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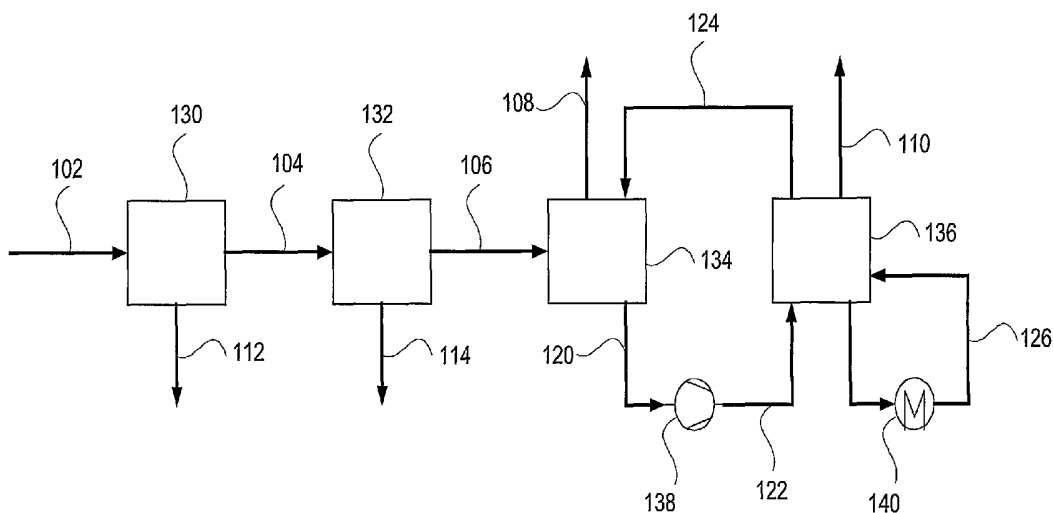
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(54) Title: ULTRA CLEANING OF COMBUSTION GAS INCLUDING THE REMOVAL OF CO₂



(57) Abstract: Ultra cleaning of combustion gas to near zero concentration of residual contaminants followed by the capture of CO₂ is provided. The high removal efficiency of residual contaminants is accomplished by direct contact cooling and scrubbing of the gas with cold water. The temperature of the combustion gas is reduced to 0-20 degrees Celsius to achieve maximum condensation and gas cleaning effect. The CO₂ is captured from the cooled and clean flue gas in a CO₂ absorber (134) utilizing an ammoniated solution or slurry in the NH₃-CO₂-H₂O system. The absorber operates at 0-20 degrees Celsius. Regeneration is accomplished by elevating the pressure and temperature of the CO₂-rich solution from the absorber. The CO₂ vapor pressure is high and a pressurized CO₂ stream, with low concentration of NH₃ and water vapor is generated. The high pressure CO₂ stream is cooled and washed to recover the ammonia and moisture from the gas.

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PATENT APPLICATION

FOR

ULTRA CLEANING OF COMBUSTION GAS INCLUDING THE
REMOVAL OF CO₂

FIELD OF THE INVENTION

The present invention relates to systems and methods for ultra cleaning of combustion gas followed by the capture and regeneration of CO₂.

BACKGROUND

Most of the energy used in the world today is derived from the combustion of carbon and hydrogen containing fuels such as coal, oil and natural gas. In addition to carbon and hydrogen, these fuels contain oxygen, moisture and contaminants such as ash, sulfur, nitrogen compounds, chlorine, mercury and other trace elements. Awareness to the damaging effects of the contaminants released during combustion triggers the enforcement of ever more stringent limits on emissions from power plants, refineries and other industrial processes. There is an increased pressure on operators of such plants to achieve near zero emission of contaminants and to reduce CO₂ emission.

The art teaches various processes and technologies designed to reduce the emission of contaminants from combustion gases. Baghouses, electrostatic precipitators and wet scrubbers are typically used to capture particulate matter, various chemical processes are

used to reduce sulfur oxides, HCl and HF emissions, combustion modifications and NO_x reduction processes are used to reduce NO_x emission and processes are being developed to capture mercury and other trace elements from combustion gas.

Significant progress has been made in the last 20-30 years and plants today are a lot cleaner and safer to the environment than in the past. However, there are growing indications that even small concentration of particulate matter and especially the very fine, less than 2.5 micron size particles (PM_{2.5}), sulfur oxides, acid mist and mercury are harmful to human health and need to be controlled.

Controlling the residual emission is still a challenge and with existing technologies the cost of capturing the last few percents of harmful contaminants is very high.

In addition, in the last few years, there is a growing concern related to the accumulation of CO₂, a greenhouse gas, in the atmosphere. The accelerated increase of CO₂ concentration in the atmosphere is attributed to the growing use of fuels, such as coal, oil and gas, which release billions of tons of CO₂ to the atmosphere every year.

Reduction in CO₂ emission can be achieved by improving efficiency of energy utilization, by switching to lower carbon concentration fuels and by using alternative, CO₂ neutral, energy sources. However, short of a major breakthrough in energy technology, CO₂ emitting fuels will continue to be the main source of energy in the foreseeable future. Consequently, a low cost low energy consuming process for capturing and sequestering CO₂ is needed to reverse the trend of global warming.

State of the art technologies for capturing CO₂ are not suitable for operation with dirty, low pressure, low CO₂ concentration, and oxygen containing combustion gases. Available commercial technologies for CO₂ capture are energy intensive and high cost. If applied they would impose a heavy toll on the cost of energy utilization.

An applicable process currently available for post combustion CO₂ capture is the amine process using Mono-Ethanol-Amine (MEA) or similar amines to react with CO₂. The MEA process is capable of achieving high capture efficiency and of generating a concentrated CO₂ stream for sequestration. However, the process has several drawbacks including:

- The MEA reagent is expensive and degrades in oxygen and CO₂ environment.
- The MEA is corrosive and can be used only in a relatively diluted form.
- The reaction of MEA with CO₂ is highly exothermic.
- Regeneration is energy intensive.
- The process is a large consumer of heat and auxiliary power.

The cost of the amine process and system is very high and the net power output of a power plant equipped with amine system to capture CO₂ is greatly reduced.

To achieve clean burning of fuels with near zero emission, including the emission of CO₂, there is a need for a low cost low energy process that:

- Captures residual contaminants
- Captures CO₂ and releases it in a concentrated and high pressure form for sequestration.

Accordingly, it would be considered an advance in the art to develop new systems and methods to overcome the current problems and shortcomings.

SUMMARY OF THE INVENTION

The present invention is an integrated method and system to efficiently and cost effectively reduce the emission of residuals, such as SO₂, SO₃, HCl, HF and particulate matter including PM_{2.5}, from combustion gas, downstream of conventional air pollution control systems, to near zero levels. Further, the system of the current invention reduces CO₂ emission by capturing and delivering it to sequestration in a concentrated form and at high pressure. It is the objective of this invention that the process would be relatively uncomplicated, would utilize low cost reagent, would generate no additional waste streams and most importantly, would be a low cost and low energy consumer.

The present invention is a wet method and system whereby the saturated combustion gas, downstream of conventional air pollution control equipment and system, is cooled to well below its ambient saturation temperature. The cooling is achieved by direct contact with cold water in dedicated vessels. The direct contact between the gas and the liquid, combining with massive condensation of moisture from the saturated gas, is a very efficient wet scrubber. Optionally, alkaline materials such as sodium or ammonium carbonate can be added to the direct contact cooler to enhance the capture of the acidic species in the gas. The direct cooling to low temperature can be achieved in one or more cooling stages. Continuous bleed from the direct contact cooler, prevents the accumulation of the captured contaminants in the direct contact coolers.

In a preferred embodiment, the chilled water will be generated in cooling towers with additional cooling, to low temperature in the range of 0-20, or even 0-10, degrees Celsius, by efficient mechanical vapor compression where the water itself is used as the refrigerant.

In accordance with the current invention, cooling of the gas substantially reduces its moisture content. The cooled and low moisture gas has relatively low volume and relatively high CO₂ concentration thus making the efficient capture of CO₂ easier and lower cost.

The invention further involves the mass transfer and the reaction of gaseous CO₂ from the combustion gas with CO₂-lean ammoniated solution to form CO₂-rich ammoniated solution. According to the current invention, the absorption reaction occurs in a CO₂ absorber operating at about atmospheric pressure and at low temperature preferably in the temperature range of 0-20, or even 0-10, degrees Celsius. The low temperature enhances mass transfer of CO₂ to the solution while substantially reducing the vapor pressure of ammonia and preventing its evaporation into the gas stream. One or more stages of CO₂ absorption can be used depending on the capture efficiency requirements.

Further, in accordance with the current invention, the pressure of the CO₂-rich solution from the CO₂ absorber is elevated by high-pressure pump to the range of 30-2000 psi and it is heated to the temperature range of 50-200 degrees Celsius and preferably to the temperature range of 100-150 degrees Celsius. Under the conditions above the CO₂ separates from the solution and evolves as a relatively clean and high-pressure gas stream. The high pressure CO₂ gas stream contains low concentration of ammonia and water vapor, which can be recovered by cold washing of the CO₂ gas stream.

The regeneration reaction is endothermic. However, the heat of reaction is low and the overall heat consumption of the process is relatively low. Moreover, the high-pressure regeneration minimizes the evaporation of ammonia and water thus minimizing the energy consumed in the process. Also, low-grade heat can be used for the regeneration of the CO₂ to further reduce the impact of the CO₂ capture on the overall efficiency of the plant. The CO₂-lean solution used in the absorber to capture the CO₂ contains NH₃/CO₂ mole ratio in the range of 1.5-4.0 and preferably in the range of 1.5-3.0. The CO₂-rich solution sent for regeneration contains NH₃/CO₂ mole ratio in the range of 1.0-2.0 and preferably in the range of 1.0-1.5.

The present invention has the advantage of high efficiency low cost capture of residual contaminants from the combustion gas followed by high efficiency low cost capture and regeneration of CO₂. Low temperature absorption and high-pressure regeneration are critical to successful operation of the process and system. The simple, low cost and efficient system has notable advantage over other cleaning and CO₂ capturing processes and it is a real breakthrough in achieving the objective of near zero emission of contaminants.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other advantages of this invention will become more apparent from the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic representation of the integrated system to capture residual contaminants and CO₂ from combustion gas downstream of conventional air pollution control systems. The system includes gas cleaning, CO₂ absorption and CO₂ regeneration.

FIG. 2 is a schematic of the subsystems for the cooling of the gas and for deep cleaning

of residual contaminants.

FIG. 3 is a schematic of the CO₂ capture and regeneration subsystems. It includes CO₂ absorber which operates at low temperature and CO₂ regenerator which operates at moderate temperature and at high pressure.

DETAILED DESCRIPTION OF THE INVENTION

In accordance with the present invention, a process and system to remove most contaminants, including CO₂, from gas streams is provided. These gases are typically resulting from the combustion or gasification of coal, liquid fuels, gaseous fuels and organic waste materials. The contaminants include residual of e.g. SO₂, SO₃, HCl, HF, CO₂, particulate matter including PM_{2.5}, mercury and other volatile matter. The high removal efficiency of the contaminants is achieved by saturation and efficient cooling of the gas to below its adiabatic saturation temperature and preferably to as low as 0-20, or even 0-10, degrees Celsius. Fine particles and acid mist are nucleation sites for the condensation of water. Thus, practically all fine particles and acid mist are removed from the gas stream. The low temperature creates an environment of low vapor pressure of SO₂, SO₃, HCl, HF, Mercury and other volatile matter, which condense into the cold water as well.

The cooling of the flue gas enables the efficient capture of CO₂ in CO₂-lean ammoniated solution or slurry. Absorption of the CO₂ is achieved at low temperature preferably at as low as 0-20 degrees Celsius or at as low as 0-10 degrees Celsius. The absorbent is regenerated by elevating the temperature of the solution or slurry to the range of 50-200 degrees Celsius and to pressures in the range of 30-2000 psig. The low temperature of absorption and the high pressure of regeneration result in high CO₂ capture efficiency, low energy consumption and low loss of ammonia through evaporation.

The CO₂ absorption takes place in the aqueous NH₃-CO₂-H₂O system where the ammonia can be in the form of ammonium ion, NH₄⁺, or in the form of dissolved molecular NH₃. The CO₂ can be in the form of carbonate, CO₃⁼, bicarbonate, HCO₃⁻ or in the form of dissolved molecular CO₂. The capacity of the solution to absorb CO₂ and the form in which the species are present depends on the ammonia concentration, on the NH₃/CO₂ mole ratio and on the temperature and pressure.

High NH₃/CO₂ mole ratio increases the vapor pressure of ammonia and results in ammonia losses through evaporation. Low NH₃/CO₂ ratio increases the vapor pressure of CO₂ and decreases its capture efficiency. Thus, the optimal NH₃/CO₂ mole ratio for absorption is in the range of 1.0-4.0 and preferably in the range of 1.5 to 3.0. High temperature increases the vapor pressure of both ammonia and CO₂. As a result, the absorber should operate at the lowest practical temperature and preferably in the 0-20 degrees Celsius temperature range or even in the 0-10 degrees Celsius temperature range.

At high concentration and lower temperature the solubility limits may be reached and solids particles precipitate. These solids particles are typically in the form of ammonium carbonate (NH₄)₂CO₃ for high NH₃/CO₂ ratio and ammonium bicarbonate NH₄HCO₃ for low NH₃/CO₂ ratio.

The mass transfer and absorption reactions for concentrated low temperature slurries are the following:

- CO₂ (g) -----> CO₂ (aq)
- CO₂ (aq) + H₂O -----> H⁺ + HCO₃⁻

- $(\text{NH}_4)_2\text{CO}_3 (\text{s}) \rightleftharpoons 2\text{NH}_4^+ + \text{CO}_3^{2-}$
- $\text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \text{HCO}_3^-$
- $\text{HCO}_3^- + \text{NH}_4^+ \rightleftharpoons \text{NH}_4\text{HCO}_3 (\text{s})$

Where CO_2 captured from the gas converts ammonium carbonate to ammonium bicarbonate. The reactions above are reversible and CO_2 is stripped from the liquid phase at elevated temperature.

Depending on the operating conditions, side undesired reactions may occur such as:

- $\text{NH}_4^+ + \text{CO}_3^{2-} \rightleftharpoons \text{NH}_3 (\text{g}) + \text{HCO}_3^-$
- $\text{NH}_4^+ + \text{HCO}_3^- \rightleftharpoons \text{NH}_3 (\text{g}) + \text{CO}_2 (\text{g}) + \text{H}_2\text{O}$

Causing emission of NH_3 into the gas phase. Lower temperature and lower NH_3/CO_2 ratio in the absorber suppresses these undesired reactions. However, during the regeneration and at elevated temperature, gaseous ammonia is formed. To prevent ammonia from escaping from the liquid phase (and for other reasons) the regenerator is designed to operate under elevated pressure and under conditions where the solubility of ammonia in the solution is very high and the emission of gaseous ammonia is very low.

FIG. 1 is a schematic representation of the integrated process, which includes cleaning and cooling of the gas, CO_2 absorption into CO_2 -lean ammoniated solution and CO_2 regeneration from the CO_2 -rich solution. Stream **102** is a gas stream from combustion or industrial process containing residual contaminants, CO_2 and inert gas species. The CO_2 concentration of the gas is typically 10-15% for coal combustion and 3-4% for natural gas combustion. Subsystem **130** represents a series of conventional air pollution control

processes which, depending on the source of the gas may include particulate collectors, NO_x and SO₂ control, acid mist capturing device and more. The contaminants collected in the system are removed in stream **112**. Stream **104**, downstream of the conventional cleaning devices, contains residual contaminants not collected by the conventional systems. It is typically water saturated and in the temperature range of 40-70 degrees Celsius. Subsystem **132** is a series of one or more Direct Contact Coolers (DCC), where cold water generated in cooling towers and chillers (not shown) is used to wash and scrub the gas, capture its residual contaminants and lower its moisture content. Stream **114**, is a bleed from subsystem **132** designed to purge all the residual contaminants captured.

Stream **106** is a cooled gas suitable for CO₂ capture in the CO₂ absorber. Subsystem **134** represents the CO₂ absorber and may comprise of a series of absorber stages, depending on the removal efficiency required and the operating conditions of the plant. The clean gas with low CO₂ concentration, stream **108**, is released to the atmosphere. Stream **124** is a cooled CO₂-lean ammoniated solution from the regenerator, subsystem **136**, which is used as the absorbent to capture the CO₂ in the absorber. The resultant stream **120** is a CO₂-rich ammoniated solution sent for regeneration.

The regenerator, subsystem **136**, operates at high pressure and elevated temperature and may be a single or a series of regeneration reactors. The pressure of the ammoniated solution fed to the regenerator is elevated using high pressure pump, pump **138**, to yield stream **122** which is CO₂-rich and at high pressure. Typically, the pressure of stream **122** is in the range of 50-2500 psi, higher than the regenerator pressure to prevent premature evaporation of CO₂. Heat is provided to the regenerator by heating stream **126** in heater **140**. The high pressure and high temperature in the regenerator cause the release of high-

pressure gaseous CO₂, stream **110**. The high-pressure regeneration has major cost and energy advantage. Low quality thermal energy is used to generate the high pressure CO₂ stream instead of high-value electric power.

FIG. 2 is a schematic representation of the cooling and cleaning subsystems, which may optionally include waste heat recovery, heat exchanger **240**, for utilization of the residual heat in the gas. The residual heat in stream **202** can be extracted in heat exchanger **240** by transferring of the heat to a cooling medium streams **220** and **222**. The heat can then be used downstream for CO₂ regeneration.

Vessel **242** is a wet direct contact scrubber used to adiabatically cool and saturate the gas. If the gas contains high concentration of acid species, such as gas from coal or oil fired power plants, then reactor **242** is used for flue gas desulfurization. Acid absorbing reagent, such as limestone, stream **226**, is added to vessel **242** and the product, such as gypsum, stream **224**, is withdrawn. Make up water, stream **227**, is added to vessel **242** from the Direct Contact Cooler (DCC) **244**. The make up stream contains all the contaminants collected in the direct contact coolers. These contaminants are removed from the system with the discharge stream **224**. Gas stream **202** in coal fired boiler is typically at temperature in the range of 100-200 degrees Celsius, gas stream **204** is typically at temperature range of 80-100 degrees Celsius and gas stream **206** is typically water-saturated and at temperature range of 40-70 degrees Celsius.

Two stages of direct contact cooling and cleaning, vessels **244** and **246**, are shown in **FIG. 2**. The actual number of direct contact coolers may be higher and it depends on optimization between capital cost, energy efficiency and cleaning efficiency requirements.

Gas stream **206** is cooled in DCC **244** to just above the cooling water temperature of stream **230**. The temperature of the cooling water, stream **230**, depends on the ambient conditions and on the operation and process conditions of Cooling Tower **250**. Cooling Tower **250** can be of the wet type with temperature slightly below or slightly above ambient temperature, or the dry type with temperature above ambient temperature. Ambient air, Stream **212** provides the heat sink for the system and the heat is rejected in Stream **214**, which absorbs the heat from water stream **228**. The resultant cooled water stream **230**, is typically at temperature range of 25-40 degrees Celsius and the resultant cooled combustion gas stream from DCC **244** is at about 1-3 degrees Celsius higher temperature. Alkaline materials such as ammonium or sodium carbonate can be added to DCC **244** to neutralize the acidic species captured. The alkaline materials can be added in makeup water, stream **225**.

The cleaner and lower temperature, Stream **208** flows to DCC **246**, which is similar to DCC **244** except for the fact that colder water, stream **234**, is used for cooling. Stream **234** is a chilled water stream cooled by Chiller **248**, which is preferably a mechanical vapor compression machine with water as its refrigerant. Heat from Chiller **248** is rejected via stream **236** to Cooling Tower **250** with returning stream **238**. Cooling water stream **234** can be as cold as 0-3 degrees Celsius or higher resulting in combustion gas temperature, stream **210**, exiting DCC **246** being at 0-10 degrees Celsius temperature or few degrees higher. The heat absorbed from the gas stream is removed from DCC **246** via water stream **232**. More condensation occurs in DCC **246** and further capture of contaminants. These contaminants are bled from the system to vessel **242**. (Bleed stream is not shown).

Gas Stream **210**, the product of the cooling and cleaning subsystem shown in **FIG. 2**, is at low temperature; it contains low moisture and practically has no particulate matter, acidic or volatile species.

FIG. 3 is a schematic representation of the CO₂ capture and regeneration subsystem. Stream **302** is a clean and cooled gas stream, similar to stream **210** in **FIG. 2**. It flows into the CO₂ absorber **350**, where the CO₂ is absorbed by a cooled CO₂-lean ammoniated solution or slurry, Stream **324** containing NH₃/CO₂ mole ratio in the range of 1.5-4.0 and preferably 1.5-3.0. Depending on the absorber design and the number of absorption stages used, more than 90% of the CO₂ in Stream **302** can be captured to yield a cold and CO₂ depleted gas stream **304**. Residual ammonia in stream **304** can be washed in vessel **356** by cold water or by cold and slightly acidic solution, stream **338**. Stream **338** is cooled in heat exchanger **368**. As a result of the cooling, cleaning and CO₂ capture, the gas stream discharged from the system, Stream **306**, contains mainly nitrogen, oxygen and low concentration of CO₂ and H₂O.

Stream **324** is a CO₂-lean stream from the regenerator, which is cooled in the regenerative heat exchanger **354** and further by chilled water in heat exchanger **362**. It captures CO₂ in absorber **350** and discharges from the absorber, Stream **312**, as a CO₂-rich stream with NH₃/CO₂ mole ratio in the range of 1.0-2.0 and preferably with NH₃/CO₂ mole ratio in the range of 1.0-1.5. In a preferred embodiment, stream **312** contains high concentration of dissolved and suspended ammonium bicarbonate. A portion of stream **312** is optionally recycled back to the absorber while the balance, Stream **314**, is pressurized in high pressure pump **360** to yield high pressure ammoniated solution stream **316**. Stream **316** is heated in regenerative heat exchanger **354**, by exchanging heat with the hot and CO₂-lean stream

from the regenerator, stream **322**, which is a portion of stream **320** discharged at the bottom of regenerator **352**.

The CO₂-rich stream from the regenerative heat exchanger **354**, stream **318**, can be further heated with waste heat from the boiler or from other sources. It flows into the regenerator **352**, which has one or more stages of regeneration. More heat is provided to the regenerator from heat exchanger **364**, which heats stream **330**. The heat provided to the system from the various sources, elevates the regenerator temperature to 50-150 degrees Celsius or higher, depending on the desired pressure of the CO₂ stream **308** and subject to cost optimization consideration. The higher the temperature the higher will be the pressure of the CO₂ that evolves from the solution, stream **308**. The higher the pressure the lower will be the ammonia and water vapor content of stream **308**. To generate low temperature and highly concentrated CO₂ stream, stream **308** is washed and cooled in direct contact vessel **358** with cold water, stream **336** from heat exchanger **366**. Excess water and NH₃ captured in vessel **358**, stream **332**, flows back to regenerator **352** while the balance, stream **334**, is cooled and recycled to the wash chamber, vessel **358**.

The present invention has now been described in accordance with several exemplary embodiments, which are intended to be illustrative in all aspects, rather than restrictive. Thus, the present invention is capable of many variations in detailed implementation, which may be derived from the description contained herein by a person of ordinary skill in the art. All such variations and other variations are considered to be within the scope and spirit of the present invention as defined by the following claims and their legal equivalents.

CLAIMS

What is claimed is:

1. A system for ultra cleaning of a contaminated combustion gas, comprising:
 - (a) a cooling subsystem with one or more direct and wet cooling stages to cool down a gas stream to condense water from said gas stream and to capture and remove contaminants from said gas stream;
 - (b) an absorbing subsystem with one or more CO₂ absorbing stages to absorb CO₂ from said cooled gas stream using an ammoniated solution or slurry; and
 - (c) a regeneration subsystem with one or more CO₂ regeneration stages to separate CO₂ from said absorbed and ammoniated CO₂.
2. The system as set forth in claim 1, wherein said cooling subsystem cools down said gas stream to about 0-20 degrees Celsius.
3. The system as set forth in claim 1, wherein said cooling subsystem cools down said gas stream to about 0-10 degrees Celsius.
4. The system as set forth in claim 1, wherein said CO₂ is absorbed into a CO₂-lean NH₃-CO₂-H₂O solution or slurry.
5. The system as set forth in claim 4, wherein said CO₂-lean solution or slurry has a NH₃/CO₂ mole ratio in the range of 1.5-4.0.

6. The system as set forth in claim 4, wherein said CO₂-lean solution or slurry has a NH₃/CO₂ mole ratio in the range of 1.5-3.0.
7. The system as set forth in claim 1, wherein said absorbing subsystem operates at a temperature in the range of 0-20 degrees Celsius.
8. The system as set forth in claim 1, wherein said absorbing subsystem operates at a temperature in the range of 0-10 degrees Celsius.
9. The system as set forth in claim 1, wherein said absorbing subsystem generates a CO₂-rich NH₃-CO₂-H₂O solution.
10. The system as set forth in claim 9, wherein said CO₂-rich solution has a NH₃/CO₂ mole ratio in the range of 1.0-2.0.
11. The system as set forth in claim 9, wherein said CO₂-rich solution has a NH₃/CO₂ mole ratio in the range of 1.0-1.5.
12. The system as set forth in claim 1, wherein said regeneration subsystem operates at a temperature in the range of 50-200 degrees Celsius.
13. The system as set forth in claim 1, wherein said regeneration subsystem operates at a temperature in the range of 100-150 degrees Celsius.

14. The system as set forth in claim 1, wherein said regeneration subsystem operates at a pressure in the range of 30-2000 psi.
15. The system as set forth in claim 1, wherein said regeneration subsystem operates at a pressure in the range of 150-400 psi.
16. A method for ultra cleaning of a contaminated combustion gas, comprising the steps of:
 - (a) cooling down a gas stream with one or more direct and wet cooling stages to condense water from said gas stream and to capture and remove contaminants from said gas stream;
 - (b) absorbing CO₂ from said cooled gas stream with one or more CO₂ absorbing stages using an ammoniated solution or slurry; and
 - (c) regenerating CO₂ with one or more CO₂ regeneration stages to separate CO₂ from said absorbed and ammoniated CO₂.
17. The method as set forth in claim 16, wherein said cooling step occurs at a temperature in the range of 0-20 degrees Celsius.
18. The method as set forth in claim 16, wherein said cooling step occurs at a temperature in the range of 0-10 degrees Celsius.
19. The method as set forth in claim 16, wherein said CO₂ is absorbed into a CO₂-lean NH₃-CO₂-H₂O solution or slurry.

20. The method as set forth in claim 19, wherein said CO₂-lean solution or slurry has a NH₃/CO₂ mole ratio in the range of 1.5-4.0.
21. The method as set forth in claim 19, wherein said CO₂-lean solution or slurry has a NH₃/CO₂ mole ratio in the range of 1.5-3.0.
22. The method as set forth in claim 19, wherein the species in said NH₃-CO₂-H₂O solution or slurry are in water-dissolved form.
23. The method as set forth in claim 19, wherein the species in said NH₃-CO₂-H₂O solution or slurry is concentrated such to contain dissolved and suspended solids having ammonium carbonate, (NH₄)₂CO₃, and ammonium bicarbonate, NH₄HCO₃, salts.
24. The method as set forth in claim 16, wherein said absorbing step occurs at a temperature in the range of 0-20 degrees Celsius.
25. The method as set forth in claim 16, wherein said absorbing step occurs at temperature in the range of 0-10 degrees Celsius.
26. The method as set forth in claim 16, wherein said absorbing step generates a CO₂-rich NH₃-CO₂-H₂O solution.

27. The method as set forth in claim 26, wherein said CO₂-rich solution has a NH₃/CO₂ mole ratio in the range of 1.0-2.0.
28. The method as set forth in claim 26, wherein said CO₂-rich solution has a NH₃/CO₂ mole ratio in the range of 1.0-1.5.
29. The method as set forth in claim 16, wherein said regenerating step occurs at a temperature in the range of 50-200 degrees Celsius.
30. The method as set forth in claim 16, wherein said regenerating step occurs at a temperature in the range of 100-150 degrees Celsius.
31. The method as set forth in claim 16, wherein said regenerating step occurs at a pressure in the range of 30-2000 psi.
32. The method as set forth in claim 16, wherein said regenerating step occurs at a pressure in the range of 150-400 psi.

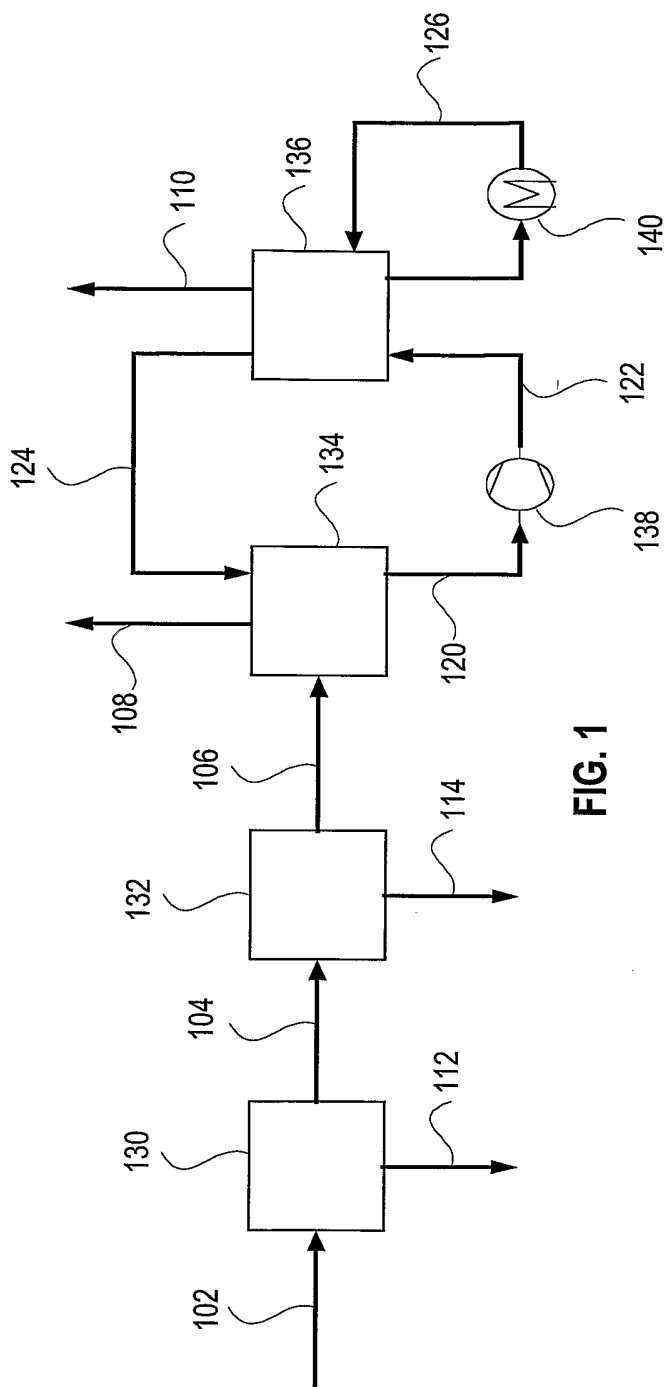


FIG. 1

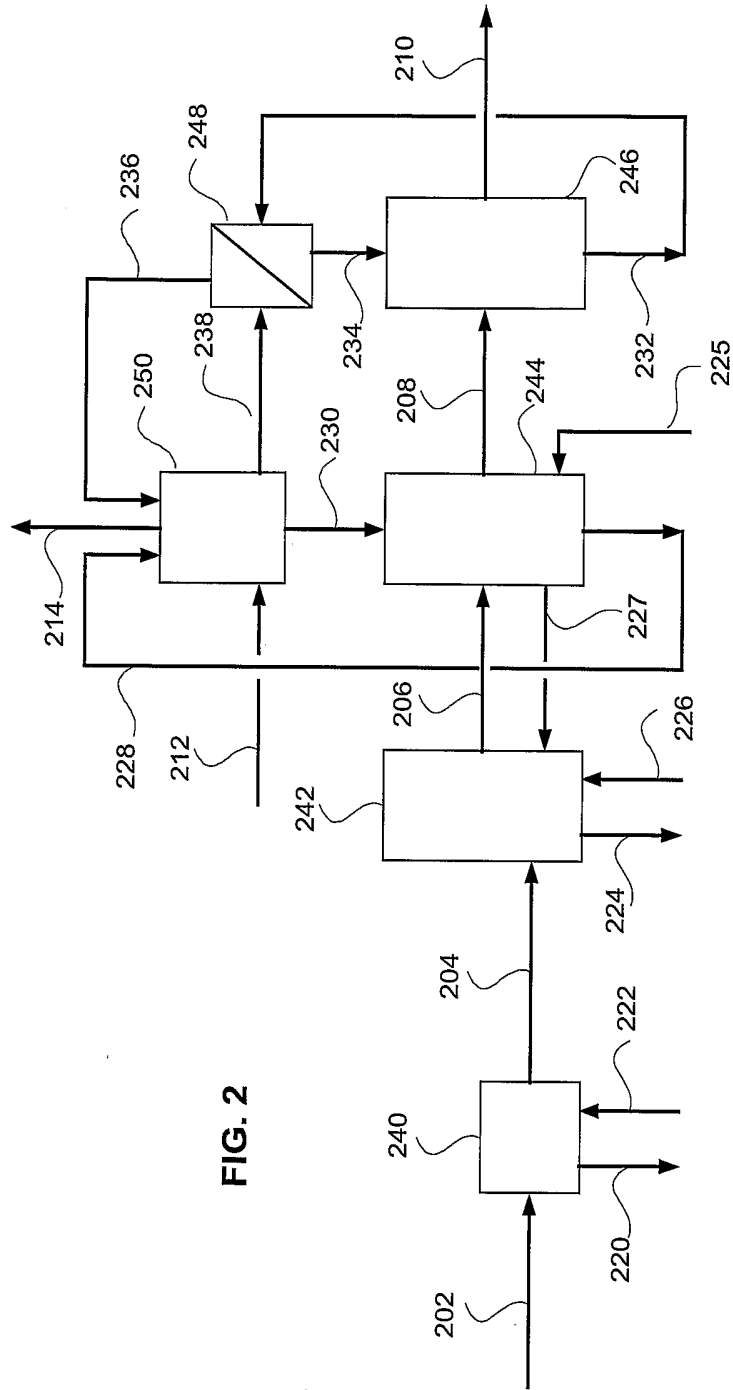


FIG. 2

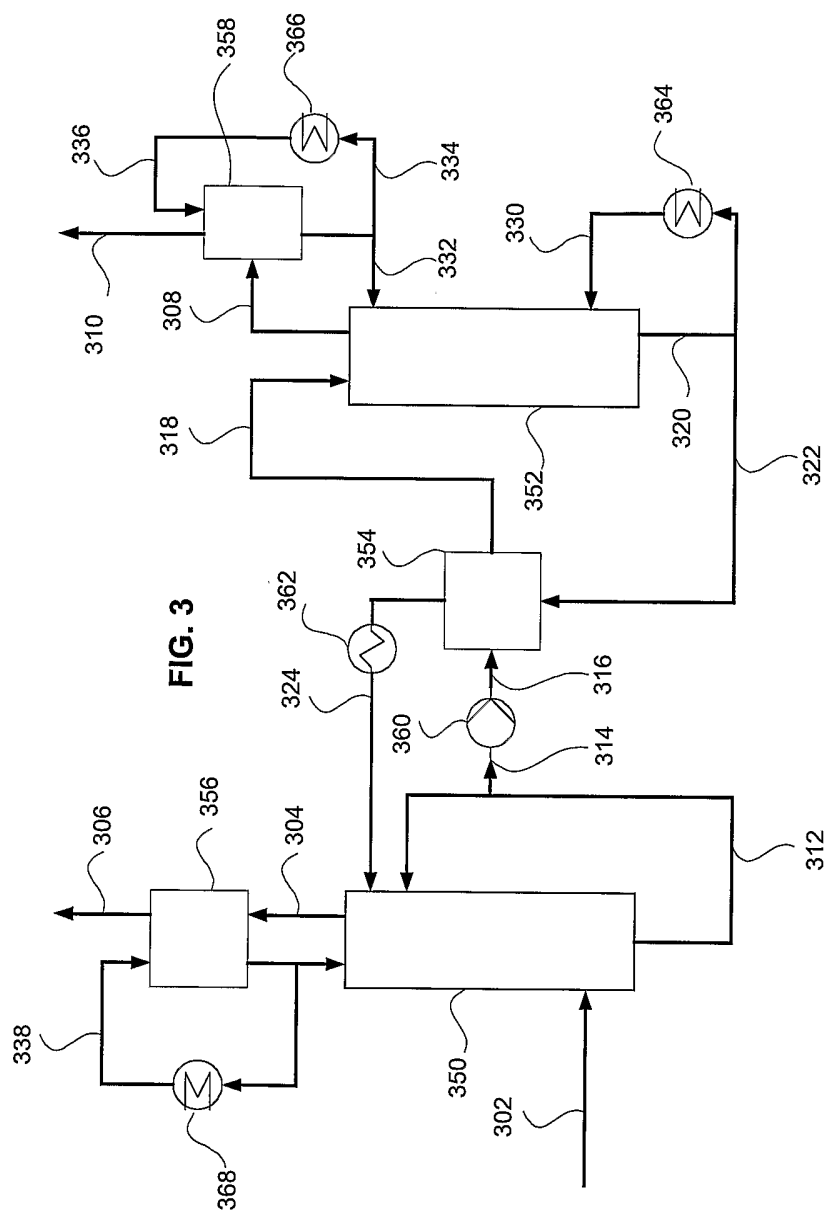


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US05/12794

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : B01D 53/14
 US CL : 95/187, 229, 236; 96/242

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 U.S. : 95/187, 199, 223, 225, 229, 236; 96/234, 242; 423/220, 234

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/0140786 A1 (IJIMA) 31 July 2003 (31.07.2003), figure 2, paragraphs 11-14, 30-32	1-15
X	US 5,318,758 A (FUJII et al) 07 June 1994 (07.06.1994), figures, col. 2, lines 16-44, col. 5, line 43 to col. 6, line 20	1-15
A	US 6,485,547 B1 (IJIMA) 26 November 2002 (26.11.2002)	1-32
A	US 4,515,760 A (LANG et al) 07 May 1985 (07.05.1985)	1-32

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:	"T"
"A" document defining the general state of the art which is not considered to be of particular relevance	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

20 June 2005 (20.06.2005)

Date of mailing of the international search report

14 SEP 2005

Name and mailing address of the ISA/US

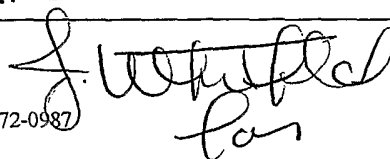
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Facsimile No. (703) 305-3230

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Telephone No. 571-272-0987



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US05/12794

Continuation of B. FIELDS SEARCHED Item 3:
DERWENT
search terms: carbon dioxide, absorption, solvent