US 20040185402A1

(19) **United States**

(12) **Patent Application Publication**

Moberg

(10) **Pub. No.: US 2004/0185402 A1**

(43) **Pub. Date: Sep. 23, 2004**

(54) **MIXING PROCESS FOR INCREASING CHEMICAL REACTION EFFICIENCY AND REDUCTION OF BYPRODUCTS**

(76) Inventor: **Goran Moberg**, Cary, NC (US)

Correspondence Address:
JINAN GLASGOW
P O BOX 28539
RALEIGH, NC 276118539

(21) Appl. No.: **10/459,789**

(22) Filed: **Jun. 12, 2003**

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/391,825, filed on Mar. 19, 2003.

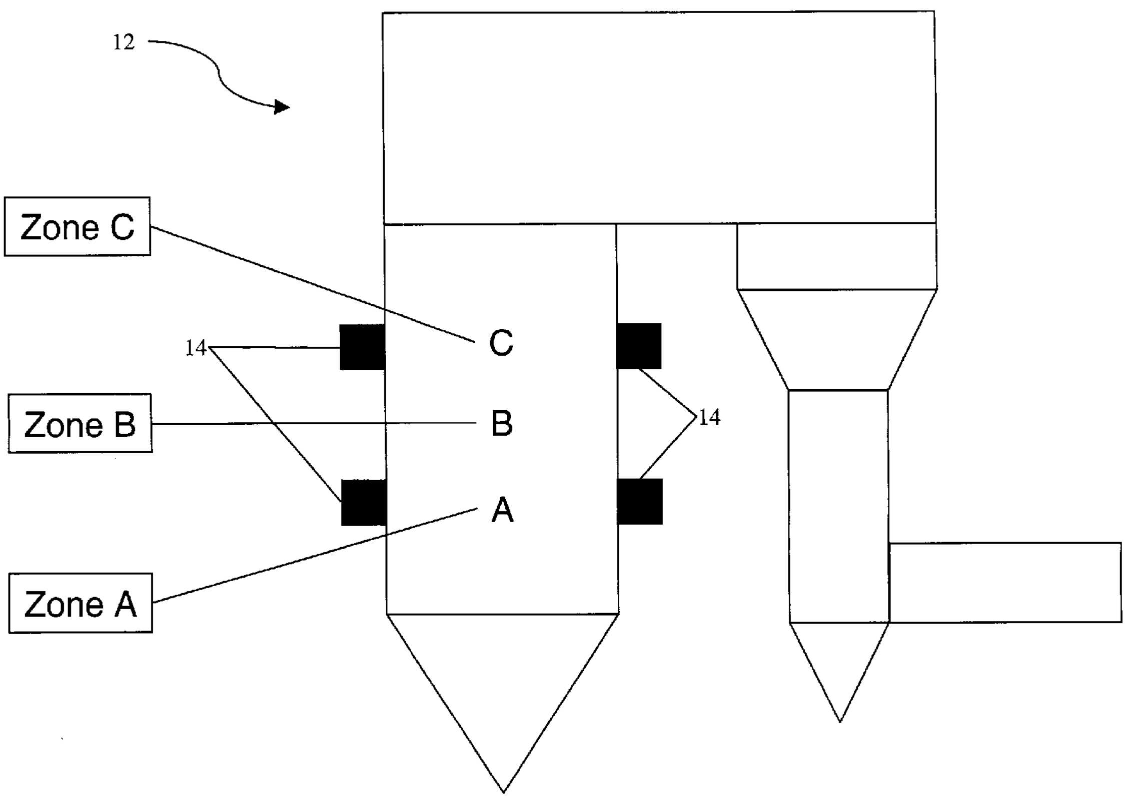
Publication Classification

(51) **Int. Cl.**[7] **F23M 3/00**

(52) **U.S. Cl.** **431/9**

(57) **ABSTRACT**

A system and method for increasing reaction and reactor efficiency, including the steps of providing a reactor with a plurality of reagent introduction or injection ducts, asymmetrically positioned in a tangentially reinforcing manner at spaced apart predetermined locations; injecting at least one reagent; wherein the velocity of the injected reagent(s) is such that the ratio of the reagent velocity to the reactor width is between about 2 sec^{-1} to about 150 sec^{-1}; thereby increasing reaction and reactor efficiency and reducing the byproducts produced thereby, via mixing and rotation of the reaction space.



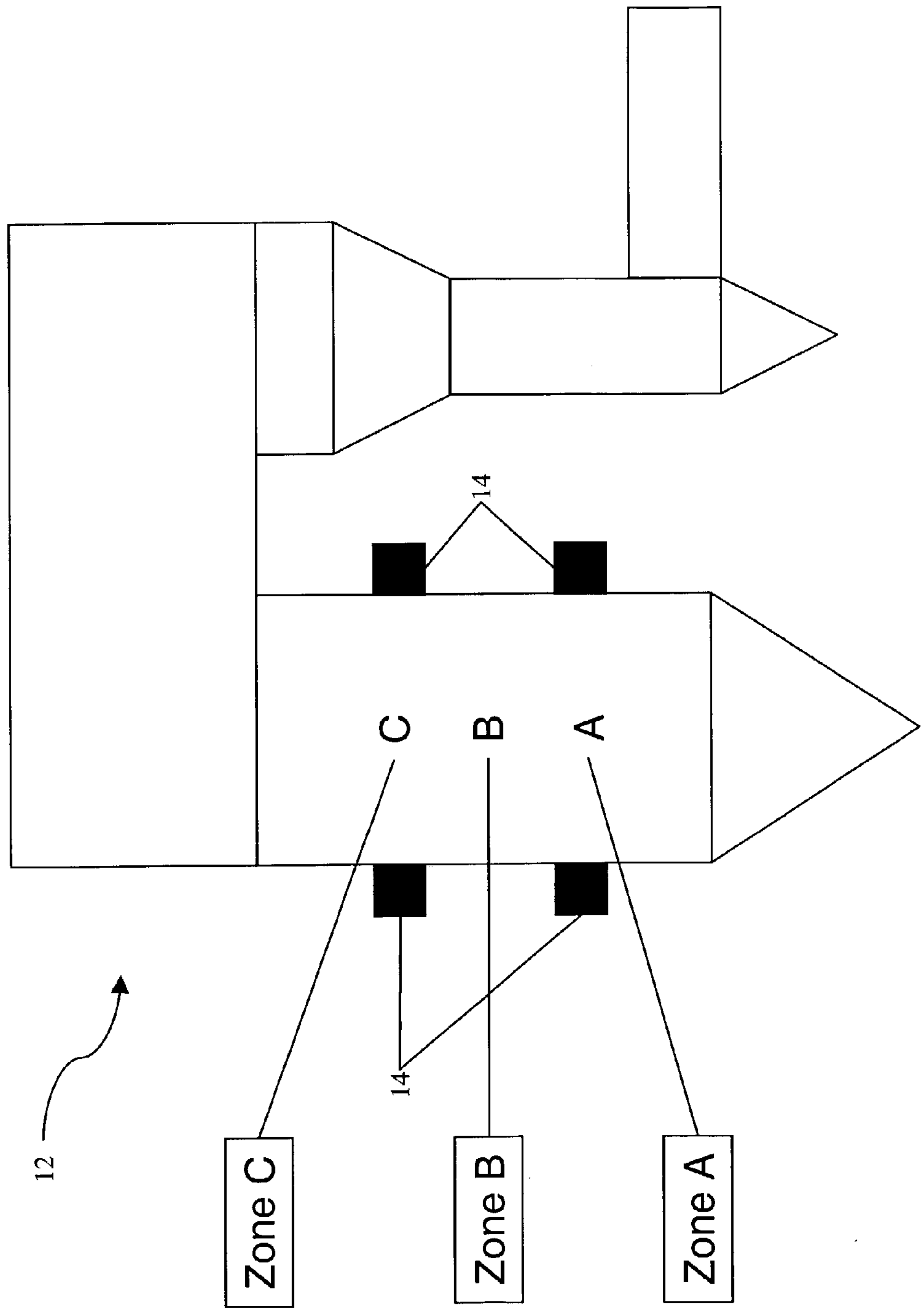


Figure 1

Figure 2

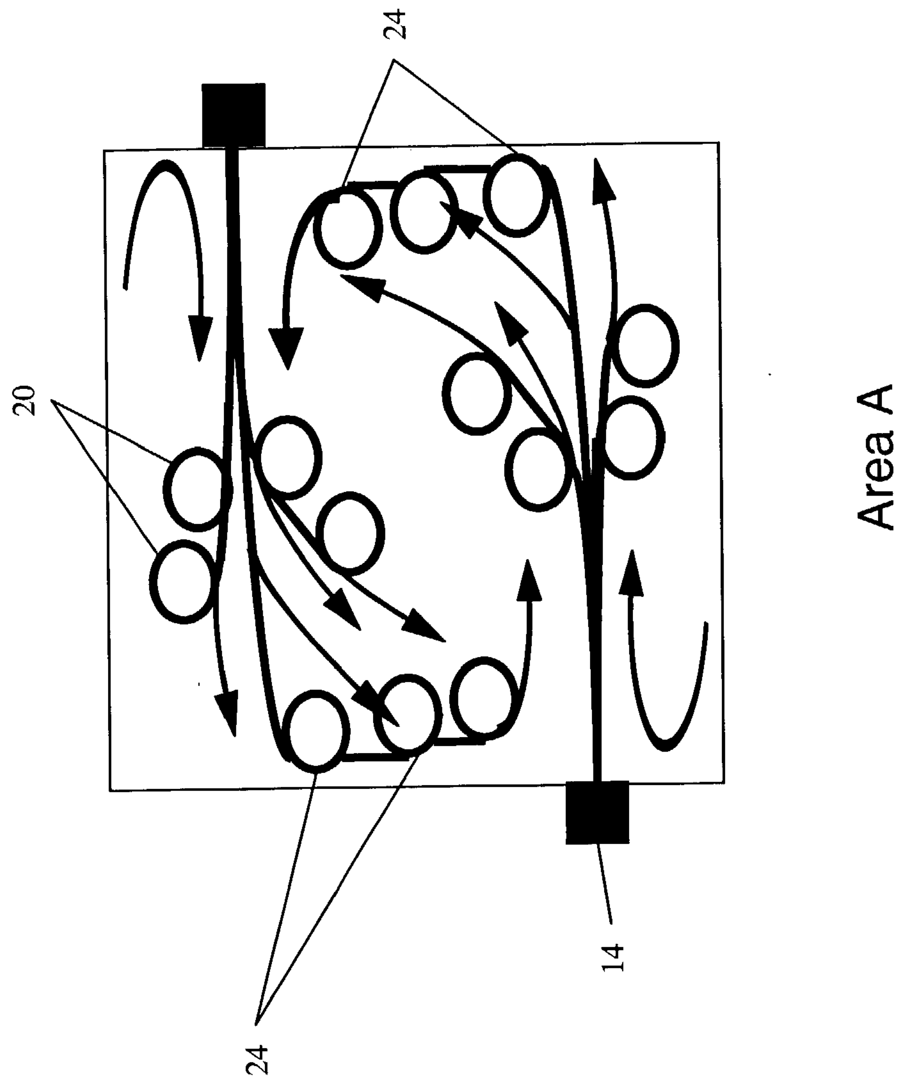
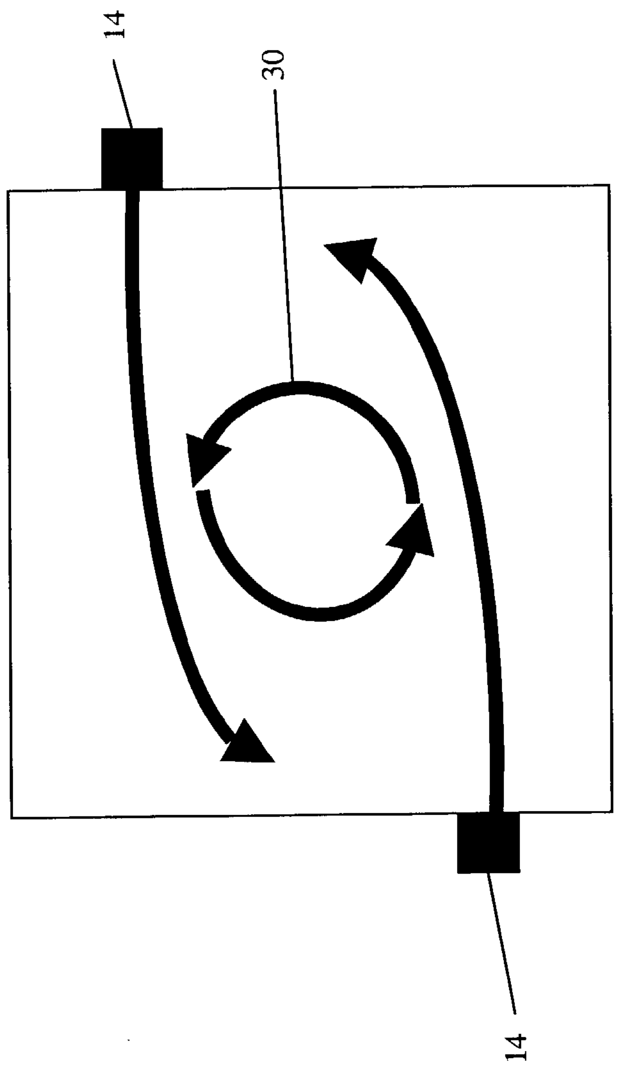


Figure 3



Area A

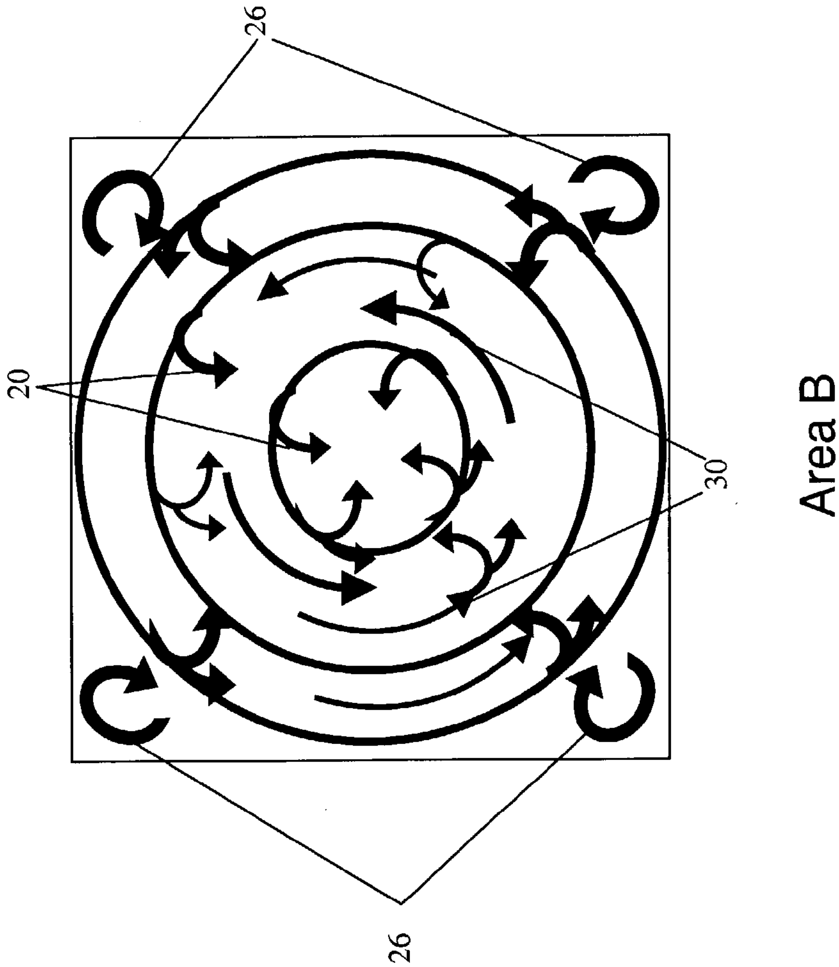
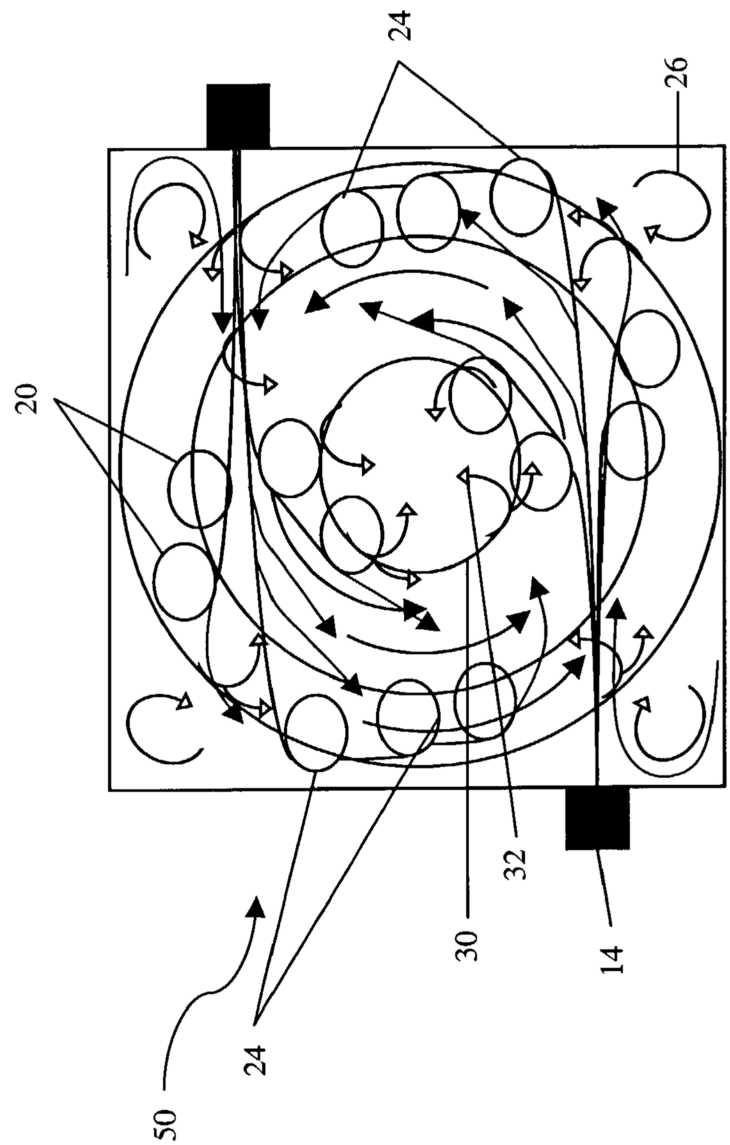


Figure 4

Figure 5



Area C

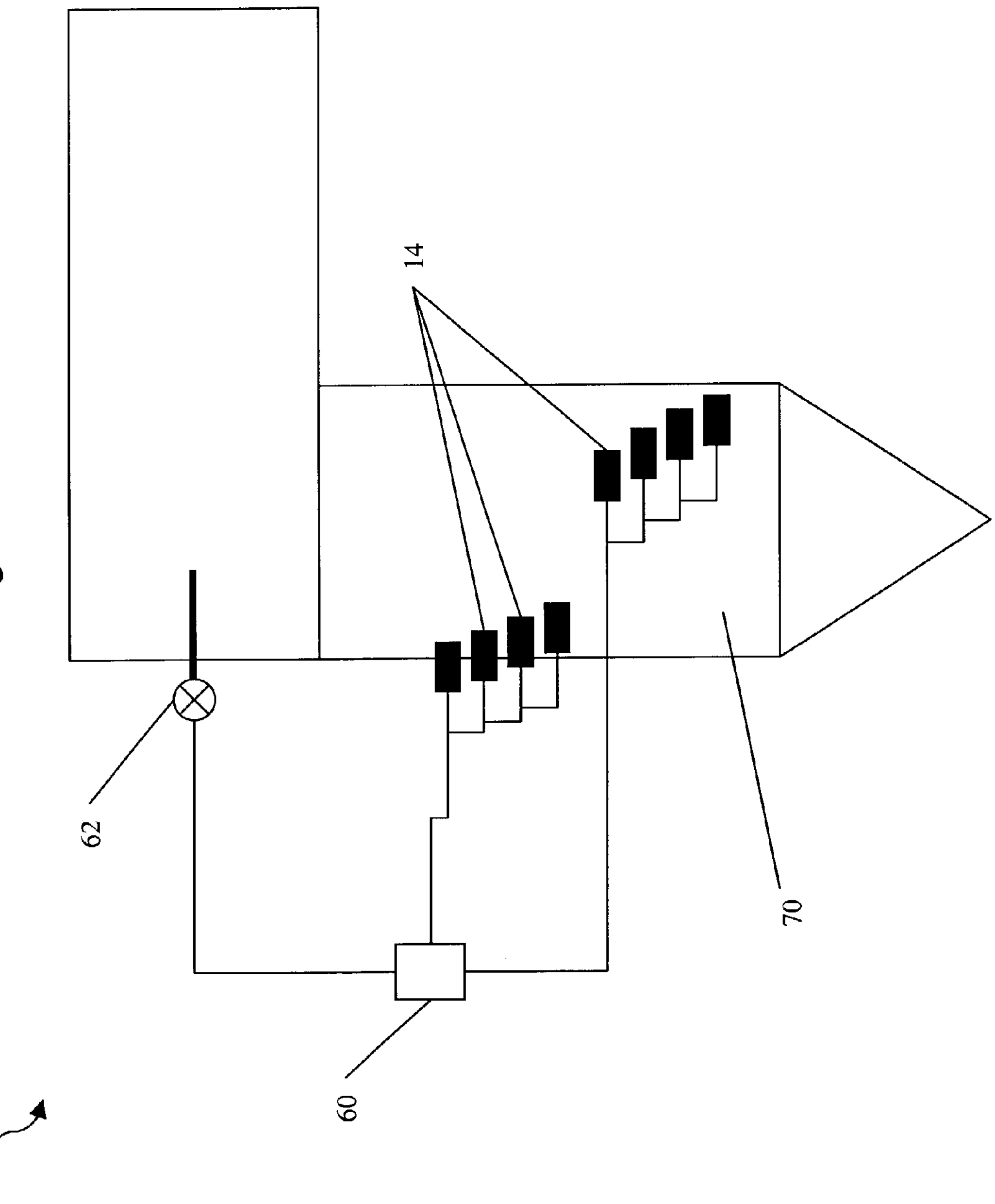


Figure 6

MIXING PROCESS FOR INCREASING CHEMICAL REACTION EFFICIENCY AND REDUCTION OF BYPRODUCTS

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 chemical reactions and for reducing byproducts production, and, more particularly, to a system and method for improving combustion efficiency and reduction of nitrogen oxides (NOx).

[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.

SUMMARY

[0007] The present invention is directed to a mixing process and system for increased chemical reaction and chemical reactor efficiency and for improved reduction of by-products, in particular NOx reduction.

[0008] The present invention is further directed to a system and method for increased furnace efficiency through increased retention time in the furnace. 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.

[0009] The present invention is directed toward increasing furnace energy efficiency via increased combustion efficiency and increased furnace thermal flux, thereby also improving the reduction of pollutants, in particular the reduction of NOx.

[0010] It is one aspect of the present invention to increase chemical reaction efficiency by the asymmetrical, staged addition of reagents at high-velocity for the induction of turbulent mixing in the reaction mixture. Another aspect of the present invention is to increase reactor and reaction efficiency by increasing the residence time of the reactor and reducing laminar flow at surfaces. Yet another aspect of the present invention is to increase thermal flux in a reactor by increasing the residence time of combustion gases in the reactor and decreasing the laminar flow at heat exchange surface. In the present invention, these parameters are improved by the induction of turbulence in the reaction mixture and at the mixture/reactor interface.

[0011] Furthermore, the present invention increases the reaction efficiency through the rapid, thorough mixing of the injected secondary reagents with the reaction mixture via increased turbulence. This rapid, thorough mixing effects a more complete reaction of the primary reagent while reducing the secondary reagent requirements.

[0012] 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

[0013] **FIG. 1** is a side view of a combustion furnace operated according to the present invention.

[0014] **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.

[0015] **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.

[0016] **FIG. 4** is a cross-sectional view of Zone B of the furnace showing the turbulence induced by rotation in a non-circular furnace.

[0017] **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.

[0018] **FIG. 6** shows a schematic view of a system according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0019] 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.

[0020] 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.

[**0021**] According to the present invention, a method is 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; introducing the 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, 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.

[**0022**] In one exemplary embodiment, 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.

[**0023**] As shown in **FIG. 2**, another embodiment according to the present invention, injection of the overfire air into the combustion gases is effected in a manner such 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**.

[**0024**] 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 Svendssen. 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.

[**0025**] 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=density of fluid×Area×average fluid velocity normal to Area

[**0026**] 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.

[**0027**] 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.

[**0028**] 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.

[**0029**] 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.

[0030] 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.

[0031] 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.

[0032] 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}.

[0033] 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.

[0034] Alternatively, the velocity of the injected air needs to be such that the penetration of the injected reagent(s), which may include air, is greater than the reactor width by at least about 1.5 reactor widths, more preferably by at least 2 reactor widths.

[0035] 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.

[0036] 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 thermal flux, or heat transfer, across the interface. This effect can be advantageously used to improve the efficiency of exothermic and endothermic reactions. For exothermic reactions, the thermal flux may be advantageously used to remove heat from the reaction space, thereby reducing the reaction temperature and favoring the exothermic reaction. For endothermic reactions, the thermal flux may be used to add heat to the reaction space, thereby raising the temperature of the reaction space and favoring the endothermic reaction. 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 coordinated, reinforcing, tangential, or asymmetrical, injection of high-velocity secondary air as a reagent into the combustion column of the reactor.

[0037] 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 NOx.

[0038] Thus, the present invention utilizes the co-ordinated, reinforcing, tangential injection of high-velocity secondary reagents to improve the reaction efficiency and thermal flux efficiency of reactors of various cross-sectional shapes.

[0039] A method according to the present invention for increasing reactor efficiency 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 a first reagent such as fuel with a second reagent such as primary air through the burners prior to the injection of secondary air; injecting secondary air reagent through the plurality of reagent introduction or injection ducts at a velocity 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 reaction efficiency and reactor efficiency via mixing and rotation of the reactor space, and improving the reduction of byproducts such as pollutants.

[0040] Alternatively or additionally, the velocity of the injected secondary reagent is such that the penetration of the secondary 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.

[0041] **FIG. 6** shows a schematic view of a preferred system according to the present invention, generally described as **20**, including a staged reaction system including a reactor **70**, a multiplicity of injection devices **14** for introduction of at least one reagent into a reaction process by asymmetrical injection at predetermined, spaced apart locations; at least 1 probe **40** installed downstream of at least one of the injectors of the system, and a controller **62** for 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 and mixing of the reaction space; thereby providing increased reaction efficiency and reduced byproducts formation in the reaction process.

[0042] 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 reaction efficiency and for reducing byproducts formation, comprising the steps of:

providing a staged reaction system including a reactor and at least one reagent for introduction into a reaction process,

introducing the 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 and mixing of the reaction space,

thereby providing increased reaction efficiency and reduced byproducts 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, at high velocity.

3. The method according to claim 1, wherein at least one reagent is fuel.

4. The method according to claim 1, wherein at least one reagent is secondary air.

5. The method according to claim 2, wherein the additional reagents are 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-induce turbulence of the reactor.

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

11. The method of claim 10, wherein the system has at least three levels of injection ducts for injection of the at least one reagent.

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 byproducts 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 second reagent is such that the penetration of the injected reagents is greater than the reactor width by at least about 1.5 widths;

thereby increasing reaction efficiency and reducing pollutants via mixing and rotation of the reaction space.

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 chemical reaction efficiency, comprising:

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

injecting at least one reagent through the ducts in stages;

wherein the velocity of the at least one reagent is such that the at least one injected reagent rotates at least one half revolution prior to exiting the reactor;

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

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.

* * * * *