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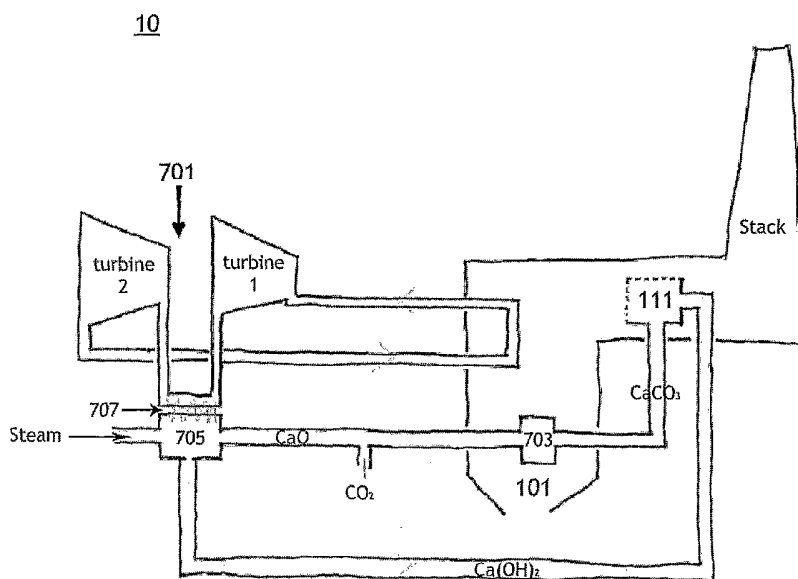
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(54) Title: METHODS AND SYSTEMS FOR REDUCING EMISSIONS



(57) Abstract: The present invention relates to method and systems for reducing emission of carbon dioxide, hi certain embodiments, the invention relates a reduced carbon dioxide emission kiln. Other embodiments of the invention relate to heat exchangers utilizing lime, slaked lime, and limestone. The invention also relates to methods for increasing efficiency of combustion sytems and methods for capturing carbon dioxide from combustion systems to reduce carbon dioxide emission.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

METHODS AND SYSTEMS FOR REDUCING EMISSIONS

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FIELD OF THE INVENTION

[0002] The invention relates to methods and systems for reducing emissions. In certain embodiments, the invention relates to kilns having reduced emissions. The invention also relates to methods and systems for improving the efficiency of a combustion system. The invention further relates to methods and systems for capturing carbon dioxide from a combustion system.

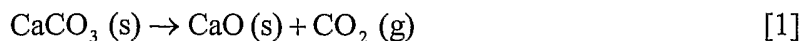
CROSS-REFERENCE TO RELATED APPLICATION

[0003] The present application claims the benefit of U.S. Patent Application No. 60/672,279, filed on April 18, 2005, the content of which is hereby incorporated by reference herein in its entirety.

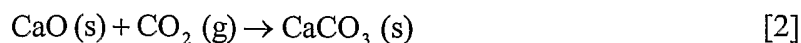
BACKGROUND OF THE INVENTION

[0004] Climate change concerns have resulted in the need for reduced carbon dioxide emissions. For example, the lime and cement industries are responsible for approximately 5% of global carbon dioxide emissions. Of these emissions, about 50% arise from the chemical liberation of carbon dioxide bound in carbonates and 40% from fuel consumption.

[0005] Lime is manufactured from limestone and dolomite by heating these materials in a limekiln, and this process results in the evolution of carbon dioxide. This reaction shown in Equation [1], and is termed the calcination reaction. It is also part of the cement making process.



[0006] Combustion of carbonaceous fuel is another example where reduction of carbon dioxide emissions is desired. Currently, to reduce carbon dioxide emissions, lime is utilized to convert the carbon dioxide into limestone as shown in Equation [2]



Then, limestone is fired and converted back into lime as shown Equation [1] and this cycle repeats. However, after repeated cycling, sintering of the lime occurs and its capacity to capture carbon dioxide is greatly reduced.

[0007] It would be environmentally advantageous to develop methods and systems by which the carbon dioxide emissions could be minimized or completely eliminated. As such, a need remains in the art for methods and systems having dramatically reduced carbon dioxide emissions. The present invention addresses this need.

SUMMARY OF THE INVENTION

[0008] The invention relates to methods and systems for reducing carbon dioxide emission.

[0009] In certain embodiments, the invention relates to reduced carbon dioxide emission kilns having a calcination zone for converting limestone into lime and carbon dioxide gas; an oxygen inlet; and a fuel inlet. The heat carbon dioxide can be recycled back into the kiln via and/or it can be captured to reduce the carbon dioxide emission.

[0010] In certain embodiments, the invention relates to heat-exchange systems having a heat-release zone for reacting lime and steam to generate slaked lime in an exothermic process; and a heat-absorption zone that is heated by a heat source to transform the slaked lime back into lime and steam. The lime and steam produced in the heat-absorption zone can be recycled back into the heat release zone. The heat generated in the exothermic process may be utilized to dry fuel entering a combustion system or to increase the efficiency of one or more power generating systems. For example, the power generating system can be a turbine power plant for generating electricity and the heat generated in the exothermic process can be utilized to heat feedwater for driving one or more turbines of the turbine power plant.

[0011] In other embodiments, the invention relates to methods for improving the efficiency of a combustion system. The methods of the invention can include (a) combining lime and steam to form slaked lime in an exothermic process; (b) utilizing heat generated by the exothermic process to increase the efficiency of the combustion system or to increase the efficiency of a different power generating system (e.g., to heat feedwater for driving one or more turbines in a turbine power plant); (c) utilizing a heated exhaust gas from the combustion system to heat the slaked lime generated in step (a), resulting in the formation of lime and steam; and (d) utilizing the lime and steam generated in step (c) to repeat the

process of step (a). In certain embodiments, the combustion system can be at a temperature greater than 500 °C. In other embodiments, the heat generated by the exothermic process can be utilized to dry solids entering the combustion system.

[0012] In some other embodiments, the invention relates to methods for capturing carbon dioxide from a combustion system. The methods of the invention can include (a) contacting carbon dioxide from an exhaust gas of the combustion system with slaked lime to form limestone; (b) heating the limestone to form lime and carbon dioxide; and (c) capturing the carbon dioxide generated in step (b).

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 shows a process schematic diagram of methods and systems for combusting carbonaceous fuel with reduced emissions in accordance with certain embodiments of the invention;

[0014] FIG. 2 shows a process schematic diagram of methods and systems for exchanging heat in accordance with certain embodiments of the invention;

[0015] FIG. 3 shows a graph of the mass loss that occurs as slaked lime ($\text{Ca}(\text{OH})_2$) is heated in a heat absorption zone in accordance with certain embodiments of the invention;

[0016] FIG. 4 shows a graph of the mass increase that occurs when lime (CaO) and slaked lime ($\text{Ca}(\text{OH})_2$) are contacted with carbon dioxide (CO_2) in accordance with certain embodiments of the invention;

[0017] FIG. 5 shows a process schematic diagram of a reduced emission kiln in accordance with certain embodiments of the invention;

[0018] FIG. 6 shows a graph comparing the conversion of lime (CaO) and slaked lime ($\text{Ca}(\text{OH})_2$) into limestone in accordance with certain embodiments of the invention; and

[0019] FIG. 7 shows another process schematic diagram of methods and systems for combusting carbonaceous fuel with reduced emissions in accordance with certain embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Definitions

[0020] The term “lime” as used herein refers to a material predominantly composed of CaO.

[0021] The term “slaked lime” as used herein refers to a material predominantly composed of Ca(OH)₂.

[0022] The term “limestone” as used herein refers to a material predominantly composed of CaCO₃. For example, the term “limestone” may refer to a material having CaCO₃ and MgCO₃ (dolomite).

[0023] The terms “reduced carbon dioxide emission kiln” and related term as used herein can include a kiln wherein the kiln’s total carbon dioxide emissions into the environment outside of the kiln are less than about 1% or 10,000 ppm of the total gas in the system. In various embodiments, the kiln releases about 10,000 ppm, about 1,000 ppm, about 100 ppm, about 10 ppm, 9 ppm, about 8 ppm, about 7 ppm, about 6 ppm, about 5 ppm, about 4 ppm, about 3 ppm, about 2 ppm, about 1 ppm, or about 0 ppm of carbon dioxide into the environment outside of the kiln. In a specific embodiment, the kiln does not release any carbon dioxide into the environment outside of the kiln.

[0024] The term “carbonaceous fuel” as used herein can include, but are not limited to, coal, fuel oil, natural gas, petro-coke, waste oil, a gaseous hydrocarbon, such as methane, ethane, propane or butane, tires, or biomass.

Combustion System 10

[0025] As shown in **FIG. 1**, a combustion system **10**, such as a carbonaceous fuel combustion system, may contain a combustion zone **101** for burning carbonaceous fuel. For example, the combustion system **10** may be a boiler where the combustion zone **101** is heated to temperatures greater than about 1000 °C. As the carbonaceous fuel burns, solid ash may be created and removed from the bottom of the combustion zone **101**. Burning of the carbonaceous fuel can further generate a heated gas stream **102** that contains carbon dioxide, fly ash, and other contaminants (such as sulfur dioxide (SO₂) gas). The heated gas stream **102** may indirectly heat pipes **103** containing, for example, steam, which can then drive one or more turbines (not shown) to generate power, such as electricity. From the combustion zone **101**, gas stream **102** can pass through a particle separator **105**, heat-exchange system **107**, contaminant removal system **109**, and carbon dioxide capture system **111**.

Particle Separator 105

[0026] Particle separator **105** may be any suitable particle separator capable of removing particulate matters, such as fly ash. For example, particle separator **105** may be an electrostatic precipitator or filters.

Heat-Exchange System 107

[0027] In certain embodiments, the invention provides a heat-exchange system **107** useful for improving the efficiency of a combustion system. For example, heat-exchange system **107** may further extract additional heat that was not extracted through pipes **103** and used for any desired processes as described herein.

[0028] As shown in **FIG. 2**, heat-exchange system **107** may be based on a calcium-driven heat-exchange process. First, gas stream **102** may indirectly contact or pass over a heat absorption zone **201** (e.g., made of tubes) that contains steam and slaked lime. For example, gas stream **102** can initially be at a temperature above about 500 °C, 550 °C, 600 °C, 700 °C, 800 °C, or 900 °C. Heat from gas stream **102** may be transferred to heat absorption zone **201** and slaked lime can be converted to lime and steam as shown in Equation [3].



[0029] In certain embodiments, the temperature of the resulting lime and/or steam may be above about 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 550 °C, 600 °C, 700 °C, 800 °C, or 900 °C. In certain embodiments, heat absorption zone **201** may absorb up to about 100 % of the heat from gas stream **102**.

[0030] Heat-exchange system **107** can further contain a heat release zone **203**, wherein lime and steam obtained from reaction [3] combine to form slaked lime in an exothermic process as shown in Equation [4].



The heat generated by the exothermic process can be used elsewhere in the system and can be transported via one or more heat exchangers **205**.

[0031] Moreover, the slaked lime generated in the heat release zone **203** can be recycled into the heat absorption zone **201** and the reactions shown in Equations [3] and [4] can be continuously repeated.

[0032] In certain embodiments, heat-exchange system 107 can be integrally incorporated within the combustion system 10. For example, gas stream 102 may pass over heat absorption zone 201 and the heat generated by the exothermic process of Equation [4] can be utilized to dry solids entering the combustion system 10. Moreover, the heat generated by the exothermic process of Equation [4] can be utilized to heat the feedwater to drive the one or more turbines for generating electricity.

[0033] In other embodiments, the heat absorption zone 201, heat release zone 203, and heat exchangers 205 is not necessarily limited as a component of the combustion system 10 and may be embodied as a separate component that may be used in any suitable systems or processes. For example, any heat containing substance may be contact or pass over the heat absorption zone 201 and the heat generated by the exothermic process of Equation [4] can be utilized in any desired process, such as to heat feedwater for another process.

[0034] In one embodiment, the calcium-driven heat exchanger and methods for improving the efficiency of a combustion system can be used to improve the efficiency of a Fischer-Tropsch process.

[0035] FIG. 3 shows an experimental graph of the mass loss that occurs as slaked lime is heated under nitrogen conditions to demonstrate the feasibility of the heat absorption zone 201. As shown, a concomitant drop in mass begins about 400 °C. This drop may correspond the onset of reaction shown in Equation [3], after which the mass stays relatively constant. It should be noted that at about 700-750 °C, a smaller, albeit noticeable, drop in mass occurs, which may correspond to a reaction that occurs on limestone that may have been present initially in the sample (FIG. 3 further shows a similar mass loss of pure limestone around 700 °C).

Contaminant Removal System 109

[0036] Contaminant removal system 109 may be any suitable system capable of removing or capturing contaminants, such as sulfur dioxide. For example, dry sorbent scrubbers or lime spraying can be utilized.

[0037] In dry sorbent scrubbers, limestone pellets can be introduced to the top of a tank where the surface of the limestone pellets reacts with contaminants (e.g. sulfur dioxide) contained in gas stream 102. The reacted pellets can fall down into a hopper and then fed into a device that scrapes the reacted outside layer of the limestone pellets. The regenerated limestone pellet can be fed back to the top of the tank and the scrubbing may be repeated.

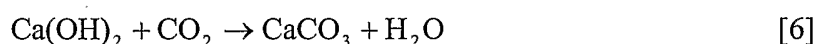
[0038] In lime spraying, powdered lime, either in the dry state or mixed with water to form a paste, can be used. The lime can be sprayed into the gas stream 102 inside a reaction chamber where it reacts with the contaminants. For example, if sulfur dioxide is the predominant contaminant to be removed, lime may turn into gypsum, which can be captured for use in other processes.

Carbon Dioxide Capture System 111

[0039] The invention also provides a carbon dioxide capture system 111 useful for reducing emission of carbon dioxide from combustion systems 10. In certain embodiments, carbon dioxide capture system 111 can include means for contacting carbon dioxide with lime as shown in Equation [5].



In other embodiments, carbon dioxide capture system 111 may include means for contacting carbon dioxide with slaked lime as shown in Equation [6].



[0040] For example, means for contacting carbon dioxide with lime or slaked lime may include a chamber, a tube, a container, or the like having holes that allow passage of carbon dioxide into and out of the chamber, tube, container, or the like. Means for contacting carbon dioxide with lime or slaked lime may also include a fluidized bed or circulating fluidized bed wherein lime or slaked lime are suspended on upward blowing stream of carbon dioxide. This system can also include a bubbling fluidized bed. Such systems may also include cyclones that separate the solids and residual exhaust or flue gas.

[0041] FIG. 4 shows the amount of mass increase that occurs as a function of temperature when lime and slaked lime are contacted with carbon dioxide. As shown, a significant increase in mass occurs from about 350 °C. FIG. 4 shows an uptake of carbon dioxide up to about 30% the initial weight of lime or slaked lime.

Sorbent Regeneration System 113

[0042] In certain embodiments, combustion system 10 can further include a sorbent regeneration system 113 for regenerating the sorbent material. The limestone generated in the carbon dioxide capture system 111 may be converted back into lime, as shown in Equation [7], and recycled back to the carbon dioxide capture system 111.



[0043] In certain embodiments, the sorbent regeneration system 113 may be a kiln having reduced emissions. In certain embodiments, the sorbent regeneration system 113 may be an oxygen-fired, reduced carbon dioxide emission kiln 50. The reduced emission kiln 50 may be integrally incorporated in combustion system 10 or may function as a separate device operably connected with the combustion system 10.

[0044] In certain embodiments, the reduced emission kiln 50 may be operating independently as a reduced emission lime kiln. For example, reduced emission kiln 50 can be utilized to produce lime and replace traditional lime kilns having higher carbon dioxide emissions.

[0045] As shown in FIG. 5, the reduced emission kiln 50 can include an inlet 501 for providing a gas containing oxygen (or pure oxygen), a fuel inlet 503 for providing a fuel source (e.g., carbonaceous fuel such as carbon), a limestone inlet 505 for receiving the limestone from the carbon dioxide capture system 111, and a calcination zone 507 for converting the limestone feedstock into lime and heated carbon dioxide gas. In certain embodiments, the reduced emission kiln 50 can further contain a carbon dioxide recycle inlet 509 for recirculating the heated carbon dioxide gas produced in the calcination zone 507 back into the reduced emission kiln 50. Alternatively, the heated carbon dioxide produced in the calcination zone 507 can be captured for subsequent sequestration.

[0046] In certain embodiments, the limestone may be preheated in a preheating zone 511 before entering the calcination zone 507. The preheating zone 511 may be heated using the heated carbon dioxide gas produced in the calcination zone 507 or using an auxiliary heating source. For example, the limestone feedstock can be preheated in the preheating zone 511 using heated exhaust gases from a combustion process that takes place outside of the reduced emission kiln 50 (e.g., heat derived from combustion zone 101 or heat exchanger 205). Preheating the limestone feedstock may allow the reduced emission kiln to operate with higher efficiency.

[0047] In other embodiments, the reduced emission kiln 50 can also include a gasification zone to convert various non-gaseous fuels to a gas prior to burning. For example, the carbon dioxide produced in the calcination zone 507 may be utilized to gasify the carbonaceous fuel in a gasification zone 513 according to the Boudouard reaction shown in Equation [8].



In certain embodiments, the various non-gaseous fuels can include, but are not limited to, carbonaceous fuel. For example, coal may be gasified prior to burning in the reduced emission kiln 50.

[0048] In yet other embodiments, carbon dioxide produced in the calcination zone 507 can be recycled and used as a flood gas to temper the combustion reaction taking place in the kiln. For example, use of high purity oxygen for combustion may excessively raise the temperature of the kiln and hot carbon dioxide gas may be utilized to temper the flame temperature.

[0049] In certain embodiments, the calcination zone 507 may be a fluidized bed that avoids mixing air with the carbon dioxide produced in a calcination process. In this fluidized bed, oxygen can enter the calciner through a mixed solid oxide membrane that separates the fluidized bed from the input air. The calciner can be fluidized using a stream of gases, such as methane or carbon dioxide, and the heat of combustion can be transferred to the reactive materials. The fluidized bed can operate at temperatures ranging from about room temperature to about 1000°C. The fluidized bed may produce a pure stream of carbon dioxide and the calcined product, such as lime.

[0050] It should, however, be noted that uses of such a fluidized bed includes, but is not limited to, recycling sorbent materials created in the capture of carbon dioxide. The fluidized bed may also be used for recycling metal oxide sorbent materials used in industrial processes such as power plants or in any other process that uses high-temperature fluidized beds, such as the manufacture of cement.

[0051] Uses for an oxygen-blown reduced emission kiln of the invention include, but are not limited to, the production of lime, clinker, and cement with reduced carbon dioxide emissions; reducing the emissions from power plants which are run on coal or one or more fossil fuels; reducing the carbon dioxide emissions from iron and steel blast furnaces; in the paper industry for paper production processes with reduced emissions; for performing Fischer-Tropsch processes with reduced carbon dioxide emissions; or to reduce carbon dioxide emissions in a system used for the heat treatment of solids or the volatilization of pollutants, such as a soil remediation method in which soil is burned to oxidize pollutants. For example, the oxygen-blown reduced emission kiln of the invention may be utilized to capture the carbon dioxide gases contained in the exhaust gas of one or more of the processes described above.

[0052] In certain embodiments, lime may further be hydrated into slaked lime, as shown in Equation [9], before being recycled back to the carbon dioxide capture system 111.



There may be additional benefits in utilizing slaked lime over lime as the carbon dioxide absorbent material. For example, repeated regeneration of limestone to lime can cause sintering of the sorbent material and the capacity to absorb carbon dioxide may degrade over each regeneration cycle. Certain aspects of the present invention further addresses this long-felt need for improved carbon dioxide sorbent material.

[0053] FIG. 6 shows a graph comparing the conversion of lime (bottom curve labeled as CaO; reproduced from Abanade, J.C., "The maximum capture efficiency of CO₂ using a carbonation/calcination cycle of CaO/CaCO₃," Chemical Engineering Journal, vol. 90, (2002), pp. 303-306) and slaked lime (top curve labeled as Ca(OH)₂) into limestone as a function of the number of regeneration cycle. As shown, only 40% of lime is converted to limestone after five regeneration cycles whereas >90% conversion of slaked lime into limestone is still observed after five regeneration cycles. Slaked lime appears to demonstrate superior results over lime, which is unexpected.

[0054] To produce slaked lime, lime generated in the calcination zone 507 may be transported via outlet 515 to a reaction chamber (not shown) where a hydration reaction shown in Equation [9] can be carried out. Slaked lime can then be sent into the carbon dioxide capture system 111 to improve carbon dioxide capture and to reduce emissions.

Additional Embodiments

[0055] Numerous modification of the invention may be readily apparent to one of ordinary skill in the art. For example, in some other embodiments, combustion system 10 may be designed as shown in FIG. 7. As shown, heat generated in combustion zone 101 may be utilized to drive a multi-stage turbine system 701 via steam and generate electricity. The emission gases generated from the combustion zone may be captured via a carbon dioxide capture system 111. In carbon dioxide capture system 111, slaked lime may be situated in a manner to directly contact and hence capture the carbon dioxide emission before it leaves the stack (see Equations [5] or [6]). The converted limestone may be transported to calcination zone 703 which is located near the combustion zone 101 to form lime and carbon dioxide according to reaction shown in Equation [7]. The carbon dioxide gas may be removed or captured from the product stream by any suitable means. For example, the phase difference

between the gaseous carbon dioxide and the solid lime may be utilized to separate the carbon dioxide gas and preferentially remove or capture the carbon dioxide gas. The solid lime may be transported to a hydration chamber 705 to be combined with steam to form slaked lime according to reaction shown in Equation [9]. The generated slaked lime may then be transported to the carbon dioxide capture system 111 and continuously recycled as shown.

[0056] It will be readily apparent to one of ordinary skill in the art that if the carbon dioxide capture system 111 utilizes lime rather than slaked lime, lime may be directly recycled to the carbon dioxide capture system 111 without passing through the hydration chamber 705.

[0057] In addition, energy released in the exothermic reaction occurring in hydration chamber 705 may further be extracted to aid in driving the multi-stage turbine system 701. For example, heat exchangers 707 may be provided between hydration chamber 705 and the multi-stage turbine system 701 after the steam has expanded in a first turbine to allow driving a second turbine shown on the left. Such an operation may be analogous to the operation of the heat release zone 203 and heat exchangers 707 of the heat-exchange system 107.

Additional Advantage of the Invention

[0058] Numerous advantages of the invention over that of the prior art may be mentioned. First, use of the reactions shown in Equations [3] and [4] can be utilized as an energy storage loop, which may reduce water consumption and can increase efficiency of the combustion system 10 by transferring heat to the feedwater intake that drive one or more turbines for generating electricity.

[0059] Moreover, use of the hydration reaction shown in Equation [9] can be utilized to reduce the loss of reactivity of the sorbent material for carbon dioxide capture.

[0060] Upon review of the description and embodiments of the present invention, those skilled in the art will understand that modification and equivalent substitutions may be performed in carrying out the invention without departing from the essence of the invention. Thus, the invention is not meant to be limiting by the embodiments described explicitly above, and is limited only by the claims which follow.

What is claimed is:

1. A reduced carbon dioxide emission kiln comprising:
 - (a) a calcination zone for converting limestone into lime and carbon dioxide gas;
 - (b) a first inlet for oxygen; and
 - (c) a second inlet for fuel,wherein the carbon dioxide gas is recycled back into the kiln via a recycle inlet or captured.
2. The kiln of claim 1 further comprising a fuel gasification zone.
3. The kiln of claim 2, wherein the heated carbon dioxide gas is diverted to the fuel gasification zone to gasify the fuel source.
4. The kiln of claim 3, wherein the fuel source comprises carbonaceous fuel.
5. The kiln of claim 4, wherein the fuel comprises coal.
6. The kiln of claim 4, wherein the carbonaceous fuel is gasified according to the Boudouard reaction.
7. The kiln of claim 1 further comprising a preheating zone.
8. The kiln of claim 7, wherein the preheating zone comprises a limestone feedstock and the heated carbon dioxide gas heats the limestone feedstock.
9. The kiln of claim 1, wherein the recycled carbon dioxide gas is utilized to temper the combustion of the fuel source.
10. The kiln of claim 1, further comprising a filter to isolate oxygen from air, and the oxygen is provided into the first inlet.
11. A method for capturing carbon dioxide from a combustion system, the method comprising:

(a) contacting carbon dioxide from an exhaust gas of the combustion system with slaked lime to form limestone;

(b) heating the limestone to form lime and carbon dioxide; and

(c) capturing the carbon dioxide generated in step (b).

12. The method of claim 11, further comprising:

(d) contacting the lime with water or steam to generate heat and slaked lime; and

(e) further carrying out at least one of steps (a), (b), (c), (d), and (e).

13. The method of claim 12, further comprising:

(f) utilizing the heat from step (d) to increase efficiency of the combustion system or to increase the efficiency of a different power generating system.

14. The method of claim 13, wherein the heat from step (d) is utilized to dry solids entering the combustion system.

15. The method of claim 13, wherein the different power generating system is a turbine power plant for generating electricity and the heat from step (d) is utilized to heat feedwater for driving one or more turbines of the turbine power plant.

16. The method of claim 12, wherein step (b) is carried out by isolating the limestone near a combustion zone of the combustion system.

17. A system for capturing carbon dioxide from a combustion system, the system comprising:

means for contacting carbon dioxide from an exhaust gas of the combustion system with slaked lime to form limestone;

means for heating the limestone to form lime and carbon dioxide; and

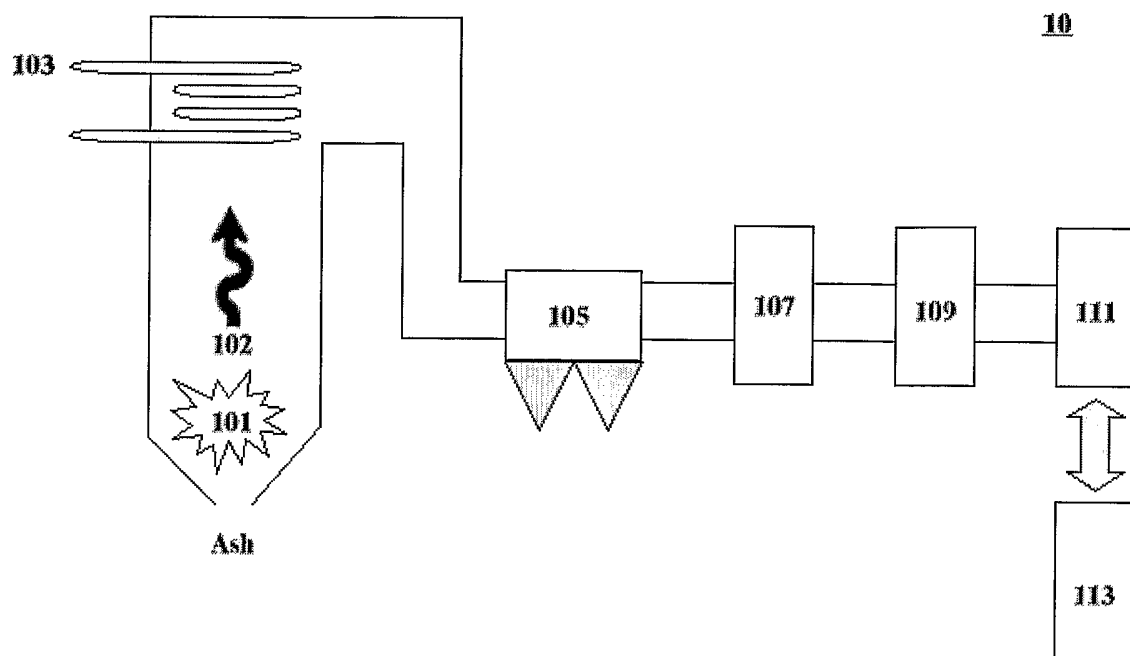
means capturing the carbon dioxide generated in the means for heating the limestone.

18. The system of claim 17, further comprising:

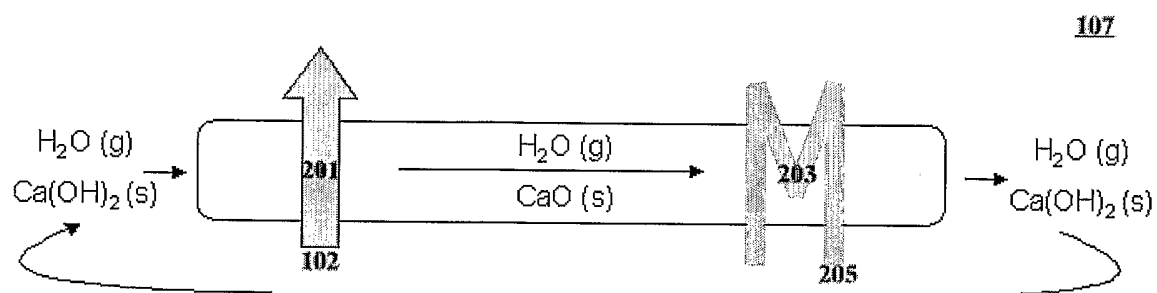
means for contacting the lime with water or steam to generate heat and slaked lime.

19. The system of claim 18, further comprising:
means for utilizing the heat generated from the means for contacting the lime with water or steam to increase efficiency of the combustion system or to increase the efficiency of a different power generating system.
20. The system of claim 17, wherein the combustion system utilizes carbonaceous fuel as a fuel source.

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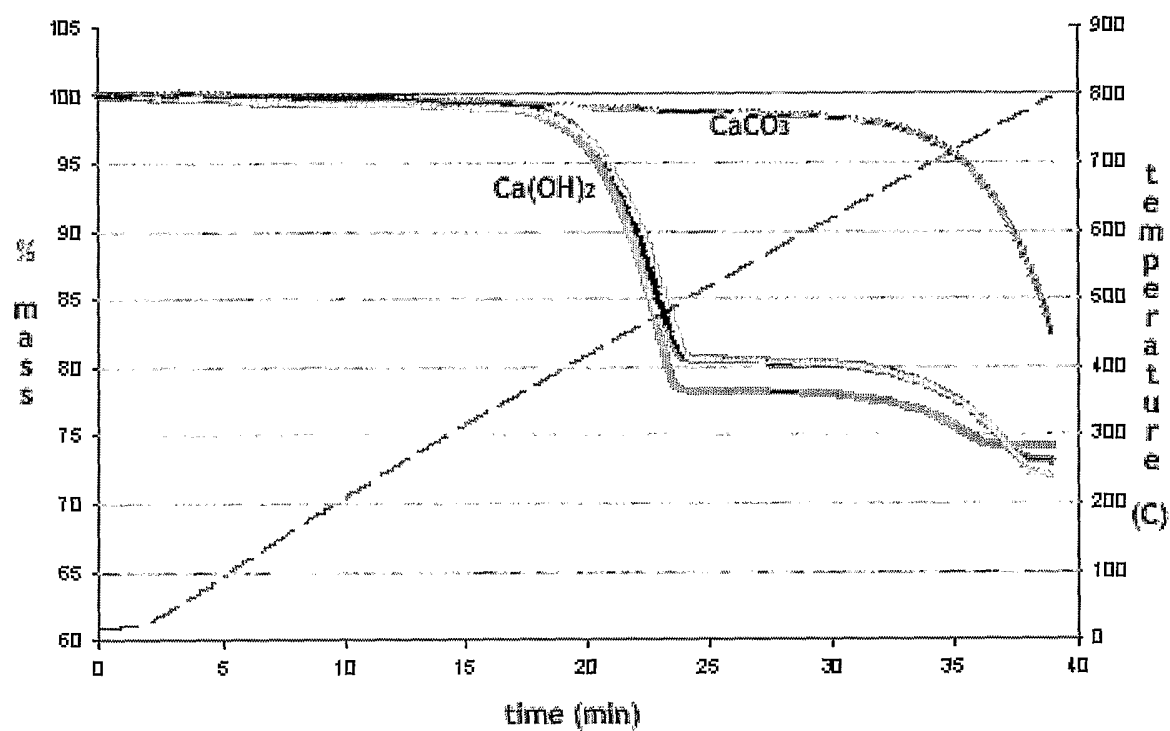
**FIG. 1**

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**FIG. 2**

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Profile of Mass Lost in Nitrogen Atmosphere

**FIG. 3**

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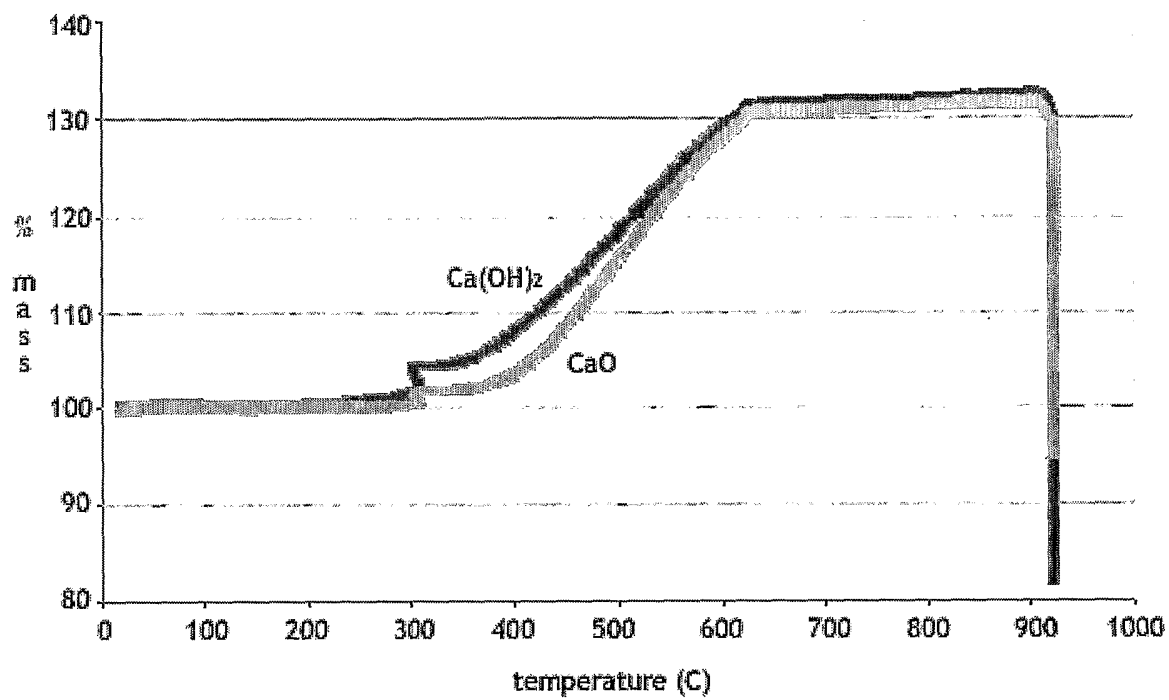
Comparison of Absorption with Hydroxide and Oxide in CO₂

FIG. 4

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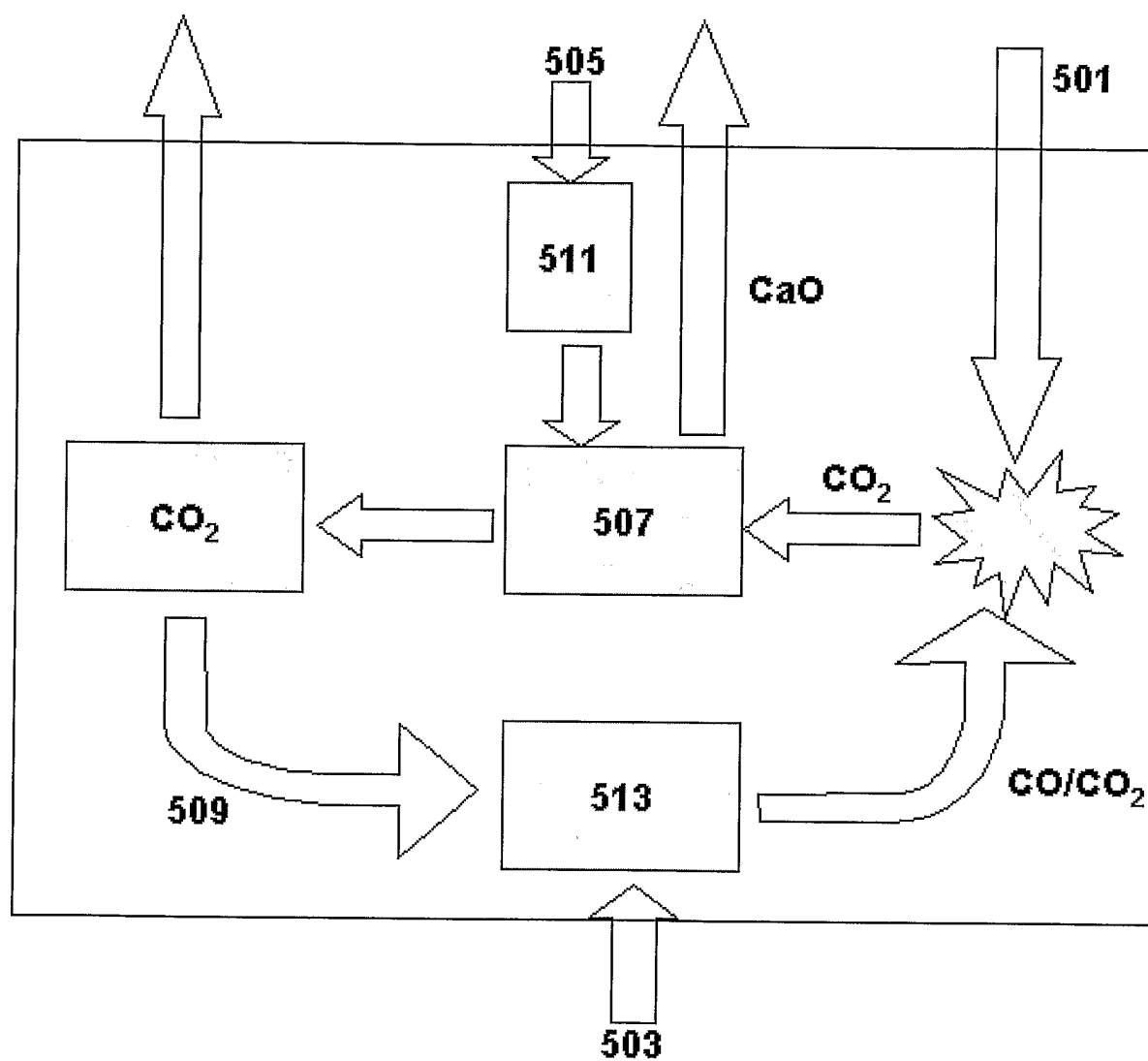
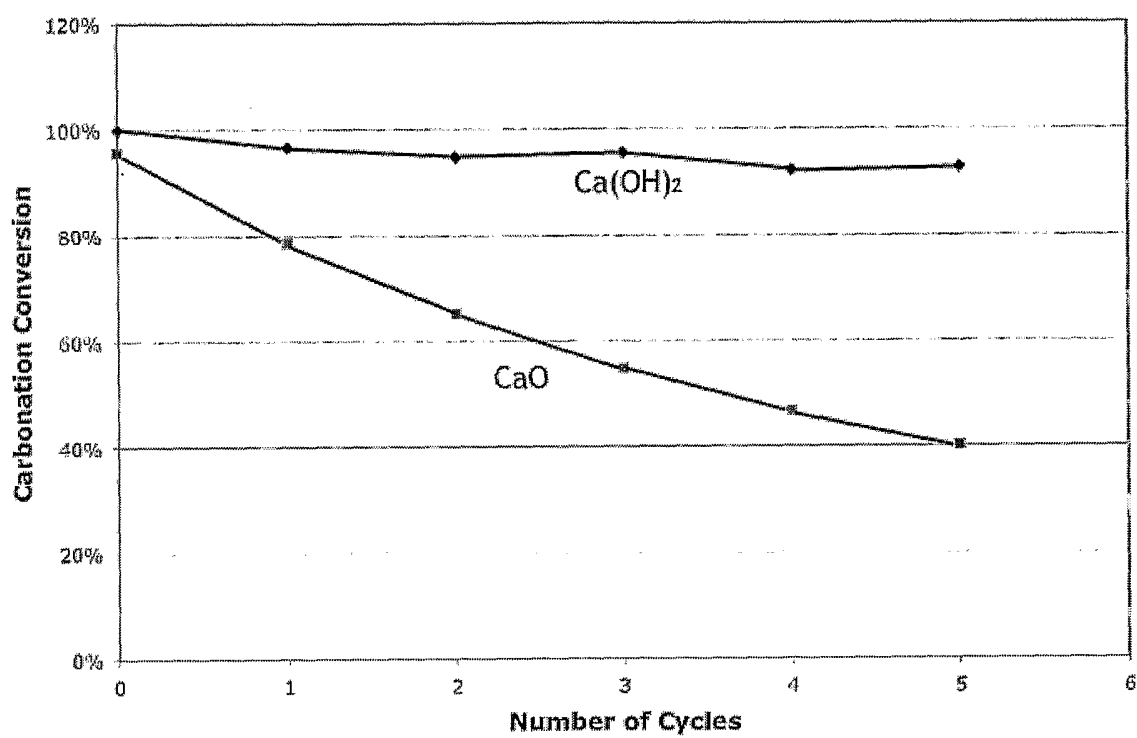


FIG. 5

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**FIG. 6**

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