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(54) A method of controlling nitrous oxide in circulating fluidized bed steam generators

(57) A method of controlling N_2O emissions from a circulating fluidized bed steam generator (CFB) (2) while concomitantly therewith maintaining acceptable levels of NO_x emissions and SO_x emissions from the circulating fluidized bed steam generator (CFB) (2), by increasing the temperature of the combustion gases (32) prior to their discharge from cyclone exit (8a) and at the same time lowering their temperature at the furnace exit (4c).

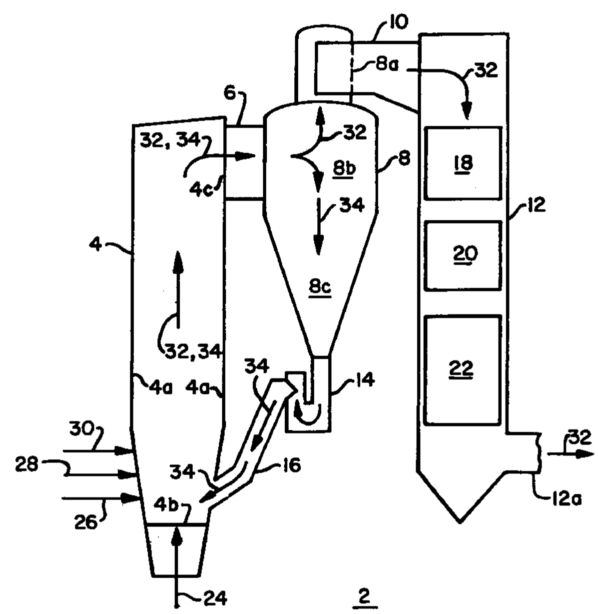

Fig. 1

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Description

BACKGROUND OF THE INVENTION

This invention relates to fossil fuel-fired circulating fluidized bed steam generators (CFB), and more specifically to a method of controlling nitrous oxides in such fossil fuel-fired circulating fluidized bed steam generators (CFB) while concomitantly maintaining acceptable NO_x and SO_x emission levels therefrom.

It has been known heretofore in the prior art to provide fluidized bed steam generators of various types. In this regard, one convenient method of differentiating between such various types of fluidized bed steam generators is by the nature of the fluidization that takes place therewithin. As employed in this context, the term "fluidization" refers to the manner in which solid materials are provided with a free-flowing, fluid-like behavior. To this end, as a gas is made to pass upwardly in a fluidized bed steam generator through a bed of solid particles that is present therewithin, such a flow of gases produces forces that tend to separate the solid particles one from another. At low gas velocities such forces can be insufficient to cause the solid particles to separate one from another such that the solid particles remain in contact with one another, i.e., tend to resist movement therebetween. When such a condition exists, it is referred to as being a fixed bed. As such, fluidized bed steam generators in which such a condition exists are commonly referred to in the art as being fixed bed fluidized bed steam generators.

On the other hand, as the gas velocity is increased, a point is reached wherein the gas velocity is sufficient such that the forces acting upon the solid particles are adequate to cause separation of the solid particles. When this occurs, the bed of solid particles then become fluidized in that the gas cushion between the solid particles permit the solid particles to move freely, thus giving the bed of solid particles liquid-like characteristics.

The design of fluidized bed steam generators is generally such that for purposes of the combustion process that takes place therewithin, fuel is burned in a bed of hot incombustible particles, the latter particles being suspended by an upwardly flow of fluidizing gas. Moreover, this fluidizing gas normally is comprised of both air, which is being supplied to the fluidized bed steam generator to support the combustion of fuel therewithin, and the gaseous byproducts, which result from such combustion of fuel and air.

Fluidized bed steam generators, including but not limited to circulating fluidized bed steam generators (CFB), are normally intended to be operative to produce steam. Moreover, such production of steam results from the combustion of fuel and air within the fluidized bed steam generators. Furthermore, the steam that is so produced within the fluidized bed steam generator (CFB) is designed to be operative to function in accordance with a preselected thermodynamic steam cycle.

Inasmuch as the subject matter of the instant application relates in particular to circulating fluidized bed steam generators (CFB), the discussion hereinafter will be presented in the context of a circulating fluidized bed steam generator (CFB). To this end, a circulating fluidized bed steam generator (CFB) includes a furnace volume, the walls of which are comprised of vertical waterwall tubes. In the lower segment of the furnace volume, fuel and sorbent are mixed with and burned in air, producing hot combustion gases in which hot solids become entrained. As these hot combustion gases and hot solids entrained therewithin rise within the furnace volume, heat is transferred to the aforementioned waterwall tubes thereby causing saturated steam to be evaporatively produced in conventional fashion from the water rising within the waterwall tubes. This saturated steam is a mix of steam and water, which is thereafter separated in known fashion in a steam drum. From the steam drum, the water is returned to the waterwall tubes in the lower segment of the furnace volume thereby completing an evaporative loop, while the steam is delivered to a superheater.

From the top of the furnace volume, the hot combustion gases and hot solids entrained therewithin are directed to a cyclone where unburned fuel, flyash and sorbent above a predetermined size are mechanically separated from the hot combustion gases. This unburned fuel, flyash and sorbent are collected from the cyclone, then are made to fall under the influence of gravity through a stand pipe and a seal pot, and are thereafter reintroduced into the lower segment of the furnace volume whereupon this unburned fuel, flyash and sorbent are once again subjected to the combustion process. The foregoing describes the circulation path followed by the hot solids, which are above a predetermined size, that become entrained in the hot combustion gases.

The hot combustion gases entering the cyclone, which hereinafter will be referred to as flue gases, still contain useful energy, and after separation therefrom of the unburned fuel, flyash and sorbent above a predetermined size, are directed to a backpass, with which the circulating fluidized bed steam generator (CFB) is suitably provided, wherein additional heat exchange surfaces are located. These additional heat exchange surfaces commonly comprise superheat surface followed by possibly reheat surface and thereafter economizer surface. The superheat surface in known fashion is operative to heat, i.e., superheat, the steam, which as described hereinbefore has been separated from the water in the steam drum of the circulating fluidized bed steam generator (CFB), whereupon this steam, which has been subjected to superheating, is made to flow to a high pressure turbine (HPT). After expansion in the high pressure turbine (HPT), the aforementioned steam, which has been subjected to superheating, is made to flow to the reheat surface, if such reheat surface has been provided in the backpass of the circulating fluidized bed steam generator (CFB). The reheat surface is operative in known fashion to once again heat, i.e., reheat, the steam, which as described hereinbefore has been separated from the water in the steam drum of the circulating fluidized bed steam generator (CFB), whereupon this steam, which has been subjected to reheating, is made to flow to a low pressure turbine (LPT).

Continuing, after further expansion in the low pressure turbine (LPT), the aforereferenced steam, which has been subjected to reheating, is condensed to water, whereupon the water that results from condensing of the reheated steam is made to flow to the economizer surface, which is located in the backpass of the circulating fluidized bed steam generator (CFB), where this water is heated before being returned to the steam drum of the circulating fluidized bed steam generator (CFB). The foregoing completes the description of the thermodynamic steam cycle of the steam, which is produced from the combustion process that takes place within the circulating fluidized bed steam generator (CFB). In closing, however, note is made herein of the fact that at appropriate points relative to the superheat surface and to the reheat surface, which are located in the backpass of the circulating fluidized bed steam generator (CFB), water spray stations are provided that are used to control the temperature of the superheat steam, which flows to the high pressure turbine (HPT), and/or to control the temperature of the reheat steam, which flows to the low pressure turbine (LPT). The water, which is employed in these water spray stations, is extracted from the water, which is produced from the condensing of the reheat steam, that is made to flow to the economizer surface located in the backpass of the circulating fluidized bed steam generator (CFB), and as such the water, which is employed in these water spray stations, is, therefore, not available for use in generating steam.

The flue gases during the passage thereof through the backpass of the circulating fluidized bed steam generator (CFB) are cooled as a consequence of the heat exchange that occurs between the flue gases and the superheat surface, the reheat surface (if present), and the economizer surface, which are located in the backpass of the circulating fluidized bed steam generator (CFB). Upon exiting from the backpass of the circulating fluidized bed steam generator (CFB), the now cooler flue gases are then preferably utilized in known fashion to effect therewith a preheating of the air, which is supplied to the circulating fluidized bed steam generator (CFB) for the purpose of accomplishing therewith the combustion of the fuel within the circulating fluidized bed steam generator (CFB). Thereafter, the flue gases also in known fashion are generally made to flow to and through a particulate removal system for purposes of effecting the removal of particulates from the flue gases after which the flue gases are emitted to the atmosphere from a stack, which is cooperatively associated with the circulating fluidized bed steam generator (CFB). The foregoing completes the description of the path of flow of the flue gases, the latter being generated from the combustion of fuel and air within the circulating fluidized bed steam generator (CFB).

As noted herein previously, in the course of the mode of operation of a circulating fluidized bed steam generator (CFB) a hydrocarbon fuel is combusted in the presence of air in the lower segment of the furnace volume of the circulating fluidized bed steam generator (CFB). A byproduct of such combustion of hydrocarbon fuel, e.g., coal in air, is oxides of nitrogen, i.e., NO_x. There are two main forms of nitrogen. One of these, i.e., that referred to as "thermal NO_x", is produced from the nitrogen, which originates from the air that is employed in the aforereferenced combustion process. Because of the relatively low temperatures at which combustion takes place in circulating fluidized bed steam generators (CFB), thermal NO_x is essentially zero in circulating fluidized bed steam generators (CFB).

The second main form of NO_x is that referred to as "fuel NO_x". Fuel NO_x is produced from the nitrogen, which originates as organically bound nitrogen within the hydrocarbon fuel. Insofar as coal as a hydrocarbon fuel is concerned, the nitrogen content thereof is comparatively small. However, although only a fraction of the nitrogen content of a hydrocarbon fuel such as coal is converted to NO_x, fuel NO_x nevertheless comprises the primary source of the total amount of NO_x emissions from a fossil fuel-fired steam generating power plant.

Continuing, there are a number of factors that have a major influence on the rate at which fuel NO_x is formed. One of these is the rate at which the hydrocarbon fuel and the air, which is supplied for the purpose of effecting therewith the combustion of the hydrocarbon fuel, mix. Another is the temperature at which the combustion of the hydrocarbon fuel and air takes place. Yet another is the local concentration of oxygen, which is present within the furnace volume of the circulating fluidized bed steam generator (CFB).

In addition to oxides of nitrogen, organic sulfur is also oxidized during the combustion of hydrocarbon fuel and air within the furnace volume of the circulating fluidized bed steam generator (CFB), and is emitted from the furnace volume as gaseous oxides of sulfur, i.e., SO_x. Sorbent, to which reference has been had herein previously, is introduced into the furnace volume of the circulating fluidized bed steam generator (CFB) in order to effect therewith control over the extent to which SO_x formation occurs within the furnace volume of the circulating fluidized bed steam generator (CFB) during the combustion process, which takes place therewithin.

Reference is once again had to the combustion process, which takes place within the furnace volume of the circulating fluidized bed steam generator (CFB), and wherein the hydrocarbon fuel is combusted in the presence of air and sorbent. To this end, the hydrocarbon fuel is combusted in the presence of air and sorbent in accordance with certain preestablished stoichiometric conditions such that the combustion of virtually all of the hydrocarbon fuel is completed during the transit of the hydrocarbon fuel through the furnace volume of the circulating fluidized bed steam generator (CFB). It is possible, however, that some afterburning of the hydrocarbon fuel may take place between the exit of the furnace volume of the circulating fluidized bed steam generator (CFB) and the exit of the cyclone that is cooperatively associated therewith. If such afterburning does occur then the temperature of the flue gases exiting from the cyclone will exceed the temperature of the hot gases of combustion, which exit from the furnace volume of the circulating fluidized bed steam generator (CFB).

In accordance with the conventional mode of operation of a circulating fluidized bed steam generator (CFB), the air is staged in two or more vertical levels of the furnace volume of the circulating fluidized bed steam generator (CFB) and may also be equally divided amongst these various levels. As a consequence of this, there is an essentially uniform temperature of between 1550 degrees F. to 1600 degrees F. throughout the furnace volume of the circulating fluidized bed steam generator (CFB). Further, this temperature is also essentially uniform throughout the circulation path, which the hot solids, to which reference has been had herein previously, follow during the course of their passage through the circulating fluidized bed steam generator (CFB) and through the components cooperatively associated therewith.

A principal advantage of a circulating fluidized bed steam generator (CFB) resides in the fact that NO_x and SO_x emissions therefrom are lower than, for example, a pulverized coal-fired steam generator. This is attributable to the lower temperatures at which combustion takes place within the circulating fluidized bed steam generator (CFB). However, although such combustion temperatures on the one hand produce lower NO_x and SO_x emissions, such combustion temperatures on the other hand permit the formation of nitrous oxide, i.e., N_2O. N_2O is a gas, which allegedly contributes to the greenhouse effect and to ozone depletion. The formation of N_2O from the combustion of hydrocarbon fuel and air is perhaps best understood from those chemical reactions, which have been suggested by L. E. Amand and B. Leakner in "Formation of N_2O In A Circulating Fluidized-Bed Combustor" that is reported in Energy & Fuels, 1993, 7., and which in the interest of ready reference thereto are set forth herein as follows:

$$HCN + O \rightarrow NCO + H$$

$$NCO + NO \rightarrow N_2O + CO$$

$$NH_3 + NO \rightarrow N_2O + H_2$$

$$NH + NO \rightarrow N_2O + H$$

Depending upon the hydrocarbon fuel type, the levels of N_2O produced in a circulating fluidized bed steam generator (CFB) may possibly range up to about 200 ppm.

The formation of N_2O has been found to be very much dependent upon combustion temperature in that as the combustion temperature rises N_2O levels decrease linearly. However, as mentioned herein previously this rise in combustion temperature leads to an increase in NO_x and SO_x formation. Thus, it is important that any reduction in the level of N_2O formation be attainable while at the same time ensuring that the levels of NO_x emissions and SO_x emissions do not increase.

Methods and/or means for reducing N_2O emissions, be such N_2O emissions from circulating fluidized bed steam generators (CFB) or from some other type of equipment, are known to have been provided heretofore in the prior art. By way of exemplification and not limitation in this regard, one such method and/or means for reducing N_2O emissions is that to which U.S. Patent No. 5,171,553 entitled "Catalytic Decomposition Of N_2O", which issued on December 15, 1992 and which is assigned to Air Products and Chemicals, Inc., is directed. More specifically, the teachings of U.S. Patent No. 5,171,553 are directed to a catalytic pollution control process for removing N_2O from gaseous mixtures. To this end, in accordance with the subject catalytic process as taught in U.S. Patent No. 5,171,553, an N_2O-containing gaseous mixture is contacted with a catalyst comprising a crystalline zeolite which, at least in part, is composed of five membered rings having a structure type selected from the group consisting of BETA, MOR, MFI, MEL and FER and wherein the crystalline zeolite has been at least partially ion-exchanged with a metal selected from the group consisting of copper, cobalt, rhodium, iridium, ruthenium and palladium under conditions sufficient to convert the N_2O into gaseous nitrogen and gaseous oxygen.

By way of exemplification and not limitation, another such method and/or means for reducing N_2O emissions is that to which U.S. Patent No. 5,325,796 entitled "Process For Decreasing N_2O Emissions From A Fluidized Bed Reactor", which issued on July 5, 1994 and which is assigned to Foster Wheeler Energy Corporation, is directed. In accordance with the teachings of U.S. Patent No. 5,325,796, emissions of nitrous oxide (N_2O) are lowered utilizing two-staged combustion. To this end, in accordance with the teachings of U.S. Patent No. 5,325,796, on the one hand a lower region of the furnace section of the fluidized bed reactor is operated under substoichiometric conditions so that combustion in the lower region is incomplete, thereby inhibiting formation of N_2O and nitrogen oxides (NO_x). On the other hand an upper region of the furnace section of the fluidized bed reactor is operated under oxidizing conditions to promote further combustion. Furthermore, an amount of particulate material is present in this upper region, and this amount of particulate material in the upper region is controlled to maintain a temperature in the upper region for destroying N_2O formed during combustion.

By way of exemplification and not limitation, yet another such method and/or means for reducing N_2O emissions is that to which U.S. Patent No. 5,344,629 entitled "Reducing N_2O Emissions", which issued on September 6, 1994 and which is assigned to A. Ahlstrom Corporation, is directed. In accordance with the teachings of U.S. Patent No. 5,344,629, the amount of N_2O in flue gases discharged from a fluidized bed combustion system is minimized by effecting vigorous and intimate mixing of the flue gases (with entrained particles) from a fluidized bed by increasing the velocity of the flue gases and then decreasing the velocity from the increased level, introducing a N_2O decomposing catalyst such as CaO or limestone into the flue gases and particles immediately after increasing and decreasing of the velocity, and mixing the N_2O catalyst with the flue gases and particles, to effect decomposition of the N_2O.

By way of exemplification and not limitation, yet still another such method and/or means for reducing N_2O emissions is that to which U.S. Patent No. 5,378,443 entitled "Method For Reducing Emissions When Burning Nitrogen Containing Fuels", which issued on January 3, 1995 and which is assigned to A. Ahlstrom Corporation, is directed. In accordance with the teachings of U.S. Patent No. 5,378,443, a method for reducing the emissions of N_2O in flue gases from the combustion of nitrogen containing fuel in a fluidized bed combustor is provided. The subject method for reducing the emissions of N_2O in flue gases comprises the steps of (a) supplying nitrogen containing fuel and an oxygen containing gas for combustion of the fuel in the combustion stage of the combustor; (b) maintaining a temperature of about 700 degrees C. to 1000 degrees C. in the combustion stage; (c) supplying a Ca-based sulfur absorbent to the combustor for reducing sulfur emissions in flue gases; (d) discharging flue gases from the combustor; (e) removing particles from the flue gases, and passing the flue gases with removed particles to a reactor stage; (f) in the reactor stage, introducing an N_2O decomposing catalyst into the flue gases without significantly raising the temperature of the flue gases; and (g) discharging the flue gases with the N_2O therein decomposed from the reactor stage.

Last but not least with regard to such methods and/or means for reducing N_2O emissions reference is further had to the prior art and in particular to U.S. Patent No. 5,048,432, European Patent Application EP 0 406 185 and German Patent Application DE 39 33 286, all of which contain teachings wherein it is suggested to raise the temperature of flue gases to a level above 900 degrees C. for reducing N_2O emissions.

Although the aforereferenced prior art methods and/or means for reducing N_2O emissions are alleged to be operative for their intended purposes, nevertheless there still exists a need for a new and improved method for reducing N_2O emissions. In particular, there has been shown to exist a need for such a new and improved method for reducing N_2O emissions, which is not dependent on the use of a catalyst, and as such is not disadvantageously characterized either by the added expense of procuring catalytic agents or the added expense of designing a system capable of delivering a catalytic agent to the combustion process or the added complexity of operating a steam generator that is occasioned by the need to utilize a catalytic agent.

It is, therefore, an object of the present invention to provide a new and improved method for reducing N_2O emissions.

It is another object of the present invention to provide such a new and improved method for reducing N_2O emissions, which is particularly suited for effecting therewith the reduction of N_2O emissions from a circulating fluidized bed steam generator (CFB).

It is still another object of the present invention to provide such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction of N_2O emissions is achievable therewith without at the same time increasing either the level of NO_x emissions or the level of SO_x emissions from the circulating fluidized bed steam generator (CFB).

Another object of the present invention is to provide such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction of N_2O emissions is achievable therewith while at the same time the overall operating efficiency of the circulating fluidized bed steam generator (CFB) is still maintained and while at the same time the stoichiometric ratio of the combustion process of the circulating fluidized bed steam generator (CFB) is also still maintained.

A still another object of the present invention is to provide such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction of N_2O emissions is achievable therewith while concomitantly it is possible to reduce the required surface area of the superheater and/or reheater and/or the economizer that are located in the backpass volume of the circulating fluidized bed steam generator (CFB).

A further object of the present invention is to provide such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction of N_2O emissions is achievable therewith while concomitantly it is possible to reduce the volume required by the backpass volume of the circulating fluidized bed steam generator (CFB).

Yet another object of the present invention is to provide such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction of N_2O emissions is achievable therewith in such a manner that the operational versatility of the circulating fluidized bed steam generator (CFB) is enhanced in that the cyclone cooperatively associated therewith is operative as a separator for effecting therewithin separation of entrained solids from flue gases and as a combustor within which combustion can take place.

Yet still another object of the present invention is to provide such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that the reduction of N_2O emissions is achievable therewith without requiring either the added expense or the added complexity that is inherently associated with the use of catalytic agents for purposes of effecting the reduction of N_2O emissions.

SUMMARY OF THE INVENTION

In accordance with the present invention there is provided a method for reducing N_2O emissions and in particular N_2O emissions from a circulating fluidized bed steam generator (CFB). The subject method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB) is operative wherein through the appropriate distribution of air with which the combustion of hydrocarbon fuel is effected and/or through the selective sizing of the particles of hydrocarbon fuel, which is subjected to combustion, it is possible with the subject method to have afterburning occur under controlled conditions within the cyclone, which is cooperatively associated with the furnace volume of the circulating fluidized bed steam generator (CFB) whereby as a consequence of such afterburning a reduction is realized in the level of N_2O emissions while concomitantly therewith NO_x emissions and SO_x emissions are maintained at acceptable levels.

Continuing, as a consequence of shifting upward the vertical distribution of the air with which the combustion of the hydrocarbon fuel is effected, the combustion of the hydrocarbon fuel is delayed as the hydrocarbon fuel traverses the furnace volume of the circulating fluidized bed steam generator (CFB). As such, the lower segment of the furnace volume of the circulating fluidized bed steam generator (CFB) is operated under substoichiometric or fuel rich conditions while the upper segment of the furnace volume of the circulating fluidized bed steam generator (CFB) is operated under oxidizing or fuel lean conditions. This results in a lower overall furnace temperature as well as a vertical temperature gradient within the furnace volume of the circulating fluidized bed steam generator (CFB) such that the temperature of the upper segment of the furnace volume of the circulating fluidized bed steam generator (CFB) exceeds that of the lower segment of the furnace volume of the circulating fluidized bed steam generator (CFB). Also, because of the afterburning, which takes place within the cyclone that is cooperatively associated with the furnace volume of the circulating fluidized bed steam generator (CFB), the temperature differential is increased between the hot combustion gases at the exit of the furnace volume of the circulating fluidized bed steam generator (CFB) and the exit of the aforesaid cyclone. Moreover, because of the increased temperature at which afterburning occurs, the N2O that is formed within the circulating fluidized bed steam generator (CFB) is reduced. Furthermore, this reduction in N_2O emissions is accomplished while NO_x emissions and SO_x emissions are maintained at acceptable levels due to the lower temperature within the furnace volume of the circulating fluidized bed steam generator (CFB).

In accordance with the subject method of the present invention, it is also possible therewith to achieve a similar effect, as that attainable through the aforedescribed distribution of air, by decreasing the particle size of the hydrocarbon fuel, which is combusted within the circulating fluidized bed steam generator (CFB). To this end, a lighter weight particle of hydrocarbon fuel is more quickly blown toward the upper segment of the furnace volume of the circulating fluidized bed steam generator (CFB) thereby resulting in insufficient time for the particles of hydrocarbon fuel to entirely combust by the time the particle of hydrocarbon fuel has completed its traverse of the furnace volume of the circulating fluidized bed steam generator (CFB). Rather, combustion of the particle of hydrocarbon fuel is more likely to take place between the exit of the furnace volume of the circulating fluidized bed steam generator (CFB) and the exit of the cyclone cooperatively associated with the furnace volume of the circulating fluidized bed steam generator (CFB) thereby raising the temperature between the aforesaid exit of the furnace volume and the aforesaid exit of the cyclone with a concomitant reduction being had in the level of N_2O emissions from the circulating fluidized bed steam generator (CFB).

In addition to being operative to accomplish the foregoing, the subject method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB) is also advantageously characterized in that such reduction of N_2O emissions is achievable therewith while at the same time the overall operating efficiency of the circulating fluidized bed steam generator (CFB) is still maintained and while at the same time the stoichiometric ratio of the combustion process of the circulating fluidized bed steam generator (CFB) is also still maintained. Furthermore, the subject method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB) is additionally characterized in that due to the higher flue gas temperature at the exit of the cyclone cooperatively associated with the furnace volume of the circulating fluidized bed steam generator (CFB), it is possible with the subject method of the present invention both to effect reduction of N_2O emissions therewith while concomitantly effecting a reduction in the required surface area of the superheater and/or the reheater and/or the economizer that are provided in the backpass volume of the circulating fluidized bed steam generator (CFB) as well as in the volume required for the backpass volume itself.

BRIEF DESCRIPTION OF THE DRAWING

The drawing is a schematic representation in the nature of a side elevational view of a circulating fluidized bed steam generator (CFB) including a furnace volume, a cyclone section cooperatively associated with the furnace volume, and a backpass volume cooperatively associated with the cyclone section, along with interconnecting ductwork and pipework, constructed in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawing, there is depicted therein a circulating fluidized bed steam generator (CFB), generally designated by the reference numeral 2. As illustrated in the drawing, the circulating fluidized bed steam generator 2 includes a furnace volume, denoted therein by the reference numeral 4, the latter being defined by waterwall tubes, denoted therein by the reference numeral 4a; a first section of ductwork, denoted therein by the reference numeral 6; a cyclone section, denoted therein by the reference numeral 8; a second section of ductwork, denoted therein by the reference numeral 10; a backpass volume, denoted therein by the reference numeral 12, from which ductwork, denoted therein by the reference numeral 12a, extends.

With further reference to the drawing it will be readily apparent therefrom that the upper segment, denoted therein by the reference numeral 8b, of the cyclone 8 is connected in fluid flow relation with the upper segment of the furnace volume 4 by means of the first section of ductwork 6. Also, it will be readily apparent from a reference to the drawing that the lower segment, denoted by the reference numeral 8c, of the cyclone 8 is connected in fluid flow relation with the lower segment of the furnace volume 4 by means of pipework, which in accordance with the illustration thereof in the drawing consists of a seal pot, denoted therein by the reference numeral 14 and a hot solids inlet, denoted therein by the reference numeral 16.

For purposes of the discussion that follows the flow path, which extends from the furnace volume 4 through the first section of ductwork 6 and through the cyclone 8 and the pipework 14,16, and returning to the lower segment of the furnace volume 4, will be referred to hereinafter as the hot solids circulation path 4, 6, 8, 14, 16, 4. Also, for purposes of the discussion that follows the flow path, which begins at the furnace exit, denoted in the drawing by the reference numeral 4c, and which continues through the first section of ductwork 6 and through the upper segment 8b of the cyclone 8, and which terminates at the cyclone exit, denoted in the drawing by the reference numeral 8a, will be referred to hereinafter as the afterburning volume 4c, 6, 8b, 8a.

Continuing, in accordance with conventional practice and as will be readily apparent from a reference to the drawing, the furnace volume 4 is supplied with a mixture of fuel and sorbent, denoted in the drawing by the reference numeral 28, and a first source of air, denoted in the drawing by the reference numeral 24. In addition, the furnace volume 4 is also supplied with a second source of air, denoted in the drawing by the reference numeral 26, and a third source of air, denoted in the drawing by the reference numeral 30. The first source of air is fed through an air distributor, denoted in the drawing by the reference numeral 4c, to the lower segment of the furnace from therebeneath. Furthermore, the second source of air 26 and the third source of air 30, in accordance with the illustration thereof in the drawing, are suitably arranged relative to each other such that the third source of air 30 is located above the second source of air 26 and such that the mixture of fuel and sorbent 28 is interposed between the second source of air 26 and the third source of air 30.

With further regard to the drawing, it will be understood from reference thereto that in the lower segment of the furnace volume 4 the mixture of fuel and sorbent 28 is combusted in the presence of a combination of the first air 24, the second air 26 and the third air 30. In known fashion, from this combustion hot combustion gases, denoted in the drawing by the reference numeral 32, are produced and hot solids, denoted in the drawing by the reference numeral 34, are entrained in the hot combustion gases 32. These hot combustion gases 32 with the hot solids 34 entrained therewith rise within the furnace volume 4 giving up heat to the waterwall tubes 4a whereby steam is evaporatively produced therewithin. At the top of the furnace volume 4 the hot combustion gases 32 with the hot solids 34 entrained therewith are made to flow through the first section of ductwork 6 to the cyclone 8. Within the cyclone 8, the hot solids 34 that are made to flow thereto, which are above a predetermined size, are separated from the hot combustion gases 32 in which the hot solids 34 are entrained. The separated hot solids 34, which contain unburned fuel, flyash and sorbent flow through the cyclone. From the cyclone 8 the hot solids 34 are discharged under the influence of gravity into the seal pot 14. Thereafter, from the seal pot 14, the hot solids 34 are reintroduced into the lower segment of the furnace volume 4 by means of the hot solids inlet 16 whereupon the hot solids 34 are once again subjected to the combustion process that takes place in the circulating fluidized bed steam generator 2.

Continuing, on the other hand the hot combustion gases 32 leaving the cyclone 8, hereinafter referred to as flue gases, are directed by means of the second section of ductwork 10 from the cyclone 8 to the backpass volume 12 of the circulating fluidized bed steam generator 2. As the flue gases 32 traverse the backpass volume 12 additional heat transfer duty is performed therewith in accordance with a predetermined thermodynamic steam cycle relative to the heat transfer surfaces, e.g., the superheater, the reheater and the economizer, denoted by the reference numerals 18, 20, 22, respectively, which are suitably located for this purpose in the backpass volume 12. From the backpass volume 12 the flue gases 32 exit through the ductwork 12a to a particulate removal system (not shown in the interest of maintaining clarity of illustration in the drawing) whereupon the flue gases 32 are discharged to the atmosphere through a stack (not shown in the interest of maintaining clarity of illustration in the drawing).

In accordance with the normal operating conditions, i.e., for a given fuel and a given fuel particle size, of the circulating fluidized bed steam generator 2, the total amount of air supplied to the furnace volume 4 by the second source of air 26 and the third source of air 30 is ordinarily evenly distributed therebetween such that the furnace volume 4 is subjected to certain prescribed stoichiometric conditions. To this end, such prescribed stoichiometric conditions are designed to produce an essentially constant temperature of between approximately 1550 degrees F. and 1600 degrees F. throughout the furnace volume 4. It is also the desired intent that this temperature be essentially constant throughout the hot solids circulation path 4, 6, 8, 14, 16, 4, to which reference previously has been had herein. Relative to the foregoing, it may be possible that afterburning may occur to a very slight extent between the furnace exit 4c and the cyclone exit 8a. The term afterburning as employed herein is meant to refer to the combustion of unburned fuel, which occurs within the afterburning volume 4c, 6, 8b, 8a, to which reference previously has been had herein. Inasmuch as there is no means available for the transfer of the heat that is generated, should such afterburning occur, during such afterburning, the temperature of the flue gases 32 at the cyclone exit 8a will as a consequence of such afterburning slightly exceed the temperature of the hot combustion gases 32 at the furnace exit 4c.

If the distribution of the air 26, 30 is such that the amount of the third source of air 30, which is injected into the furnace volume 4, is greater than the amount of the second source of air 26, which is injected into the furnace volume 4, completion of the combustion of the fuel 28 will be delayed as the fuel 28 traverses the furnace volume 4. As a consequence of such distribution of the air 26, 20 the lower segment of the furnace volume 4 will be operated under substoichiometric conditions and the upper segment of the furnace volume 4 will be operated under oxidizing conditions. Moreover, this will result in a lowering of the overall furnace temperature as well as a lowering of the temperature gradient within the furnace volume 4 such that the temperature within the upper segment of the furnace volume 4 is greater than within the lower segment of the furnace volume 4. Furthermore, such distribution of the air 26, 30 also results in an increase in the amount of afterburning that occurs between the furnace exit 4c and the cyclone exit 8a. This is because of the fact that completion of the combustion of the fuel 28 now takes place within the afterburning volume 4c, 6, 8b, 8a, to which reference previously has been had hereinbefore, rather than in the furnace volume 4 as is customary in accordance with the conventional mode of operation of circulating fluidized bed steam generators (CFB). Consequently, there is an increase in the temperature differential that would otherwise exist between the temperature of the hot combustion gases at the furnace exit 4c and the temperature of the flue gases at the cyclone exit 8a. From the foregoing discussion it can thus be seen that by manipulating the distribution of air 26, 30, it is possible to effect therefrom a reduction in N_2O emissions by increasing the temperature of the flue gases 32 prior to the flue gases 32 being discharged from the cyclone exit 8a. Moreover, this can be achieved while concomitantly the temperature of the hot combustion gases 32 at the furnace exit 4c is lowered such that by virtue of such lowering of the temperature NO_x emissions and SO_x emissions are maintained at acceptable levels.

In addition, it is also possible to lower N_2O emissions for a given fuel 28 and a given distribution of the air 26, 30 through controlled afterburning that is effected by manipulating the particle size of the fuel, which is intended to be subjected to combustion within the circulating fluidized bed steam generator 2. To this end, by reducing the particle size of the fuel, the effect thereof is that the lighter weight particles of fuel, i.e., the fuel particles of smaller size, will become more quickly entrained within the hot combustion gases 32, and thus will reach the upper segment of the furnace volume 4 before combustion thereof takes place. Consequently, completion of the combustion of the fuel 28 is delayed as the fuel 28 traverses the furnace volume 4. Therefore, combustion of the fuel 28 is not completed within the furnace volume 4. Instead, completion of the combustion of the fuel 28 occurs after the fuel 28 leaves the furnace exit 4c and before the fuel 28 reaches the cyclone exit 8a. It can thus be seen from the foregoing discussion that insofar as effecting the reduction of N_2O emissions is concerned, manipulation of fuel particle size has the same effect as that which is achievable from a shifting of the distribution of the air 26, 30 as described herein in the preceding paragraph. To this end, the overall temperature of the furnace volume 4 is reduced and the temperature differential between the temperature of the flue gases 32 at the cyclone 8a and the temperature of the hot combustion gases 32 at the furnace exit 4c is increased by virtue of the afterburning, which takes place between the furnace exit 4c and the cyclone exit 8a. Thus, it can be seen that by manipulating the particle size of the fuel 28, it is possible to effect therefrom a reduction in N_2O emissions by increasing the temperature of the flue gases 32 prior to the flue gases being discharged from the cyclone exit 8a. Moreover, this is achievable while concomitantly the temperature of the hot combustion gases 32 at the furnace exit 4c is lowered such that by virtue of such lowering of the temperature NO_x emissions and SO_x emissions are maintained at acceptable levels.

Although as has been set forth in the foregoing discussions, it is possible in accordance with the present invention to effect a reduction in N_2O emissions from the circulating fluidized bed steam generator 2 entirely as a result of manipulating the distribution of the air 26, 30 such that the amount of the third source of air 30 that is injected into the furnace volume 4 is greater than the amount of the second source of air 26 that is injected into the furnace volume 4 and also entirely as a result of manipulating the particle size of the fuel that is to be subjected to combustion, it is to be understood that N_2O emissions may in addition be reduced in accordance with the present invention by manipulating together in combination both the distribution of the air 26, 30 and the particle size of the fuel.

Note is also made herein of a further benefit that is derivable from the present invention. To this end, by virtue of the fact that the temperature of the flue gases 32 at the cyclone exit 8a is increased in accordance with the present invention, more useful energy in the form of heat is, therefore, available in the flue gases 32. Moreover, this additional heat energy embodied in the flue gases 32 is capable of being transferred to the superheat, reheat and economizer surfaces 18, 20, 22, respectively, that are located in the backpass volume 12 of the circulating fluidized bed steam generator 2. Thus, for purposes of the heat transfer duty that is required to be performed thereby, the area of the superheat, reheat and economizer surfaces 18, 20, 22, respectively, that is necessary to effect therewith the required amount of heat transfer duty can be reduced. Consequently, in accordance with the present invention, in addition to the superheat, reheat and economizer surfaces 18, 20, 22, respectively, being reduced the backpass volume 12 may also be reduced with attendant cost savings being realizable from the reduction in the superheat, reheat and economizer surfaces 18, 20, 22, respectively, and/or from the reduction in the backpass volume 12.

Note is further made herein of the fact that notwithstanding the distribution of the air 26, 30 and the particle size of the fuel 28 being manipulated, either separately or in combination to effect therefrom a reduction in the N_2O emissions from the circulating fluidized bed steam generator 2, the overall stoichiometry of the combustion process remains unchanged. This is by virtue of the fact that the same amount of fuel 28 and the same amount of air 24, 26, 30 is still being utilized. Consequently, the overall efficiency of the circulating fluidized bed steam generator 2 also remains unchanged. Therefore, it is possible in accordance with the present invention to enhance the operational versatility of the circulating fluidized bed steam generator 2 without affecting the critical operating parameters thereof, e.g., the overall efficiency thereof, the levels of NO_x emissions and SO_x emissions therefrom, etc.

Thus, in accordance with the present invention there has been provided a new and improved method for reducing N_2O emissions. Besides, there has been provided in accord with the present invention such a new and improved method for reducing N_2O emissions, which is particularly suited for effecting therewith the reduction of N_2O emissions from a circulating fluidized bed steam generator (CFB). Moreover, in accordance with the present invention there has been provided such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction of N_2O emissions is achievable therewith without at the same time increasing either the level of NO_x emissions or the level of SO_x emissions from the circulating fluidized bed steam generator (CFB). Also, there has been provided in accord with the present invention such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction in N_2O emissions is achievable therewith while at the same time the overall operating efficiency of the circulating fluidized bed steam generator (CFB) is still maintained and while at the same time the stoichiometric ratio of the combustion process of the circulating fluidized bed steam generator (CFB) is also still maintained. Further, in accordance with the present invention there has been provided such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction of N_2O emissions is achievable therewith while concomitantly it is possible to reduce the required surface area of the superheater and/or the reheater and/or the economizer that are located in the backpass volume of the circulating fluidized bed steam generator (CFB). Moreover, there has been provided in accord with the present invention such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction of N_2O emissions is achievable therewith while concomitantly it is possible to reduce the volume required by the backpass volume of the circulating fluidized bed steam generator (CFB). Penultimately, in accordance with the present invention there has been provided such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that such reduction of N_2O emissions is achievable therewith in such a manner that the operational versatility of the circulating fluidized bed steam generator (CFB) is enhanced in that the cyclone cooperatively associated with the furnace volume of the circulating fluidized bed steam generator (CFB) is operative as a separator for effecting therewithin the separation of entrained solids from flue gases and as a combustor within which combustion can take place. Finally, there has been provided in accord with the present invention such a new and improved method for reducing N_2O emissions from a circulating fluidized bed steam generator (CFB), which is characterized in that the reduction of N_2O emissions is achievable therewith without requiring either the added expense or the added complexity that is inherently associated with the use of catalytic agents for purposes of effecting the reduction of N_2O emissions.

While only one embodiment of our invention has been shown, it will be appreciated that modifications thereof, some of which have been alluded to hereinabove, may still be readily made thereto by those skilled in the art. We, therefore, intend by the appended claims to cover the modifications alluded to herein as well as the other modifications that fall within the true spirit and scope of our invention.

Claims

1. In a circulating fluidized bed steam generator including a furnace volume having an exit therefrom provided at at least one end thereof, a cyclone operative as both a separator and a combustor and having an exit therefrom provided at at least one end thereof, a backpass volume embodying therewithin heat transfer surfaces, first conduit means connecting the furnace volume in fluid flow relation with the cyclone, and second conduit means connecting the cyclone in fluid flow relation with the backpass volume, the improvement of a method for controlling N_2O emissions from the circulating fluidized bed steam generator, said method for controlling N_2O emissions from the circulating fluidized bed steam generator comprising the steps of :

   a. injecting fuel of a predetermined size into the furnace volume;
   b. injecting from beneath the furnace volume air from a first source thereof into the furnace volume;
   c. injecting air from a second source thereof into the furnace volume below the point of injection of the fuel into the furnace volume;
   d. injecting air from a third source thereof into the furnace volume above the point of injection of the fuel into the furnace volume;
   e. effecting partial combustion of the fuel within the furnace volume causing flue gases and hot solids to be generated as a consequence of such partial combustion of the fuel;
   f. delaying the remainder of the combustion of the fuel until the fuel has passed beyond the exit of the furnace volume; and
   g. effecting completion of the remainder of the combustion of the fuel between the exit of the furnace volume and the exit of the cyclone so as to produce a temperature therefrom operative to effect a reduction in N_2O emissions.

2. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 1 wherein the partial combustion of the fuel within the furnace volume is effected so as to produce a temperature therefrom low enough to maintain NO_x emissions and SO_x emissions from the circulating fluidized bed steam generator at acceptable levels.

3. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 2 wherein the delay in effecting the combustion of the remainder of the fuel is occasioned by the manipulation of the distribution of air injected into the furnace volume from the second source of air and from the third source of air.

4. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 3 wherein the amount of air injected into the furnace volume from the third source of air is greater than the amount of air injected into the furnace volume from the second source of air.

5. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 2 wherein the delay in effecting the combustion of the remainder of the fuel is occasioned by the manipulation of the particle size of the fuel.

6. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 2 wherein the delay in effecting the combustion of the remainder of the fuel is occasioned both by the manipulation of the distribution of air injected into the furnace volume from the second source of air and from the third source of air and by the manipulation of the particle size of the fuel.

7. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 2 wherein the air injected into the furnace volume from a first source of air is injected into the furnace volume through an air distribution means.

8. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in

Claim 2 further comprising the step of maintaining the desired overall efficiency of the circulating fluidized bed steam generator.

9. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 2 further comprising the step of maintaining the desired stoichiometric ratio of the combustion process occurring within the circulating fluidized bed steam generator.

10. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 2 wherein the cyclone is operative to effect therewithin the separation from the flue gases of the hot solids entrained therewith.

11. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 2 wherein the cyclone is operative to effect the combustion of the remainder of the fuel therewithin.

12. In a circulating fluidized bed steam generator, the method of controlling N_2O emissions from a circulating fluidized bed steam generator as set forth in Claim 2 wherein the cyclone is operative both to effect therewithin the separation from the flue gases of the hot solids entrained therewith and to effect the combustion of the remainder of the fuel therewithin.

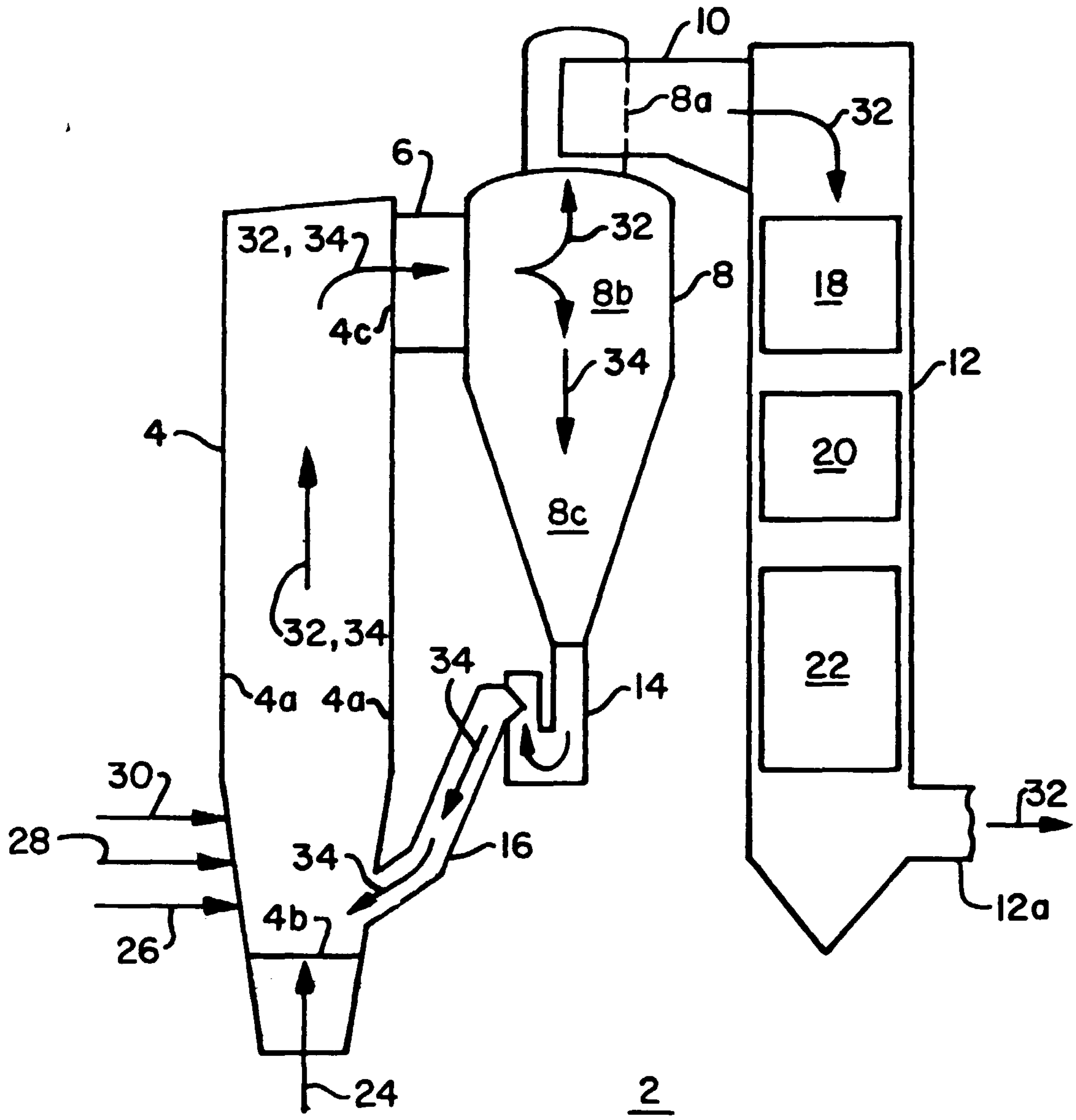
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Fig. 1