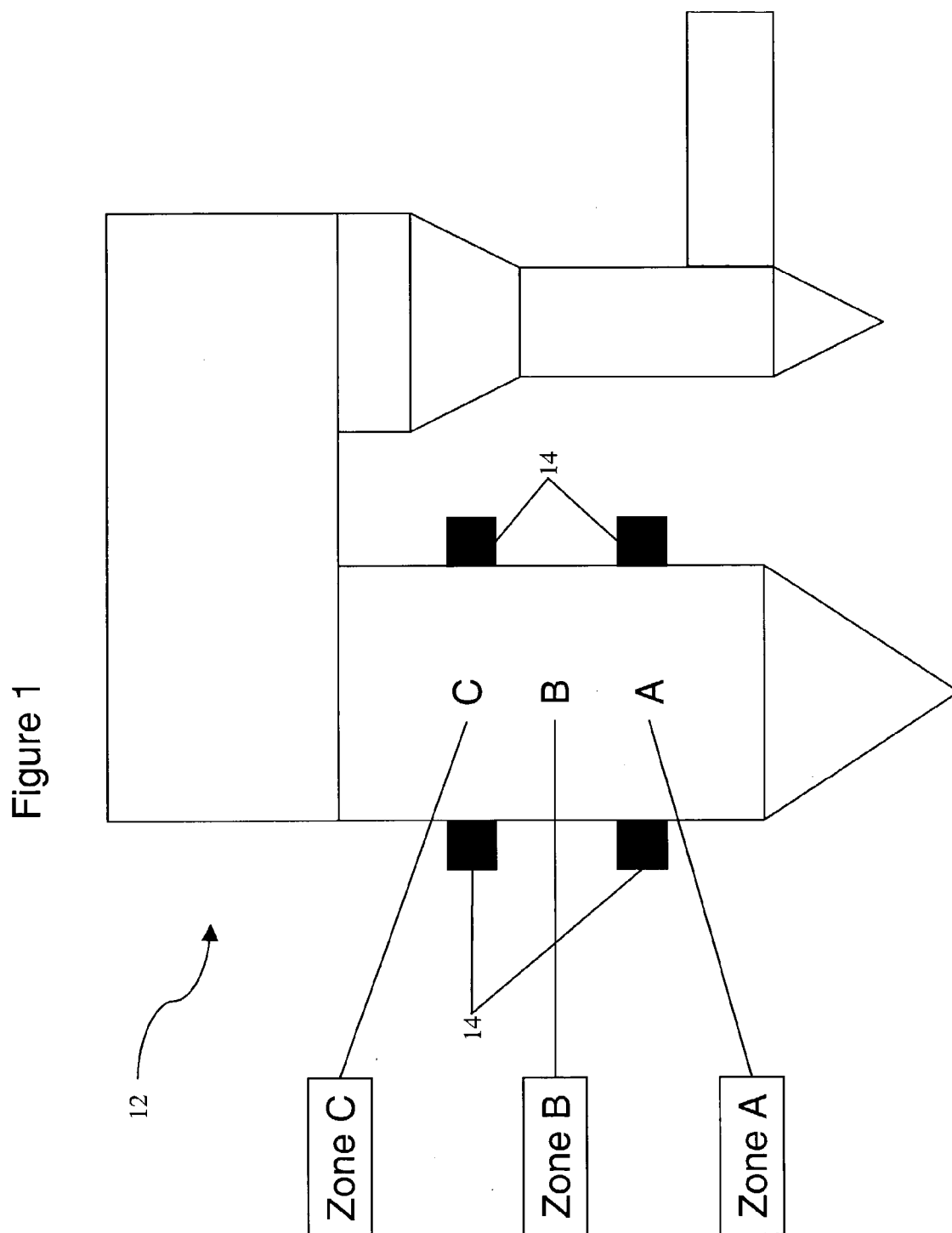
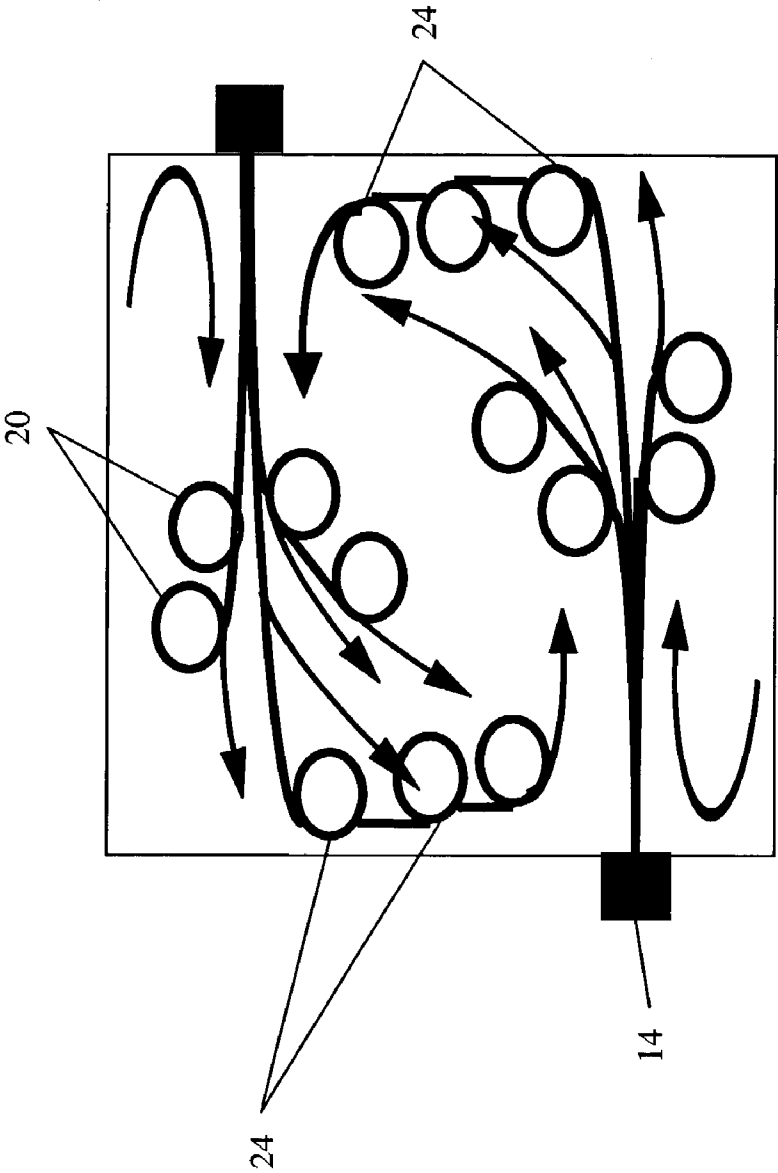


Figure 2



Area A

Figure 3

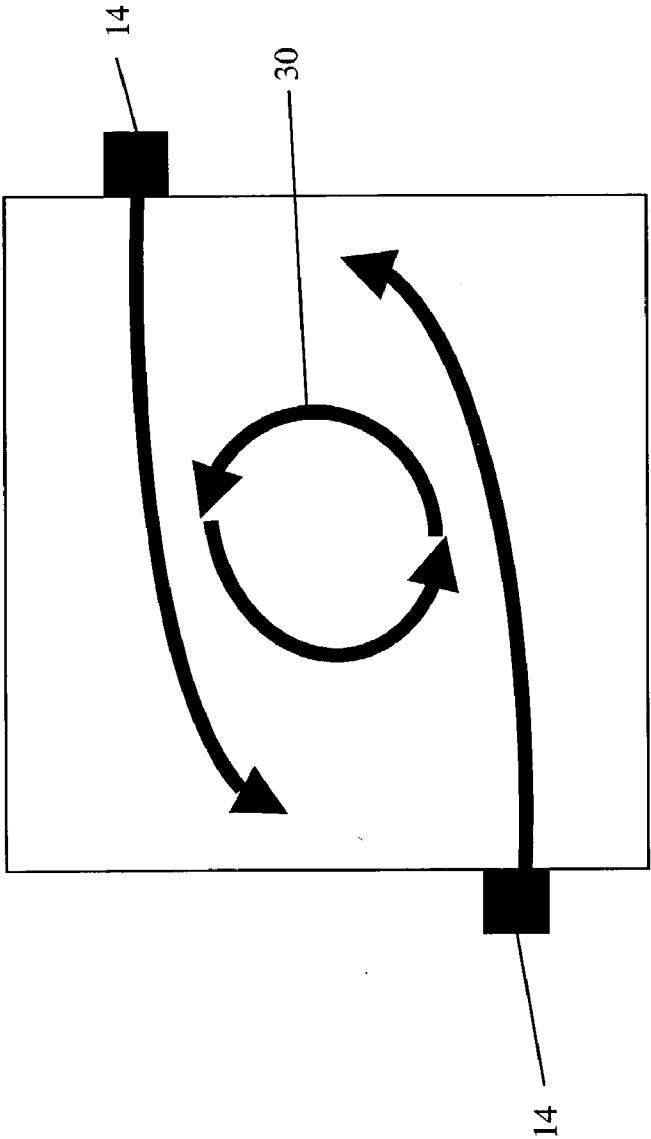


Figure 4

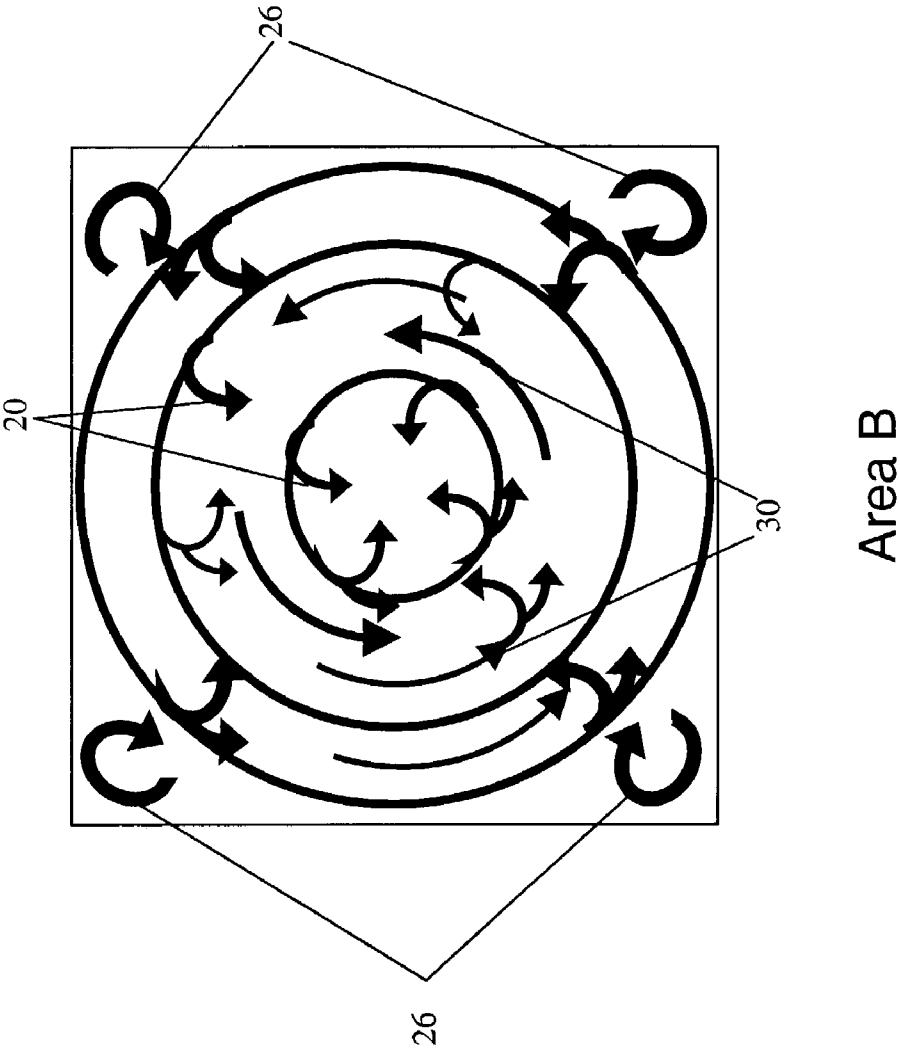
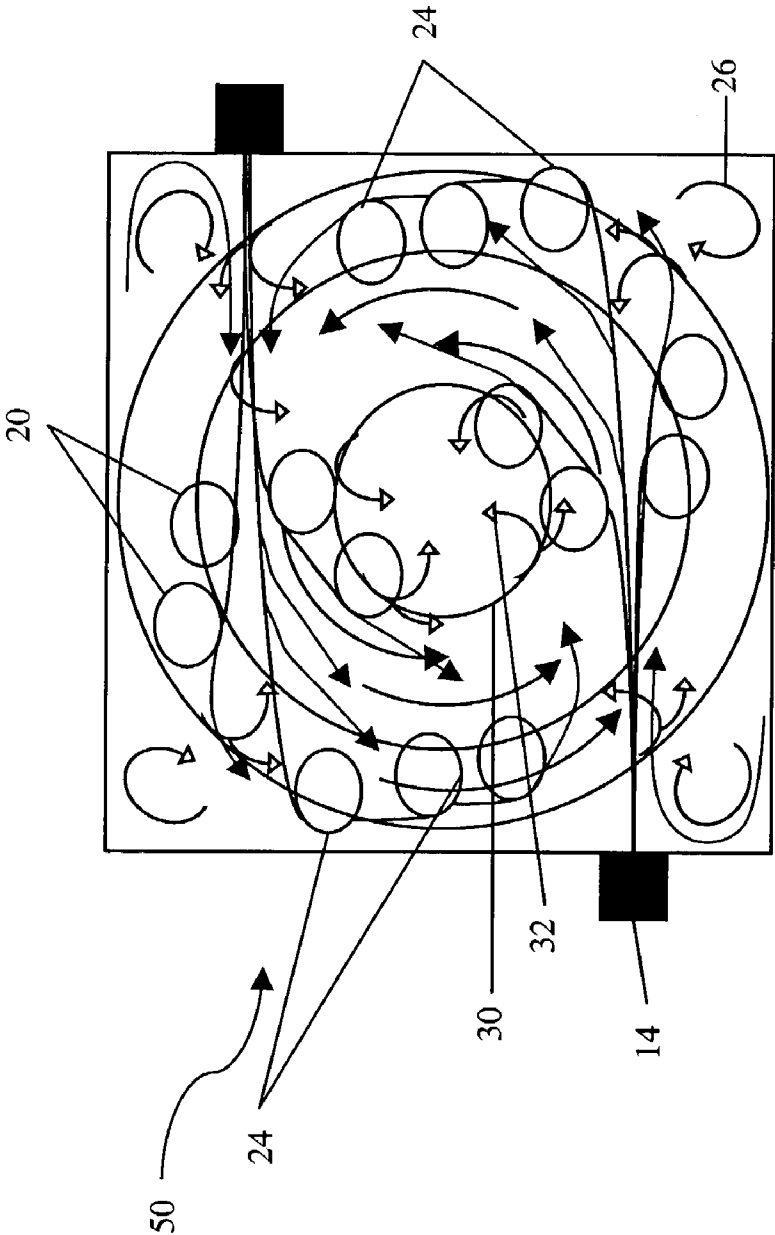
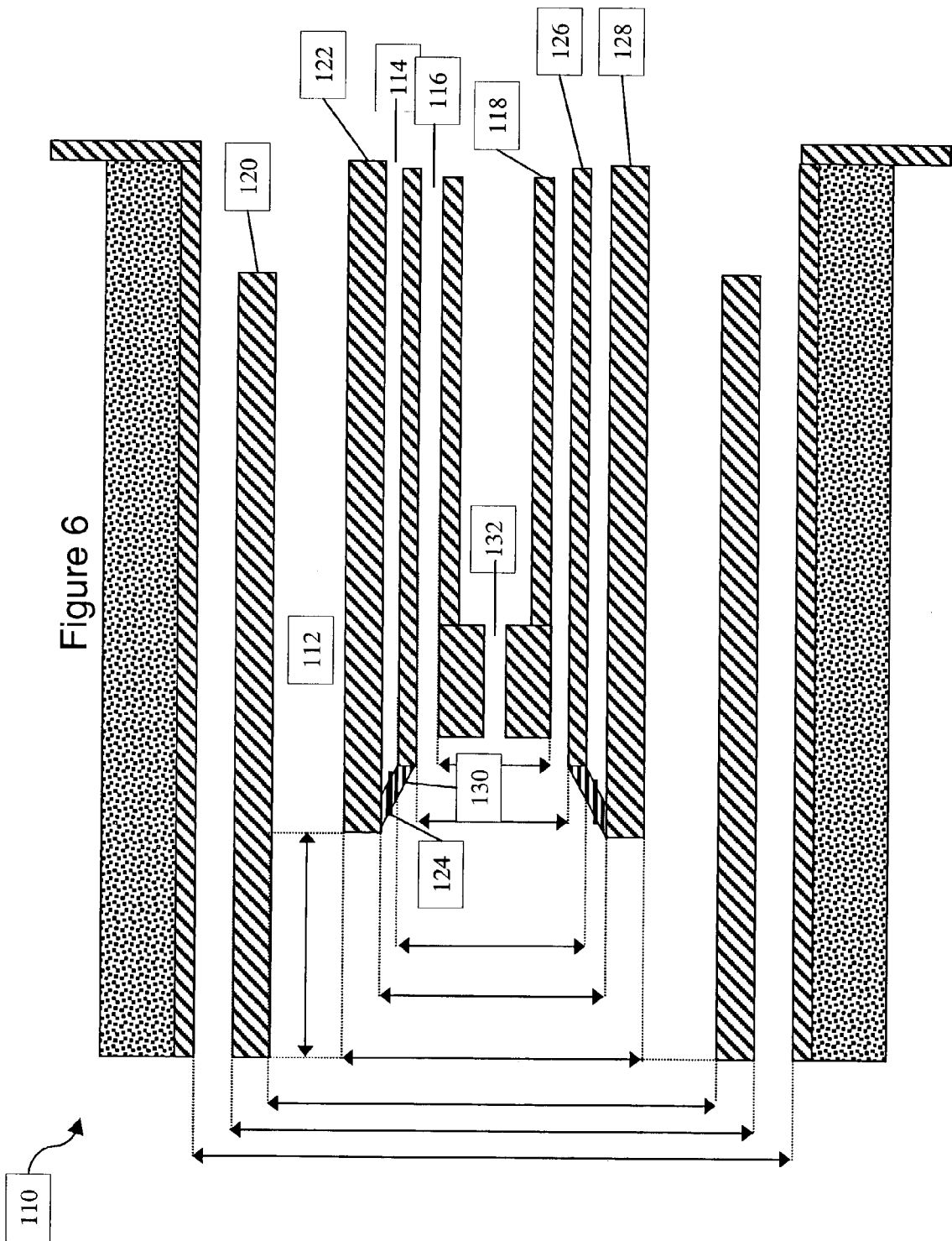
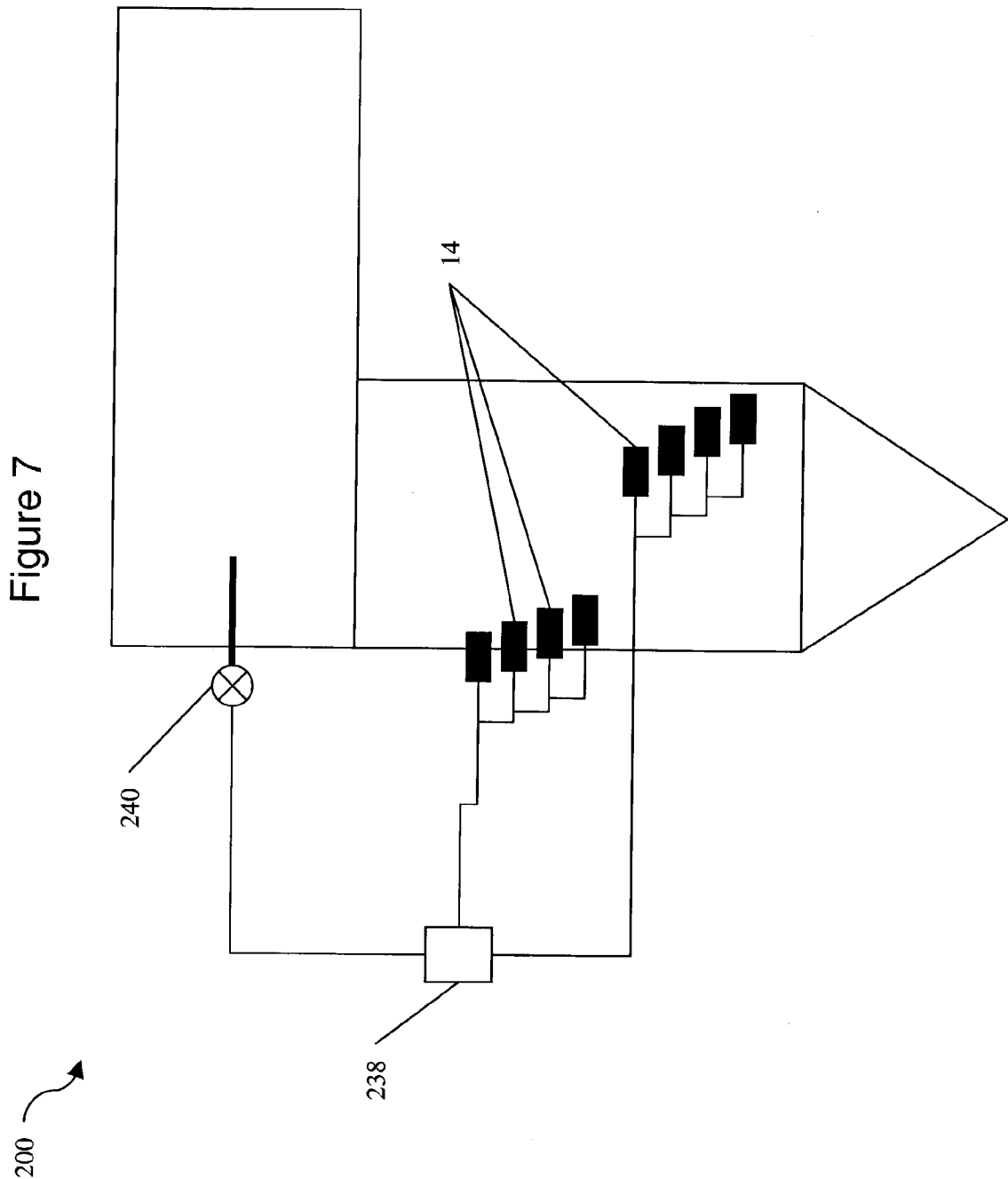


Figure 5



Area C





UREA-BASED MIXING PROCESS FOR INCREASING COMBUSTION EFFICIENCY AND REDUCTION OF NITROGEN OXIDES (NOX)

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This nonprovisional utility patent application claims the benefit of one or more prior filed copending nonprovisional applications; a reference to each such prior application is identified as the relationship of the applications and application number (series code/serial number): The present application is a Continuation-In-Part of application Ser. No. 10/391,825, which is incorporated herein by reference in its/their entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates generally to a system and method for improving the efficiency of combustion reactions and for reducing pollutants, and, more particularly, to a system and method for improving combustion efficiency and reduction of nitrogen oxides (NOx) using nitrogenous agents.

[0004] 2. Description of the Prior Art

[0005] Increases in fuel costs have required power generation plants seek increases in furnace efficiencies in order to reduce power generation costs. However, NOx formation must also be prevented to comply with environmental regulations. NOx formation is reduced in furnaces by the process of stage combustion, which includes administering an initial substoichiometric or suboptimal ratio of oxygen to fuel to maintain combustion gas temperatures below the peak NOx-producing temperature, about 2,800 degrees F. (approximately 1540 degrees C.), followed by the addition of secondary air, or over-fire-air (OFA), to finish the combustion reaction. Proper mixing of secondary air and combustion gases inside a furnace is thus important to achieve optimum combustion and has been improved by the use of rotating over-fire-air (ROFA). However, these existing NOx reduction systems do not optimize combustion efficiency or furnace heat exchange efficiency.

[0006] Therefore, a need exists to improve energy efficiency of ROFA systems without negatively affecting, or even improving the reduction of pollutants, in particular NOx reduction.

[0007] The use of urea and NH₃-generating compounds is known in the prior art. Example of the use of urea and NH₃-generating compounds include U.S. Pat. No. 4,992, 249 issued Feb. 12, 1991 to Bowers for Reduction of nitrogen- and carbon-based pollutants through the use of urea solutions and U.S. Pat. No. 4,927,612 issued May 22, 1990 invented by Bowers for Reduction of nitrogen- and carbon-based pollutants teaches process using a dispersion of aqueous urea solution is injected into an effluent for reducing nitrogen oxides in an effluent from the combustion of carbonaceous fuel.

[0008] U.S. Pat. No. 5,057,293 issued May 22, 1990 invented by Epperly, et al. and assigned to Fuel Tech, Inc. for Multi-stage process for reducing the concentration of pollutants in an effluent teaches a process for the reduction of

the concentration of nitrogen oxides in the effluent from the combustion of a carbonaceous fuel, the process comprising selecting a plurality of locations for introduction of chemical formulations and introducing at each of said locations at least one chemical formulation, selected from the group consisting of urea, ammonia, hexamethylenetetraamine, an oxygenated hydrocarbon, a paraffinic hydrocarbon, an olefinic hydrocarbon, an aromatic hydrocarbon, an ammonium salt of an organic acid having a carbon to nitrogen ratio of greater than 1:1, a hydroxy amino hydrocarbon, a heterocyclic hydrocarbon having at least one cyclic oxygen, a five- or six-membered heterocyclic hydrocarbon having at least one cyclic nitrogen, hydrogen peroxide, guanidine, guanidine carbonate, biguanidine, guanylurea sulfate, melamine, dicyandiamide, calcium cyanamide, biuret, 1,1'-azobisformamide, methylol urea, methylol urea-urea condensation product, dimethylol urea, methyl urea, methyl urea, and mixtures thereof, effective to reduce the concentration of nitrogen oxides at the effluent temperature existing at said location, such that optimization of the level of injection at each of said locations leads to the reduction of the level of nitrogen oxides below a predetermined target level.

[0009] U.S. Pat. No. 4,208,386 issued Jun. 17, 1980 to Arand, et al. for Urea reduction of NOx in combustion effluents and U.S. Pat. No. 4,325,924 issued to Arand, et al. on Apr. 20, 1982 for Urea reduction of NO_x in fuel rich combustion effluents teach methods for reducing NOx in combustion effluents involving introducing urea into the combustion effluent.

SUMMARY

[0010] The present invention is directed to a mixing process and system for increased combustion reactor efficiency and for improved reduction of pollutants, in particular NOx reduction, using a nitrogenous agent as one of at least one reagents introduced to the system via a plurality of asymmetrical ducts in the reactor at predetermined spaced apart locations.

[0011] The present invention is further directed to a system and method for increased furnace efficiency through increased retention time in the furnace, in particular including urea as a reagent. In a preferred embodiment, the process employs systems and methods to improve the reaction homogeneity and combustion zone swirling, resulting in combustion efficiency gains and thermal flux gains with corresponding gains in reactor efficiency.

[0012] The present invention is directed toward increasing reactor energy efficiency via increased combustion efficiency and increased furnace thermal flux, thereby also improving the reduction of pollutants, in particular the reduction of NOx.

[0013] It is one aspect of the present invention to increase combustion efficiency by the induction of turbulence in the gas column. Another aspect of the present invention is to increase thermal flux in a furnace by increasing the residence time of combustion gases in furnace and decreasing the laminar flow at heat exchange surface. In the present invention, these parameters are increased by the induction of turbulence in the combustion gases and at the combustion gas/furnace interface.

[0014] Furthermore, the present invention increases the combustion efficiency through the rapid, thorough mixing of

the injected secondary air with the combustion gases via increased turbulence. This rapid, thorough mixing effects a more complete burning of the fuel while reducing the secondary air requirements.

[0015] These and other aspects of the present invention will become apparent to those skilled in the art after a reading of the following description of the preferred embodiment when considered with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is a side view of a combustion furnace operated according to the present invention.

[0017] FIG. 2 is a cross-sectional view of Zone A of the furnace of FIG. 1 showing the gas swirl and deflection turbulence induced by operation according to the present invention.

[0018] FIG. 3 is a cross-sectional view of Zone A of the furnace of FIG. 1 showing the gas rotation induced by operation according to the present invention.

[0019] FIG. 4 is a cross-sectional view of Zone B of the furnace showing the turbulence induced by rotation in a non-circular furnace.

[0020] FIG. 5 is a cross-sectional view of Zone C of the furnace showing the swirl, deflection, and rotation-induced turbulence induced by operation according to the present invention.

[0021] FIG. 6 is a cut-away, side view of a coaxial injection device constructed according to the present invention.

[0022] FIG. 7 is a side view of a multiple coaxial device injection system according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0023] In the following description, like reference characters designate like or corresponding parts throughout the several views. Also in the following description, it is to be understood that such terms as "forward," "rearward," "front," "back," "right," "left," "upwardly," "downwardly," and the like are words of convenience and are not to be construed as limiting terms.

[0024] Referring now to the drawings in general, the illustrations are for the purpose of describing a preferred embodiment of the invention and are not intended to limit the invention thereto. Shown in FIG. 1 is a side view of a combustion furnace, generally described as 12, equipped with an air injection system composed of injection ports 14. As best seen in FIGS. 2 and 3, the present invention provides for an air injection system that creates swirl 20, peripheral turbulence 24, and air column rotation 30 through the tangential injection of secondary air into the furnace. The present invention thus creates turbulence and improves mixing of the overfire air with the combustion gases.

[0025] According to the present invention, a system and method are provided for increasing reaction efficiency and for reducing byproducts formation, including the steps of providing a staged reaction system including a reactor and at least one reagent for introduction into a reaction process, preferably one that takes place within the reactor; introduc-

ing the at least one reagent, in particular urea, and more particularly solid urea, to the reactor by asymmetrical injection at predetermined, spaced apart locations; controlling the asymmetrical injection to produce a high velocity mass flow and a turbulence resulting in dispersion of the at least one reagent into the reaction system, thereby providing increased reaction efficiency and reduced byproducts formation in the reaction process. Preferably, the at least one reagent is a multiplicity of reagents, more preferably, at least a first reagent and a second reagent wherein the first reagent is introduced prior to the introduction of the second reagent in a first stage and the second reagent is introduced in a second stage, and wherein the stages are spaced apart in location and/or time.

[0026] Furthermore, staged additives or reagents are introduced into the reactor system. Preferably, at least one staged additive is introduced via the asymmetrical injection method as set forth herein, wherein the additive is a nitrogenous treatment agent comprising urea, ammonia, ammonium carbamate, ammonium carbonate, mixtures of ammonia and ammonium bicarbonate, one or more of the hydrolysis products of urea or mixtures or complexes thereof, compounds which produce ammonia as a byproduct, ammonium formate, ammonium oxalate, hexamethylenetetramine, ammonium salts of organic acids, 5- or 6- membered heterocyclic hydrocarbons having at least one cyclic nitrogen, hydroxy amino hydrocarbons, amino acids, proteins, monoethanolamine, guanidine, guanidine carbonate, biguanidine, guanylurea sulfate, melamine, dicyandiamide, calcium cyanamide, 1,1'-azobisformamide, methylol urea, methylol urea-urea condensation product, dimethylol urea, methyl urea, dimethyl urea, cyanuric acid (1,3,5-Triazine-2,4,6(1H,3H,5H)-trione; 1,3,5-Triazine-2,4,6-triol; 2,4,6-Trihydroxy-1,3,5-triazine; Isocyanuric acid; Normalcyanuric acid; Pseudocyanuric acid; sym-triazine-2,4,6-triol; symtriazinetriol; Triazine-2,4,6(1H,3H,5H)-trione; Triazine-2,4,6 triol; Triazinetriol; Triazinetrione; Tricarbimide; Tricyanic acid; Trihydroxy-1,3,5-triazine; Trihydroxycyanidine;) biuret (Allophanamide; Carbamylurea; Imidodicarbonic diamide), and the like, and combinations thereof. More preferably, urea and/or urea analogs are used.

[0027] Furthermore, the nitrogenous agents listed herein above are provided to the system and in the method according to the present invention in at least one phase, namely solid, liquid, molten, and aqueous solution, and combinations thereof. Preferably, the concentration of urea when in solution is diluted and introduced in a predetermined size including droplets, stream, prill, powder, and combinations thereof as appropriate for and corresponding to the phase, and at a predetermined rate or molar ratio.

[0028] Other reagents of the system may include reagents to reduce the pH of the combustion effluent, such as alkaline carbonates, such as lime, limestone; hydrated lime; quick lime; soda, trona. Other agents, such as activated charcoal, peroxides, free radicals; NH₃; H₂O₂; and the like, may also be used.

[0029] Preferably, according to the present invention, in reactors equipped with catalysts, the reagents or additives are introduced to the reactor system and method between about 0.1 seconds and about 0.2 seconds prior to selective catalytic reduction (SCR) to provide adequate time for mixing prior to contacting the catalyst.

[0030] Additionally, the present invention can be used for the reduction of pH of combustion gases through non-reductive acid neutralization. The NH_3 -generating compounds can be injected after the SCR process to neutralize the acids contained in the gases by acid-base reaction. For example, the NH_3 reacts with SO_3 to form the salt $(\text{NH}_4)_2\text{SO}_4$, thereby reducing the levels of sulphuric acid in the combustion gases.

[0031] Also, preferably, the reagents or additives are provided at concentrations that produce less than about 2 ppm NH_3 slip in the effluent.

[0032] In one exemplary embodiment of a reactor system and method according to the present invention, the overfire air is injected into the combustion gases at a velocity and orientation such that the swirl and high turbulence generated in the combustion gases achieve a rapid and thorough mixing of the advected gases and the combustion gases.

[0033] In the present embodiment, a nitrogenous agent, such as a Urea and/or NH_3 solution, is pumped and directed to a predetermined injector where the pressurized liquid is forced through a nozzle that disperses the liquid into droplets. The nozzle is in the proximity of a ROFA duct, which allows the droplet spray to be carried by the ROFA air into the furnace where it is mixed with the NO_x -containing combustion gases. In the case of dry chemical injection, such as lime, solid urea, and the like, the dry chemical is transported with an air stream having a velocity of about 20 m/s to avoid sedimentation of the product. The liquid nozzle is replaced with a dry nozzle and the injected dry chemical is similarly carried and disperse into the furnace by the ROFA jet.

[0034] A coaxial injection device may be used to inject the nitrogenous agent in the proximity of the ROFA air. Additionally, other reagents, including cooling liquids and gases, can be injected through the injection device, described as follows.

[0035] As best seen in FIG. 6, a coaxial injection device according to the present invention, generally described as 110, is composed of an exterior duct 112, an outer-middle injector 114, an inner-middle duct 116, and an interior injector 118.

[0036] The exterior duct 112, or high-velocity gas duct, is designed for the injection of high-velocity gas in the reactor. For example, ROFA air can be injected into the reactor through the exterior duct for combustion furnaces. The high-velocity gas mixes and disperses material injected through the other ducts and injectors. For example, cooling water, cooling air, and a nitrogenous agent solution injected into combustion gases for the reduction of NO_x are mixed by the ROFA air.

[0037] The high-velocity gas disperses solutions without the need for dispersing nozzles; therefore the reactor can use solutions containing particulate. This eliminates or reduces the requirement for pure reagents necessary to prevent obstruction of fine orifices. For example, this device allows the use of low-quality water as cooling water in combustion furnaces, thereby reducing operating expense and improving performance by reducing orifice plugging.

[0038] The high-velocity gas duct is formed by the internal wall of the insert 120 and external wall 122 of outer-

middle injector 114. The duct is located externally to and circumferentially surrounds all other injectors and ducts, thereby ensuring the dispersion of all reagents injected through the device. The dispersion improves reaction homogeneity, thereby reducing byproduct formation.

[0039] Moving inward, the next component of the device is an outer-middle injector 114 with at least one injection orifice 124, such as a hole or nozzle. Preferably, the outer-middle injector has at least 8 nozzles. The outer-middle injector is formed by two concentric cylinders 126 and 128 with a connecting end plate 30 and at least 1 injector orifice 124 in the endplate. This device preferably injects a liquid, for example, cooling water for cooling gases in proximity of injected urea droplets can be injected through this injector. The cooling water reduces free radical oxidation of NH_3 to NO_x by combustion gases. Alternatively, gases can be injected through this injector. For example, a cooling gas, such as low quality steam that cannot be used for effective power generation, can be injected instead of cooling water into a combustion furnace. Besides the cooling effect, the steam will increase the mass flow and assist the high-velocity gas in carrying and dispersing the other reagents into the furnace.

[0040] Moving inward, the next component of the device is an inner-middle duct 116. This duct is formed by the interior cylinder 126 of the outer-middle injector and exterior wall of the interior injector 118. A second gas is preferably injected through this duct. For example, cooling air to keep an injected urea solution cool prior to injection can be injected through this duct. The cooling air prevents urea decomposition prior to injection into the combustion furnace.

[0041] The innermost component of the device is an interior injector 118 with constricting orifice 32. The interior injector is preferably formed by a hollow tube with endplate, preferably by a cylinder with endplate. The endplate preferably has a constricting orifice, such as a hole or nozzle. Preferably, liquids are injected into the reactor through this injector. For example, a concentrated nitrogenous agent solution can be injected for the reduction of NO_x in a combustion furnace. The SNCR NO_x reduction in the combustion gases thereby reduces acid emissions.

[0042] The nitrogenous agent can be selected from the group consisting of urea, ammonia, cyanuric acid, ammonium carbamate, ammonium carbonate, mixtures of ammonia and ammonium bicarbonate, one or more of the hydrolysis products of urea or mixtures or complexes thereof, compounds which produce ammonia as a byproduct, ammonium formate, ammonium oxalate, hexamethylenetetramine, ammonium salts of organic acids, 5- or 6- membered heterocyclic hydrocarbons having at least one cyclic nitrogen, hydroxy amino hydrocarbons, amino acids, proteins, monoethanolamine, guanidine, guanidine carbonate, biguanidine, guanylurea sulfate, melamine, dicyandiamide, calcium cyanamide, biuret, 1,1'-azobisformamide, methylol urea, methylol urea-urea condensation product, dimethylol urea, methyl urea, dimethyl urea.

[0043] Preferably, the nitrogenous agent is urea. More preferably, the nitrogenous agent is greater than about 20% aqueous urea w/w. Alternatively, more dilute solutions of nitrogenous reagent can be used.

[0044] The outer middle injector is preferably recessed in from the edge of the insert to protect the injector orifices

from the reaction heat and reactants. The inner injector is recessed within the outer middle inject, to further protect it from the reaction heat and reactants.

[0045] A specific example of the reduction of NO_x in a combustion furnace using urea with this coaxial device follows:

[0046] A combustion furnace operating at approximately 1300 degrees C. was fitted with asymmetrical coaxial ROFA ducts. The pressure of the ROFA air was adjusted to between about 1 and about 20 bar relative to the combustion space to provide sufficient mass flow to ensure adequate turbulence for mixing and heat exchange. A 20% urea solution was injected through the inner injector at a stoichiometric rate of from about 0.1 to about 6.0 NH₃/NO_x ratio. Great NO_x reduction was achieved with a NH₃/NO_x ratio between about 1 and about 2. Cooling water was injected at about 0.5 to about 40 H₂O/NH₃ ratio. Greater reduction in NO_x was achieved with a H₂O/NH₃ ratio between about 1 to about 6. The temperature of the cooling air was maintained below 100 degrees C. and the velocity was maintained above about 2 m/s to ensure that the urea solution was not boiling in the inner injector.

[0047] As shown in FIG. 7, a multiplicity of injection devices 14 according to the present invention can be combined to form a multiple injection system, generally described as 200. The system includes a system controller 238. The multiple coaxial injection system can be operated to provide higher efficiency reactions and reduced byproducts.

[0048] The injection devices 14 are installed at spaced-apart locations along the reactor length. At least 1 probe 240 is installed downstream of at least one of the injectors of the system. Preferably, the probe is installed downstream of the last injector. In an example embodiment, the injectors are positioned along a combustion furnace and the probe is a temperature probe installed at the end of the combustion chamber.

[0049] A method of using the multiple injection system in a combustion furnace includes the following steps:

[0050] 1) measuring reactor temperature;

[0051] 2) selecting the injection device most suitable for injecting the nitrogenous agent; and

[0052] 3) injecting the nitrogenous agent through the selected injection devices.

[0053] An optional step includes flushing deselected injection devices with a cleaning fluid to prevent fouling.

[0054] As shown in FIG. 2, another embodiment according to the present invention, injection of the overfire air into the combustion gases is effected in such a manner that the advected air travels across the column of combustion gases and is deflected by the opposing wall. This forceful injection induces turbulent mixing of the advected air and combustion gases in at least three ways: 1) by the generation of swirl 20 in the gas column, 2) the generation of turbulence in proximity of the opposing wall after deflection of the advected air by the wall 24, and 3) by the turbulence caused by the rotation of the column of combustion gases in a non-circular furnace, shown as 26 in FIG. 4. Swirl 20 is also generated by the rotation of the gas column, as shown in

FIG. 4. The rotation, shown as 30 in FIG. 3, is produced through the tangential injection into the furnace of the advected ROFA air, i.e. there is an injection port on each side of the furnace. The injection port on the right may be, for example, toward the rear of the furnace while the injection port on the left side may be toward the front side of the furnace. This placement of ports results in a "swirl" being created in the furnace much like the injection of water in a whirlpool can create a swirl, resulting in mixing, such as described in U.S. Pat. No. 5,809,910 issued Sep. 22, 1998 to Svendsen. This system provides for the asymmetrical injection of overfire air (OFA) in order to create turbulence in the furnace, thus more thoroughly mixing the secondary air and the combustion gases.

[0055] Turbulence generated in proximity of the opposing wall is achieved when the advected air strikes the opposing wall before being completely mixed into the combustion gases. That is, the penetration of the injected secondary air is greater than the width of the furnace and the secondary air deflects off the opposing wall and generates turbulent flow. To achieve penetration and, therefore, turbulence, the advected gas must have sufficient linear momentum to penetrate the primary gas, strike the deflecting surface, and rotate. This linear momentum is described as mass flow for a continuous gas stream. The mass flow (m) of a fluid is defined as follows:

$$m = \text{density of fluid} \times \text{Area} \times \text{average fluid velocity normal to Area}$$

[0056] The mass flow of the advected gas must be sufficient to traverse the column of flue gas, strike the deflecting surface, and create turbulence. The distance from injection to deflection, represented by the width of the flue gas chamber, dictates the necessary mass flow required to achieve turbulence. However, since the desired rate of added gas mass is limited, it is often desirable to increase the velocity of the advected gas, thereby increasing the mass flow. Thus, greater mass flow of the advected air can be attained by increasing the velocity of the gas.

[0057] Rotation of combustion gas column in a furnace with a non-circular cross-section causes additional turbulence formation due to the non-circular cross-section. The rotation is achieved, as previously described, by the use of opposing, coordinated, tangential injection of secondary air into the combustion gas column. Thus, rotation of the gas column in a non-circular cross-section furnace produces rotation-induced turbulence, especially at the furnace/gas interface.

[0058] In a system according to the present invention, a staged system and method are provided. In one embodiment, the staged system includes a series of reagent introduction ducts with nozzles advecting the reagents into a moving column of reagents, wherein the ducts are positioned in a predetermined, spaced apart manner to create rotational flow of the combustion zone, as described in U.S. Pat. No. 5,809,910, incorporated herein by reference in its entirety. The reagent injection ducts are preferably arranged to act at mutually separate levels or stages on the mutually opposing walls of the reactor, as shown in FIGS. 1 and 2, which illustrate a furnace of an incineration unit as the reactor and/or are displaced laterally in pairs in relation to one another. Additionally, the ducts may further include nozzles, which are preferably positioned at successively increasing

distances along the axis of flow of the furnace away from the furnace, as shown in **FIG. 1**, such that rotation is maintained by the co-ordinated, reinforcing, tangential injection of high-velocity secondary air into the combustion gas column, generally described as **50** in **FIG. 5**, which is considered one of the reagents according to the present invention.

[0059] A fourth means of producing turbulence in the reactor of the present invention is through the advection of overfire air or gases that are cooler than the combustion gases. This cooler air produces additional turbulence from the thermal expansion it undergoes upon mixing with the combustion gases. That is, the advected gas expands as it is warmed to the combustion gas temperature by the combustion gas, thus displacing and further mixing the surrounding combustion gas. However, in the case of combustion power plants, the advected air should not be so cold as to reduce the temperature of the exiting combustion gases and thus reduce heat exchange efficiency. In these furnaces, ambient air between -20 and 100 degrees centigrade (-4 to 212 degrees F.) can be used in the advected gas. Preheated gas, such as from redirected combustion air, may also be used in the advected gas. The redirected combustion air is preferably between 100 and 500 degrees centigrade (200 and 930 degrees F.) and is preferably mixed, if needed, with the ambient air at between 10 to 50% of the total advected gas, to provide an advection gas with temperature of between about 40 and 460 degrees centigrade. More preferably, the redirected combustion air is mixed at 20 - 40% of the total advected gas, if needed to provide an advection gas with temperature of between about 76 and 340 degrees centigrade. This gas mixture is therefore warm enough not to reduce the combustion gas temperature significantly and can also readily participate in the combustion reaction upon mixing with the combustion gas.

[0060] These turbulences can thus be further augmented by using high-velocity secondary air, which is considered one of the at least one reagents of the present invention. During testing of the system, secondary air was injected into reactors, where, in particular embodiments tested, the reactors were furnaces of various sizes at velocities ranging from 60 - 300 m/s using booster fans. The velocity necessary to provide sufficient mixing is dependent upon the size of the reactor, the vertical velocity of the combustion gasses and the configuration of the furnace. Surprisingly, the turbulence generated was sufficient that the entire furnace began operating as a single burner. The increased turbulence, mixing swirl, and rotation in the furnace resulted in improved combustion, increased efficiency of the fuel combustion, reduction in secondary air requirements with consequential increased retention time of the combustion gases in the furnace, lower furnace exit gas temperatures due to better heat exchange in the furnace, increased boiler efficiency and lower pollutant emissions.

[0061] From the tests it was determined that the ratio of the advected air velocity to the reactor, or in a particular embodiment a furnace, width (v/w) needs to be between about 2 to about 150 sec^{-1} , preferably between about 3 and 60 sec^{-1} .

[0062] Furthermore, it was determined that the velocity of the advected air should result in the combustion gas column rotating at least one half-turn prior to exiting the furnace, more preferably at least 1 turn prior to exiting the furnace.

To achieve this rotation, at least two levels of injection of at least one reagent are required, thereby providing for at least two stages of the system and method according to the present invention. More preferably at least three levels of injection are used for providing increased efficiency and for reduction of byproducts.

[0063] Alternatively, the velocity of the injected air needs to be such that the penetration of the injected reagent(s), which may include air, and which preferably include urea and/or a urea analog as set forth in the foregoing, is greater than the reactor width by at least about 1.5 reactor widths, more preferably by at least 2 reactor widths.

[0064] The reduction in the secondary air results in a decrease in combustion gas volume, which results in an increased residence time of the combustion gases in the furnace and thus more time for thermal flux to occur into the furnace water/steam conduits for a furnace example of a reactor system and method according to the present invention.

[0065] Additionally, the rotation of reagents in a non-circular cross-section reactor generates turbulence at the reagent/reactor surface interface. This turbulence reduces the laminar flow of the combustion gases at the interface and therefore improves the heat transfer across the interface. The turbulence generated by the rotation also further mixes the combustion gases and reduces laminar or parallel flow up the reactor. Combustion reactions in prior art non-circular reactors tend to demonstrate sidedness, that is the reactions are on a particular side or zone of the furnace versus other sides, resulting in non-uniform combustion within the reactor. Thus, the present invention advantageously utilizes the non-circular nature of the reactor's cross-section to eliminate the sidedness of the reactor. The rotation that overcomes this sidedness is achieved by the co-ordinated, reinforcing, tangential, or asymmetrical, injection of high-velocity secondary air as a reagent into the combustion column of the reactor.

[0066] Similarly, the vigorous mixing in the combustion area produced by the present invention also prevents the laminar flow and consequential lower residence time of higher inertia particles in the reactor, such as combustible particulate, thereby allowing them more time to burn in the reactor and further increasing the combustion efficiency and thermal flux efficiency of the reactor, as well as reducing the formation of byproducts, in particular pollutants such as NO_x .

[0067] Thus, the present invention utilizes the co-ordinated, reinforcing, tangential injection of high-velocity secondary air to improve the combustion efficiency and thermal flux efficiency of reactors of various cross-sectional shapes.

[0068] A method according to the present invention for increasing reactor efficiency and reduced NO_x production includes providing a reactor with a plurality of reagent introduction or injection ducts, asymmetrically positioned in an opposing manner at spaced apart, predetermined locations; injecting fuel with primary air through the burners prior to the injection of secondary air; injecting secondary air reagent with a nitrogenous agent through the plurality of reagent introduction or injection ducts, controlling the asymmetrical injection to produce a high velocity mass flow and a turbulence resulting in dispersion of the at least one

reagent into the reaction system, wherein one of the at least one reagents is an NH_3 -producing compound;

[0069] thereby providing increased reaction efficiency and reduced NO_x formation in the reaction process.

[0070] The injection velocity may be controlled to achieve the desired mass flow. The injection velocity is controlled such that the ratio of the velocity to the reactor width is between about 2 sec^{-1} to about 150 sec^{-1} , preferably between about 3 and about 60 sec^{-1} ; thereby increasing combustion efficiency and reactor efficiency via mixing and rotation of the reactor space, and improving the reduction of byproducts such as pollutants.

[0071] Alternatively or additionally, the velocity of the injected air as a reagent is such that the penetration of the injected air reagent is greater than the reactor width by at least about 1.5 widths and/or the reagents acting within a reaction zone, which may include combustion activity, rotates at least one half revolution prior to exiting the reactor.

[0072] Certain modifications and improvements will occur to those skilled in the art upon a reading of the foregoing description. All modifications and improvements have been deleted herein for the sake of conciseness and readability but are properly within the scope of the following claims.

What is claimed is:

1. A method for increasing combustion process and furnace efficiency and for reducing NO_x formation, comprising the steps of:

providing a staged combustion system including a furnace with asymmetrical injection ports introducing at least one reagent to the reactor by asymmetrical injection at predetermined, spaced apart locations;

injecting fuel with primary air through a first stage prior to injection of a second air;

injecting secondary air and nitrogenous agent through the plurality of injection ducts;

controlling the asymmetrical injection of secondary air to produce a turbulence resulting in dispersion of the at least one nitrogenous agent into the reaction system, thereby providing increased reaction and reactor efficiency and reduced NO_x formation in the reaction process.

2. The method according to claim 1, further including the step of adding additional reagents in stages, spaced apart in location and time.

3. The method according to claim 1, wherein the nitrogenous agent is selected from the group consisting of urea, urea analogs, ammonia, cyanuric acid, ammonium carbamate, ammonium carbonate, mixtures of ammonia and ammonium bicarbonate, one or more of the hydrolysis products of urea or mixtures or complexes thereof, compounds which produce ammonia as a byproduct, ammonium formate, ammonium oxalate, hexamethylenetetramine, ammonium salts of organic acids, 5- or 6- membered heterocyclic hydrocarbons having at least one cyclic nitrogen, hydroxy amino hydrocarbons, amino acids, proteins, monoethanolamine, guanidine, guanidine carbonate, biguanidine, guanyurea sulfate, melamine, dicyandiamide, calcium cyanamide, biuret, 1,1'-azobisformamide, methylol urea, methylol urea-

urea condensation product, dimethylol urea, methyl urea, dimethyl urea, and combinations thereof

4. The method according to claim 1, wherein the nitrogenous agent is selected from the group consisting of solid urea, liquid urea, urea in aqueous solution, and combinations thereof.

5. The method according to claim 1, wherein the at least one reagent is introduced at a plurality of injection ducts, asymmetrically positioned in an opposing manner;

6. The method according to claim 1, wherein two reagents, a first reagent and a second reagent, are introduced to the system in a sequential manner with the first reagent being introduced prior to the second reagent.

7. The method according to claim 1, the velocity of the injected reagent is such that the ratio of the velocity to the reactor width is between about 2 sec^{-1} to about 150 sec^{-1} ;

thereby increasing combustion efficiency and furnace efficiency via swirl, peripheral turbulence, and rotation-induced turbulence of the reactor.

8. The method of claim 1, wherein the temperature of the injected reagent is between about 40 and about 460 degrees centigrade.

9. The method of claim 8, wherein the temperature of the injected reagent is between about 76 and about 340 degrees centigrade.

10. The method of claim 1, wherein the system has at least two levels of secondary air injection ducts.

11. The method of claim 10, wherein the system has at least three levels of secondary air injection ducts.

12. The method of claim 1, wherein the velocity of the injected reagent is such that the ratio of the velocity to the reactor width is between about 3 sec^{-1} to about 60 sec^{-1} .

13. A method for increasing combustion efficiency in a reactor and for reducing pollutants therein, comprising:

providing a reactor with a plurality of reagent injection ducts, asymmetrically positioned in an opposing manner;

injecting a first reagent through a first stage prior to injection of a second reagent;

injecting a second reagent through the plurality of reagent injection ducts;

wherein the velocity of the injected air is such that the penetration of the injected reagents is greater than the reactor width by at least about 1.5 widths;

thereby increasing furnace efficiency and reducing NO_x via nitrogenous reduction and mixing and rotation of the combustion space.

14. The method of claim 13, wherein the urea reagent is selected from the group consisting of urea, urea analogs, and the like, and combinations thereof.

15. The method of claim 13, wherein the urea reagent is selected from solid urea, liquid urea, urea in aqueous solution, and combinations thereof.

16. The method of claim 13, wherein the system has at least two levels of reagent introduction ducts for injection of the at least one reagent.

17. The method of claim 16, wherein the system has at least three levels of reagent ducts for injection of the at least one reagent.

18. A method for increasing combustion furnace efficiency and reducing NO_x , comprising:

providing a reactor with a plurality of reagent injection ducts, asymmetrically positioned in an opposing manner;

injecting at least one nitrogenous agent through the ducts in the proximity of high-velocity secondary air in stages, wherein one of the at least one agents is urea;

wherein the velocity of the secondary air is such that the at least one injected reagent is dispersed and the combustion gas column rotates at least one half revolution prior to exiting the reactor;

thereby increasing reactor efficiency and reducing NOx via mixing and rotation of the reagents and gases in the reactor.

19. The method of claim 18, wherein the urea reagent is selected from the group consisting of urea, urea analogs, and the like, and combinations thereof.

20. The method of claim 18, wherein the urea reagent is selected from solid urea, liquid urea, urea in aqueous solution, and combinations thereof.

21. The method of claim 18, wherein the system has at least two levels of reagent ducts for injection of the reagents.

22. The method of claim 18, wherein the system has at least three levels of reagent ducts for injection of the reagents.

23. A method for increasing combustion process and furnace efficiency and for reducing NOx formation, comprising the steps of:

providing a furnace with a plurality of secondary air injection ducts, asymmetrically positioned in an opposing manner, and a plurality of nitrogenous agent injectors in the proximity of the secondary air injection ducts;

injecting fuel with primary air through a first stage prior to injection of a second air;

injecting secondary air through the plurality of injection ducts;

injecting at least one reagent through the plurality of injectors;

controlling the asymmetrical injection of secondary air to produce a turbulence resulting in dispersion of the at least one nitrogenous agent into the reaction system,

thereby providing increased reaction and reactor efficiency and reduced NOx formation in the reaction process.

24. A method for increasing combustion process and furnace efficiency and for reducing NOx formation, comprising the steps of:

providing a staged combustion system including a furnace with asymmetrical injection ports introducing at least one reagent to the reactor by asymmetrical injection at predetermined, spaced apart locations;

injecting fuel with primary air through a first stage prior to injection of a second air;

injecting secondary air through the plurality of reagent injection ducts;

controlling the asymmetrical injection to produce a high velocity mass flow and a turbulence resulting in dispersion of the at least one reagent into the reaction system, wherein one of the at least one reagents is an NH3-producing compound;

thereby providing increased reaction efficiency and reduced NOx formation in the reaction process.

25. The method of claim 24, further including the step of injecting the NH3-producing compound after a catalyst to neutralize acids via non-reductive acid neutralization.

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