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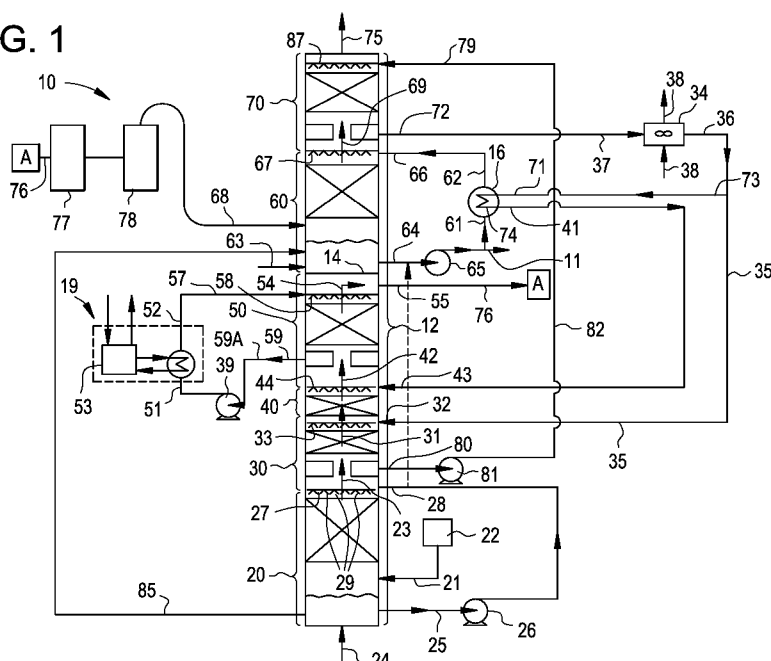
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[Continued on nextpage]

(54) Title: GAS TREATMENT SYSTEM WITH A HEAT EXCHANGER FOR REDUCTION OF CHILLER ENERGY CONSUMPTION

FIG. 1



(57) Abstract: A gas treatment system including a heat exchanger having a first side and a second side separated from one another. The first side defines a first inlet and a first outlet and the second side defines a second inlet and a second outlet. A direct contact cooler is in fluid communication with the first outlet, a direct contact heater is in fluid communication with the first inlet and/or a gas polisher is in fluid communication with the first inlet and the first outlet. The gas treatment system includes an ammonia polishing system in fluid communication with the second inlet and/or the second outlet.

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**GAS TREATMENT SYSTEM WITH A HEAT EXCHANGER FOR REDUCTION OF
CHILLER ENERGY CONSUMPTION**

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit under 35 U.S.C. §119 (e) of the Provisional Patent Application Serial No. 61/583,900 filed January 6, 2012, the disclosure of which is incorporated herein by reference in its entirety.

FIELD

[0002] The present invention is generally directed a gas treatment system for use in an ammonia based carbon dioxide (CO₂) removal system and is more specifically directed to a flue gas treatment system having a heat exchanger for use in reducing energy consumption of a chiller utilized in the ammonia based CO₂ removal system.

BACKGROUND

[0003] Energy used in the world can be derived from the combustion of carbon and hydrogen-containing fuels such as coal, oil, peat, waste and natural gas. In addition to carbon and hydrogen, these fuels contain oxygen, moisture and contaminants. The combustion of such fuels results in the production of a flue gas stream containing the contaminants in the form of ash, carbon dioxide (CO₂), sulfur compounds (often in the form of sulfur oxides, referred to as "SOx"), nitrogen compounds (often in the form of nitrogen oxides, referred to as "NOx"), chlorine, mercury, and other trace elements. Awareness regarding 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. However, removal of the contaminants from the flue gas stream requires a significant amount of energy.

SUMMARY

[0004] According to aspects disclosed herein, there is provided a gas treatment system, for example a flue gas treatment system, that includes a heat exchanger having a first side and a second side separated from one another. One example of such a heat exchanger is a tube and shell heat exchanger. The first side defines a first inlet and a first outlet and the second side defines a second inlet and a second outlet. A direct contact cooler can be in fluid

communication with the first outlet. A direct contact heater can be in fluid communication with the first inlet. A CO₂ absorber can be in fluid communication with the first inlet and the first outlet. The gas treatment system includes an ammonia polishing system in fluid communication with the second inlet and/or the second outlet. The ammonia polishing system can remove ammonia from the gas and also heat the gas.

[0005] In another aspect defined herein, the heat exchanger is operable to affect about a 5 °C to about 25 °C reduction in temperature of the gas flowing through the direct contact cooler.

[0006] In yet another aspect disclosed herein, there is provided a gas treatment system that has particular use in climates in which the ambient temperature is generally high. For example, the gas treatment system is of particular use in climates in which cooling water from a cooling tower circulating water system is greater than about 25 °C for a substantial portion of the year. The gas treatment system also has utility in systems in which the temperature of the circulating water is greater than the temperature of a fluid in a CO₂ absorber that is in communication with the gas treatment system.

[0007] The gas treatment system has a first stage that includes a first direct contact cooler (DCC). The first DCC defines a first gas inlet and a first gas outlet. The first gas inlet is in fluid communication with a gas source such as a furnace for pulverizing coal or a combined cycle power plant which combusts natural gas in a gas turbine. The gas treatment system has a second stage that includes a second DCC. The second DCC defines a second gas inlet and a second gas outlet. The first gas outlet is in fluid communication with the second gas inlet. The gas treatment system also has a third stage that includes a third DCC. The third DCC defines a third gas inlet and a third gas outlet. The second gas outlet is in fluid communication with the third gas inlet. In addition, a chiller is in fluid communication with the third stage. The gas treatment system further has a fourth stage that includes a first direct contact heater (DCH). The first DCH defines a fourth gas inlet and a fourth gas outlet. The gas treatment system also has a fifth stage comprising a second DCH. The second DCH defines a fifth gas inlet and a fifth gas outlet. The fourth gas outlet is in fluid communication with the fifth gas inlet. In addition, the gas treatment system includes a heat exchanger. The heat exchanger has a first side and a second side separated from one another. The first side defines a first fluid inlet and a first fluid outlet and the second side defines a second fluid inlet and a second fluid outlet. The first fluid inlet is in fluid communication with the fifth stage and first fluid outlet is in fluid communication with the second stage. The

second fluid inlet and the second fluid outlet are in fluid communication with the fourth stage.

[0008] The first, second and third stages cooperate to cool hot gas supplied thereto from a temperature of about 40 to 60 °C to about 5 to 10 °C. The gas is heated in the fourth and fifth stages from about 5 to 10 °C to about 40 to 60 °C. The cooling in the first stage is generally affected by cooling water from a cooling tower. The cooling in the second stage is generally affected by cooling water from the heat exchanger. The heat exchanger heats the gas in the fourth stage with heat extracted from the gas in the second stage, thereby cooling the gas in the second stage. The cooling in the third stage is affected by the chiller. Load on the chiller is reduced by the cooling provided by the heat exchanger.

[0009] In addition, a fluid such as an ammonium sulfate (AS) solution can flow through the second side of the heat exchanger. As a result, the temperature of the AS solution is increased by about 5 °C to about 20 °C across the heat exchanger. The heating of the AS solution and evaporation of water in the gas increases the concentration of the AS solution. For example, the concentration of the AS solution is increased to about 40 weight % (+ 5 weight %). Increasing the concentration of the AS solution to about 40 weight % reduces the amount of AS purging required. Since the amount of AS purging is reduced, smaller sized purging systems are required compared to gas systems which employ an AS solution having concentrations lower than about 35%.

[0010] In still another aspect disclosed herein, there is provided a gas treatment system that has particular use in climates in which the ambient temperature is generally low. For example, the gas treatment system has particular use in climates in which cooling water from a cooling tower circulating water system is less than about 25 °C for a substantial portion of the year. The gas treatment system also has utility in systems in which the temperature of the circulating water is less than the temperature of a fluid in a CO₂ absorber that is in communication with the gas treatment system.

[0011] The gas treatment system has a first stage that includes a first DCC that defines a first gas inlet and a first gas outlet. In one embodiment, the first gas inlet is in fluid communication a flue gas source such as a furnace for pulverizing coal or a combined cycle power plant which combusts natural gas in a gas turbine. The gas treatment system further has a second stage comprising a second DCC. The second DCC defines a second gas inlet and a second gas outlet. The first gas outlet is in fluid communication with the second gas inlet. In addition, a chiller is in fluid communication with the second stage. The gas treatment system also has a third stage that includes a first DCH. The first DCH defines a

third gas inlet and a third gas outlet. The gas treatment system further has a fourth stage that includes a second DCH that defines a fourth gas inlet and a fourth gas outlet. The third gas outlet is in fluid communication with the fourth gas inlet. The gas treatment system also includes a heat exchanger having a first side and a second side separated from one another. The first side defines a first fluid inlet and a first fluid outlet and the second side defines a second fluid inlet and a second fluid outlet. The first fluid inlet and the first fluid outlet are in fluid communication with a CO₂ absorber. The second fluid inlet and the second fluid outlet are in fluid communication with the fourth stage.

[0012] In one embodiment, a second chiller is in fluid communication with the CO₂ absorber. In addition, the heat exchanger can reduce the temperature of a fluid entering the first fluid inlet by about a 5 °C to about a 20 °C. Such a reduction in temperature of the fluid reduces load on the second chiller.

[0013] In one embodiment, there is a flue gas polisher positioned upstream of and in fluid communication with the first stage. The flue gas polisher has particular utility in treatment of flue gas from furnaces which combust pulverized coal. In such cases, the flue gas polisher removes SO₂, SO₃ and fly ash in the flue gas discharged from the furnace.

BRIEF DESCRIPTION OF FIGURES

[0014] With reference now to the figures where all like parts are numbered alike;

[0015] FIG. 1 is a schematic diagram of a gas treatment system disclosed herein;

[0016] FIG. 2 is a schematic diagram of another gas treatment system disclosed herein;

[0017] FIG. 3 is a schematic diagram of another flue treatment system disclosed herein; and

[0018] FIG. 4 is a schematic diagram of another flue treatment system disclosed herein.

DETAILED DESCRIPTION

[0019] As illustrated in FIG. 1, a flue gas treatment system for use in a chilled ammonia based CO₂ removal system is generally designated by the numeral 10. The flue gas treatment system 10 receives flue gas in a flue gas polisher (e.g., first stage 20) where residual contaminants and particulate matter are removed from the flue gas after initial treatment by upstream flue gas treatment systems such as scrubbers, electrostatic precipitators and bag houses (not shown). The polished flue gas is then cooled in a multi-stage cooler

(e.g., a direct contact cooler, having second stage 30, third stage 40 and fourth stage 50 coolers) in preparation for transport of the cooled (e.g., chilled) flue gas into a CO₂ absorber 78, as described below. The CO₂ absorber 78 uses an ammonia or amine based solution to absorb CO₂ from the cooled flue gas. CO₂ lean flue gas is discharged from the CO₂ absorber along with NH₃ absorbed by the flue gas, to a NH₃ water wash system 77 for initial removal of NH₃ from the CO₂ lean flue gas. The CO₂ lean flue gas is subsequently conveyed to another NH₃ removal system (e.g., fifth stage 60 and sixth stage 70 of a direct contact heater) in which the CO₂ lean flue gas is heated and polished by removing residual NH₃ prior to discharge to a stack (not shown).

[0020] The flue gas treatment system 10 includes a heat exchanger 16 that assists in the heating of the flue gas in the fifth stage 60 and assists in cooling the flue gas in the third stage 40. Use of the heat exchanger 16 reduces load on a chiller system 19 which is used to cool the flue gas in the fourth stage 50, thereby increasing the efficiency of the flue gas treatment system 10 compared to prior art systems, as described below. In one embodiment, the heat exchanger is operable to affect about a 5 °C to about 25 °C reduction in temperature of the gas flowing through the direct contact cooler, as described herein.

[0021] Referring to FIG. 1, the flue gas treatment system 10 includes a six stage Direct Contact Cooler (DCC)/Direct Contact Heater (DCH) stack 12 arranged in a common tower. In the embodiment illustrated in FIG. 1, the DCC includes a first stage 20, in fluid communication with a second stage 30. The DCC also includes a third stage 40 in fluid communication with and positioned between the second stage 30 and a fourth stage 50. The second stage 30 is positioned between the first stage 20 and the third stage 40. The DCH includes a fifth stage 60 in fluid communication with a sixth stage 70. The first stage is a polishing system for removal of contaminants, such as residual SO₂, SO₃ and fly ash, from the CO₂ rich flue gas, for example flue gas discharged from a furnace (not shown) combusting pulverized coal. The fifth stage 60 is a NH₃ polishing system for removal of residual NH₃ from the CO₂ lean flue gas. The DCC and the DCH are mechanically coupled to one another by a separator 14 positioned between the fourth stage 50 and the fifth stage 60. The flue gas treatment system 10 includes a heat exchanger 16 which defines a first side and a second side separated from one another. The first side of the heat exchanger 16 defines a first inlet 71 in fluid communication with the sixth stage 70 and a first outlet 41 in fluid communication with the third stage 40. The second side of the heat exchanger 16 defines a second inlet 61 for receiving a fluid (e.g., AS solution) cooled by chilled CO₂ lean flue gas and a second outlet 62 for discharging the fluid after heating in the heat exchanger 16, each

being in fluid communication with the fifth stage 60. In one embodiment, the heat exchanger 16 is a non-direct contact heat exchanger such as, but not limited to, a tube and shell heat exchanger.

[0022] While the flue gas treatment system 10 is shown and described as having six stages, the present disclosure is not limited in this regard as flue gas treatment systems with any number of stages of DCC and/or DCH may be employed. For example, a flue gas treatment system 110 having five stages (i.e., a first stage 120, a second stage 130, a third stage 150, a fourth stage 160 and a fifth stage 170, similar to first stage 20, the second stage 30, the fourth stage 50, the fifth stage 60 and the sixth stage 70 of the flue gas treatment system 10 of FIG. 1, respectively but having no stage that corresponds to the third stage 40 of the DCC of FIG. 1.), is described below with reference to FIG. 2. In addition, a flue gas treatment system 210 having five stages (i.e., a first stage 230, a second stage 240, a third stage 250, a fourth stage 260 and a fifth stage 270, similar to the second stage 30, the third stage 40, the fourth stage 50, the fifth stage 60 and the sixth stage 70 of the flue gas treatment system 10 of FIG. 1, respectively but having no stage that corresponds to the first stage 20 of the DCC of FIG. 1.), is described below with reference to FIG. 3. Furthermore, a flue gas treatment system 310 having four stages (i.e., a first stage 330, a second stage 350, a third stage 360 and a fourth stage 370, similar to the second stage 30, the fourth stage 50, the fifth stage 60 and the sixth stage 70 of the flue gas treatment system 10 of FIG. 1, respectively but having no stages that correspond to the first stage 20 or third stage 40 of the DCC of FIG. 1.), is described below with reference to FIG. 4.

[0023] In addition, although one heat exchanger 16 is shown and described, the present disclosure is not limited in this regard as more than one heat exchanger may be employed. While the fourth stage 50 and the fifth stage 60 are shown and described as being coupled to one another and positioned in a common tower the present disclosure is not limited in this regard as the fourth and fifth stages may be separated from one another. Although the flue gas treatment system 10 is described for treating flue gas, the present disclosure is not limited in this regard as the treatment system 10 may also be used to treat other gases.

[0024] The DCC of the flue gas treatment system 10 includes a first chiller system 19 which has an inlet 51 and an outlet 52 in fluid communication with the fourth stage 50. The first chiller system 19 includes a refrigeration system 53 that cools fluids flowing therethrough via the inlet 51 and the outlet 52, as described below. The heat exchanger 16 is operable to reduce cooling requirements of the chiller system 19.

[0025] As illustrated in FIG. 1 the first stage 20 of the DCC is a flue gas polishing system for removal of contaminants from the CO_2 rich flue gas such as residual SO_2 , SO_3 and fly ash. The first stage 20 includes a flue gas inlet 21 for receiving the CO_2 rich flue gas from an upstream source 22, such as, but not limited to a scrubber or a furnace combusting pulverized coal. The flue gas treatment system 10 having the first stage 20 for flue gas polishing can also be utilized to treat flue gas from a combined cycle power plant having a gas turbine (e.g., natural gas combustion gas turbine). However, as described below with reference to FIGS. 3 and 4 the first stage 20 for flue gas polishing may be eliminated for treatment of flue gas from such combined cycle power plants, because of the low level or absence of SO_2 , SO_3 and fly ash, generated by combustion of natural gas in gas turbines.

[0026] The first stage 20 also includes a first flue gas passage 23 which communicates with the second stage 30 for conveying flue gas into the second stage. The first stage 20 includes an ammonia inlet 24 for supplying an ammonia solution to the first stage, for example ammonium sulfate (AS). The first stage 20 includes an AS outlet 25 that is in fluid communication with an inlet of a first pump 26. The first pump 26 defines an outlet that is in fluid communication with a first liquid distribution system 27 via a line 28. The first liquid distribution system 27 is disposed in an interior area defined by the first stage 20. The first liquid distribution system 27 is configured with a plurality of spray nozzles 29 which are operable to disperse the AS, for example an AS solution having a pH of about 4 to 6, into the interior area of the first stage 20 so that the flue gas can communicate with and remove contaminants such as but not limited to SO_2 , SO_3 and fly ash from the flue gas.

[0027] As illustrated in FIG. 1, the second stage 30 of the DCC is a cooler, for example, a direct contact cooler stage for reducing the temperature of the CO_2 rich flue gas flowing therethrough in preparation for CO_2 removal in the chilled ammonia based CO_2 absorber 77, as described herein. The second stage 30 is configured to receive flue gas from the first stage 20 via the first flue gas passage 23. The second stage 30 includes a second flue gas passage 31 which communicates with the third stage 40 for conveying flue gas into the third stage. The second stage 30 includes an inlet 32 that is in fluid communication with a second liquid distribution system 33 disposed in an interior area defined by the second stage 30. The second liquid distribution system 33 is configured similar to the first liquid distribution system 27 described above. The inlet 32 is in fluid communication with a supply of a cooling liquid, for example circulating water from a cooling tower 34. The fluid communication between the inlet 32 and the cooling tower 34 is provided via a line 35 extending from a cool side outlet 36 of the cooling tower. The cooling tower 34 includes an

inlet 37 that is in fluid communication with an outlet 72 of the sixth stage 70. The cooling tower 34 includes conduits 38 for flowing a stream of air through the cooling tower.

[0028] Still referring to FIG. 1, the third stage 40 of the DCC is a cooler, for example, a direct contact cooler stage for reducing the temperature of the CO₂ rich flue gas flowing therethrough in preparation for CO₂ removal in the chilled ammonia based CO₂ absorber 77, as described herein. The third stage 40 is configured to receive flue gas from the second stage 30 via the second flue gas passage 31. The third stage 40 includes a third flue gas passage 42 which communicates with the fourth stage 50 for conveying flue gas into the fourth stage. The third stage 40 includes an inlet 43 that is in fluid communication with a third liquid distribution system 44 disposed in an interior area defined by the third stage 40. The third liquid distribution system 44 is configured similar to the first liquid distribution system 27 described above. The inlet 43 is in fluid communication with the first outlet 41 of the heat exchanger 16 which is used to cool the flue gas in the third stage 40.

[0029] Still referring to FIG. 1, the fourth stage 50 of the DCC is a cooler, for example, a direct contact cooler stage for reducing the temperature of the CO₂ rich flue gas flowing therethrough in preparation for CO₂ removal in the chilled ammonia based CO₂ absorber 77, as described herein. The fourth stage 50 is configured to receive flue gas from the third stage 40 via the third flue gas passage 42. The fourth stage 50 includes a fourth flue gas passage 54 which communicates with a flue gas outlet 55 for conveying cooled CO₂ rich flue gas out of the fourth stage to the CO₂ absorber 77 (see connecting blocks marked A). The fourth stage 50 includes an inlet 57 that is in fluid communication with a fourth liquid distribution system 58 disposed in an interior area defined by the fourth stage 50. The fourth liquid distribution system 58 is configured similar to the first liquid distribution system 27 described above. The inlet 57 is in fluid communication with the outlet 52 of the first chiller system 19. The fourth stage 50 includes an outlet 59 that is in fluid communication with the inlet 51 to the first chiller system 19 which is used to cool the flue gas in the fourth stage 50. In one embodiment, a second pump 39 is disposed in a line 59A connecting the outlet 59 of the fourth stage 50 to the inlet 51 of the first chiller system 19, for conveying fluid through the line 59A.

[0030] In the embodiment illustrated in FIG. 1, the fifth stage 60 of the DCH is a direct contact heater for heating the CO₂ lean flue gas therein. The fifth stage is also a NH₃ polishing system for removal of residual NH₃ from the CO₂ lean flue gas. The fifth stage 60 includes an inlet 63 for supplying sulfuric acid (S₂SO₄) to an interior area defined by the fifth stage for removal of the NH₃ from the flue gas as the flue gas is heated by the sulfuric acid.

The fifth stage 60 includes an outlet 64 that is in fluid communication with a suction side of a third pump 65 for conveying sulfuric acid which has cooled as a result of transferring heat to the flue gas. An outlet of the third pump 65 is in fluid communication with the second inlet 61 of the heat exchanger 16 which utilizes the cooled sulfuric acid to cool a fluid, for example water, received from a cooling tower 34, as described herein. The outlet of the third pump 65 is also in fluid communication with an AS purge line 11, which is connected to an AS purge system (not shown) for adjusting AS concentration. The fifth stage 60 includes an inlet 66 that is in fluid communication with a fifth liquid distribution system 67 disposed in an interior area defined by the fifth stage 60. The fifth liquid distribution system 67 is configured similar to the first liquid distribution system 27 described above. The inlet 66 is in fluid communication with the second outlet 62 of the heat exchanger 16. In the illustrated embodiment, a fluid flowing through the second inlet 61 flows into a shell side of the heat exchanger 16 and exits through the second outlet 62. Another fluid, for example, water from a circulating water system, flows through the first inlet 71 of the heat exchanger 16 into an interior area of tubes 74 disposed in the shell side and is discharged through the first outlet 41. The first inlet 71 of the heat exchanger 16 is in fluid communication with a branch connection 73 on the line 35.

[0031] The flue gas treatment system 10 includes ammonia and/or amine based CO₂ capture systems, including, for example, a CO₂ absorber 77 for removing CO₂ from the flue gas and water wash systems, for example, the NH₃ water wash system 78 for receiving CO₂ lean flue gas and for removing ammonia absorbed by the CO₂ lean flue gas in the CO₂ absorber, as shown in FIG. 1 and similar to those disclosed in commonly owned and copending U.S. Patent Application Serial No. 12/556,043, (Publication No. US 2010-0083831), entitled "Chilled Ammonia Based CO₂ Capture System with Water Wash System," filed September 9, 2009, and U.S. Patent Application Serial No. 12/849,128 (Publication No. 2001/0068585, entitled "Method and System for Capturing and Utilizing Energy Generated in a Flue Gas Stream Processing System" filed August 3, 2010, which are incorporated herein by reference in their entirety. The fifth stage 60 includes a flue gas inlet 68. The flue gas inlet 68 is in fluid communication with the NH₃ water wash system 78 positioned upstream of the flue gas inlet 68. The NH₃ water wash system 78 is in fluid communication with the CO₂ absorber 77, positioned upstream of the NH₃ water wash system. The CO₂ absorber 77 is in fluid communication with the fourth stage 50 via the outlet 55 and the line 76. The fifth stage 60 also includes a fifth flue gas passage 69 which provides fluid communication between the fifth stage 60 and the sixth stage 70.

[0032] As illustrated in FIG. 1, the sixth stage 70 is configured to receive and heat cooled CO₂ lean flue gas from the fifth stage 60 via the fifth flue gas passage 69. The sixth stage 70 includes an outlet 75 which discharges flue gas from the sixth stage. In one embodiment, the flue gas is discharged from the outlet 75 to a stack. The sixth stage 70 includes an inlet 79 that is in fluid communication with an outlet 80 of the second stage 30. The inlet 79 is in fluid communication with a sixth liquid distribution system 87 disposed in an interior area defined by the sixth stage 70. The sixth liquid distribution system 87 is configured similar to the first liquid distribution system 27 described above. A fourth pump 81 is provided in a line 82 connecting the outlet 80 of the second stage 30 and the inlet 79 of the sixth stage 70.

[0033] In the embodiment illustrated in FIG. 1, the first stage 20 is in fluid communication with the fifth stage 60 via a line 85 for adjusting the concentration and pH of the AS solution disposed in the fifth stage 60.

[0034] The flue gas treatment system 110 of FIG. 2 is similar to the flue gas treatment system 10 of FIG. 1. Accordingly, like elements have been assigned similar element numbers preceded by the numeral 1. As illustrated in FIG. 2, a flue gas treatment system 110 for use in a chilled ammonia based CO₂ removal system is generally designated by the numeral 110. The flue gas treatment system 110 includes a five stage Direct Contact Cooler (DCC)/Direct Contact Heater (DCH) 112, including a DCC having a first stage 120, a second stage 130 and a third stage 150, similar to first stage 20, second stage 30 and the fourth stage 50 of FIG. 1, respectively. However, the DCC of the flue gas treatment system 110 of FIG. 2 has no stage that corresponds to the third stage 40 of the DCC of FIG. 1. The DCH includes a fourth stage 160 and a fifth stage 170, similar to the fifth stage 60 and sixth stage 70 of FIG. 1, respectively.

[0035] In the embodiment illustrated in FIG. 2, the first stage 120 is in fluid communication with the second stage 130. The second stage 130 is in fluid communication with and positioned between the first stage 130 and the third stage 150. The fourth stage 160 is in fluid communication with the fifth stage 170. The DCC and the DCH are mechanically coupled to one another by a separator 114 positioned between the third stage 150 and the fourth stage 160.

[0036] The first stage 120, the second stage 130, the third stage 150, the fourth stage 160 and the fifth stage 170 are configured similar to the first stage 20, the second stage 30, the fourth stage 50, the fifth stage 60 and the sixth stage 70, respectively, of the DCC/DCH 12 described above, with the following notable exceptions. The flue gas treatment system

110 includes a heat exchanger 116 which defines a first side and a second side separated from one another. The first side defines a first inlet 171 and a first outlet 141. The second side defines a second inlet 161 and a second outlet 162. In one embodiment, the heat exchanger 116 is a non-direct contact heat exchanger such as, but not limited to, a tube and shell heat exchanger.

[0037] The first inlet 171 and the first outlet 141 are in fluid communication with a CO₂ absorber 177. The CO₂ absorber 177 defines two inlets 190 and 191 and two outlets 192 and 193. The CO₂ absorber 177 is in fluid communication with the heat exchanger 116 via a line 141B connected between the first outlet 141 of the heat exchanger and the inlet 191 of the CO₂ absorber. The outlet 192 of the CO₂ absorber 177 is in fluid communication with an ammonia regenerator system 183. The outlet 192 of the CO₂ absorber 177 includes a branch connection 188 which is in fluid communication with the first inlet 171 of the heat exchanger 116. A second refrigeration based chiller system 184 is in fluid communication with the CO₂ absorber 177 via the inlet 190. The second chiller system 184 includes an inlet 186 that is in fluid communication with the ammonia regenerator 183. In one embodiment, the first outlet 141 of the heat exchanger 116 includes a branch connection 141A that is in fluid communication with the second chiller system 184. The outlet 193 of the CO₂ absorber 177 is in fluid communication with a NH₃ water wash system 178. The heat exchanger 116 is operable to reduce cooling requirements of the second chiller system 184, as described in detail below.

[0038] As illustrated in FIG. 3, a flue gas treatment system 210 for use in a chilled ammonia CO₂ based removal system is similar to the flue gas treatment system 10 of FIG. 1, thus, similar elements have been assigned similar element numbers preceded by the numeral 2. The flue gas treatment system 210 includes a five stage Direct Contact Cooler (DCC)/Direct Contact Heater (DCH) stack 212. In the embodiment illustrated in FIG. 3, the DCC includes a first stage 230, in fluid communication with a second stage 240, which are similar to the second stage 30 and the third stage 40 of the DCC of FIG. 1. The third stage 250 is positioned between the second stage 240 of the DCC and a fourth stage 260 of the DCH. However, the DCC of the flue gas treatment system 210 of FIG. 3 does not include a flue gas polishing stage similar to the first stage 20 of FIG. 1. The first stage 20 for flue gas polishing has been eliminated in the flue gas treatment system 210 of FIG. 3 because of the low level or absence of SO₂, SO₃ and fly ash in flue gas from combined cycle power plants utilizing gas turbines.

[0039] Referring to FIG. 3, the DCH of the flue gas treatment system 210 includes a fourth stage 260 in fluid communication with a fifth stage 270. The fourth stage 260 is a NH_3 polishing system for removal of residual NH_3 from the flue gas. The DCC and the DCH are coupled to one another by a separator 214 positioned between the third stage 250 and the fourth stage 260. The flue gas treatment system 210 includes a heat exchanger 216 which defines a first side and a second side separated from one another. The first side of the heat exchanger 216 defines a first inlet 271 in fluid communication with the fifth stage 270 and a first outlet 241 in fluid communication with the second stage 240. The second side of the heat exchanger 216 defines a second inlet 261 and a second outlet 262, each being in fluid communication with the fourth stage 260. In one embodiment, the heat exchanger 216 is a non-direct contact heat exchanger such as, but not limited to, a tube and shell heat exchanger.

[0040] Referring to FIG. 3, the DCC of the flue gas treatment system 210 includes a first chiller system 219 which has an inlet 251 and an outlet 252 in fluid communication with the fourth stage 250. The first chiller system 219 includes a refrigeration system 253 that cools fluids flowing through the inlet 251 and the outlet 252, as described below. The heat exchanger 216 is operable to reduce cooling requirements of the chiller system 219.

[0041] As illustrated in FIG. 3 the first stage 230 of the DCC includes a flue gas inlet 221 for receiving CO_2 rich flue gas from an upstream source 222, such as, but not limited to a combined cycle power plant having a gas turbine for combusting natural gas. The first stage 230 includes a first flue gas passage 231 which communicates with the second stage 240 for conveying flue gas into the third stage. The first stage 230 includes an inlet 232 that is in fluid communication with a first liquid distribution system 233 disposed in an interior area defined by the first stage 230. The first liquid distribution system 233 is configured similar to the first liquid distribution system 27 described above, with reference to FIG. 1. The inlet 232 is in fluid communication with a supply of a cooling liquid, for example circulating water from a cooling tower 234. The fluid communication between the inlet 232 and the cooling tower 234 is provided via a line 235 extending from a cool side outlet 236 of the cooling tower. The cooling tower 234 includes an inlet 237 that is in fluid communication with an outlet 272 of the fifth stage 270. The cooling tower 234 includes conduits 238 for flowing a stream of air through the cooling tower.

[0042] Still referring to FIG. 3, the second stage 240 is a DCC configured to receive CO_2 rich flue gas from the first stage 230 via the second flue gas passage 231. The second stage 240 includes a second flue gas passage 242 which communicates with the third stage 250 for conveying flue gas into the fourth stage. The second stage 240 includes an inlet 243

that is in fluid communication with a second liquid distribution system 244 disposed in an interior area defined by the second stage 240. The second liquid distribution system 244 is configured similar to the first liquid distribution system 27 described above, with reference to FIG. 1. The inlet 243 is in fluid communication with the first outlet 241 of the heat exchanger 216.

[0043] Still referring to FIG. 3, the third stage 250 is a DCC configured to receive CO₂ rich flue gas from the second stage 240 via the second flue gas passage 242. The third stage 250 includes a third flue gas passage 254 which communicates with a flue gas outlet 255 for conveying CO₂ rich flue gas out of the third stage. The third stage 250 includes an inlet 257 that is in fluid communication with a third liquid distribution system 258 disposed in an interior area defined by the third stage 250. The third liquid distribution system 258 is configured similar to the first liquid distribution system 27 described above, with reference to FIG. 1. The inlet 257 is in fluid communication with the outlet 252 of the first chiller system 219. The third stage 250 includes an outlet 259 that is in fluid communication with the inlet 251 to the first chiller system 219. In one embodiment, a second pump 239 is disposed in a line 259A connecting the outlet 259 of the third stage 250 to the inlet 251 of the first chiller system 219, for conveying fluid through the line 259A.

[0044] In the embodiment illustrated in FIG. 3, the fourth stage 260 is a DCH for heating the CO₂ lean flue gas therein. The fourth stage 260 is also a NH₃ polishing system for removal of residual NH₃ from the CO₂ flue gas. The fourth stage 260 includes an inlet 263 for supplying sulfuric acid (S₂SO₄) to an interior area defined by the fourth stage. The fourth stage 260 includes an outlet 264 that is in fluid communication with a suction side of a third pump 265. An outlet of the third pump 265 is in fluid communication with the second inlet 261 of the heat exchanger 216. The outlet of the third pump 265 is also in fluid communication with an AS purge line 211, which is connected to an AS purge system (not shown). The fourth stage 260 includes an inlet 266 that is in fluid communication with a fourth liquid distribution system 267 disposed in an interior area defined by the fourth stage 260. The fourth liquid distribution system 267 is configured similar to the first liquid distribution system 27 described above, with reference to FIG. 1. The inlet 266 is in fluid communication with the second outlet 262 of the heat exchanger 216. In the illustrated embodiment, a fluid flowing through the second inlet 261 flows into a shell side of the heat exchanger 216 and exits through the second outlet 262. Another fluid, for example, water from a circulating water system, flows through the first inlet 271 of the heat exchanger 216 into an interior area of tubes 274 disposed in the shell side and is discharged through the first

outlet 241. The first inlet 271 of the heat exchanger 216 is in fluid communication with a branch connection 273 on the line 235.

[0045] Referring to FIG. 3, the fourth stage 260 includes a flue gas inlet 268. The flue gas inlet 268 is in fluid communication with a NH_3 water wash system 278 positioned upstream of the flue gas inlet 268. The NH_3 water wash system 278 is in fluid communication with a CO_2 absorber 277, positioned upstream of the NH_3 water wash system. The CO_2 absorber 277 is in fluid communication with the third stage 250 via the outlet 255 and the line 276. The fourth stage 260 also includes a fourth flue gas passage 269 which provides fluid communication between the fourth stage 260 and the fifth stage 270.

[0046] As illustrated in FIG. 3, the fifth stage 270 is configured to receive flue gas from the fourth stage 260 via the fourth flue gas passage 269. The fifth stage 270 includes an outlet 275 which discharges flue gas from the fifth stage. In one embodiment, the flue gas is discharged from the outlet 275 to a stack. The fifth stage 270 includes an inlet 279 that is in fluid communication with an outlet 280 of the first stage 230. The inlet 279 is in fluid communication with a fifth liquid distribution system 287 disposed in an interior area defined by the fifth stage 270. The fifth liquid distribution system 287 is configured similar to the first liquid distribution system 27 described above, with reference to FIG. 1. A fourth pump 281 is provided in a line 282 connecting the outlet 280 of the first stage 230 and the inlet 279 of the fifth stage 270.

[0047] The flue gas treatment system 310 of FIG. 4 is similar to the flue gas treatment system 10 of FIG. 2. Accordingly, like elements have been assigned similar element numbers with the leading numeral 1 replaced with the numeral 3. As illustrated in FIG. 4, a flue gas treatment system 310 for use in a chilled ammonia based CO_2 removal system is generally designated by the numeral 310. The flue gas treatment system 310 includes a four stage Direct Contact Cooler (DCC)/Direct Contact Heater (DCH) 312, having a first stage 330, a second stage 350, a third stage 360 and a fourth stage 370, similar to the second stage 30, the fourth stage 50, the fifth stage 60 and the sixth stage 70 of the flue gas treatment system 10 of FIG. 1, respectively. However, the flue gas treatment system 310 of FIG. 4 has no stages that correspond to the first stage 20 or the third stage 40 of the flue gas treatment system 10 of FIG. 1.

[0048] In the embodiment illustrated in FIG. 4, the first stage 330 is in fluid communication with second stage 350. The third stage 360 is in fluid communication with the fourth stage 370. The DCC and the DCH are mechanically coupled to one another by a separator 314 positioned between the second stage 350 and the third stage 360.

[0049] The first stage 330, the second stage 350, the third stage 360 and the fourth stage 370 illustrated in FIG. 4 are configured similar to the second stage 130, the third stage 150, the fourth stage 160 and the fifth stage 170, as described above for the flue gas treatments system 110 illustrated in FIG. 2. However, the first stage 330 includes an inlet 321 for receiving flue gas from an upstream source 322, such as, but not limited to a combined cycle power plant having a gas turbine for combusting natural gas.

[0050] Referring to FIG. 4, the flue gas treatment system 310 includes a heat exchanger 316 which defines a first side and a second side separated from one another. The first side defines a first inlet 371 and a first outlet 341. The second side defines a second inlet 361 and a second outlet 362. In one embodiment, the heat exchanger 316 is a non-direct contact heat exchanger such as, but not limited to, a tube and shell heat exchanger.

[0051] Referring to FIG. 4, the first inlet 371 and the first outlet 341 are in fluid communication with a CO₂ absorber 377. The CO₂ absorber 377 defines two inlets 390 and 391 and two outlets 392 and 393. The CO₂ absorber 377 is in fluid communication with the heat exchanger 316 via a line 341B connected between the first outlet 341 of the heat exchanger and the inlet 391 of the CO₂ absorber. The outlet 392 of the CO₂ absorber 377 is in fluid communication with an ammonia regenerator system 383. The outlet 392 of the CO₂ absorber 377 includes a branch connection 388 which is in fluid communication with the first inlet 371 of the heat exchanger 316. A second refrigeration based chiller system 384 is in fluid communication with the CO₂ absorber 377 via the inlet 390. The second chiller system 384 includes an inlet 386 that is in fluid communication with the ammonia regenerator 383. In one embodiment, the first outlet 341 of the heat exchanger 316 includes a branch connection 341A that is in fluid communication with the second chiller system 384. The outlet 393 of the CO₂ absorber 377 is in fluid communication with a NH₃ water wash system 378. The heat exchanger 316 is operable to reduce cooling requirements of the second chiller system 384, as described in detail below.

[0052] During operation of the flue gas treatment system 10 of FIG. 1, the DCC cools hot flue gas supplied via the inlet 121 from a temperature of about 40 to 60 °C to about 5 to 10 °C. The cooling occurs in the second stage 30, the third stage 40 and the fourth stage 50. The DCH heats the flue gas from about 5 to 10 °C to about 40 to 60 °C. The heating occurs in the fifth stage 60 and the sixth stage 70.

[0053] The cooling in the second stage 30 is generally affected by cooling water from the cooling tower 34. The cooling in the third stage 40 is generally affected by cooling water from the heat exchanger. The heat exchanger 16 heats the flue gas in the fifth stage 60 with

heat extracted from the flue gas in the third stage 40, thereby cooling the flue gas in the third stage. The cooling in the fourth stage 50 is affected by the first chiller system 19. Load on the chiller system 19 is reduced by the cooling provided by the heat exchanger 16. The heating in the fifth stage 60 is affected by the heat exchanger 16 as described above. Heating in the sixth stage 70 is affected by the flow of water from the second stage 30 which absorbs heat from the flue gas flowing there through.

[0054] The first stage 20 treats the hot flue gas with a solution of ammonia, for example an ammonium sulfate (AS) solution having a pH of about 4 to 6, to remove SO_2 , SO_3 and fly ash from the hot flue gas. The flue gas is discharged from the first stage 20 via the first flue gas passage 23 into the second stage 30 at a temperature of about 40 to 60 °C. The flue gas is cooled in the second stage 30 from about 40 to 60 °C to about 30 to 40 °C, by passing the flue gas through a spray of water supplied to the second liquid distribution system 33. The water is supplied to the liquid distribution system 33 at a temperature of about 15 to 25 °C, via the inlet 32. The water supplied to the inlet 32 is supplied from the cooling tower 34. Thus, the temperature of the water supplied to the second liquid distribution system 33 is dependent on ambient conditions, for example, the temperature of the air stream passing through the conduits 38 of the cooling tower 34.

[0055] The flue gas is conveyed to the third stage 40 via the second flue gas passage 31. The flue gas is cooled in the third stage 40 from about 30 to 40 °C to about 15 to 25 °C, by the heat exchanger 16. Thus, the heat exchanger is operable to affect about a 5 °C to about a 25 °C reduction in temperature of the flue gas flowing through the third stage 40. In one embodiment, the heat exchanger is operable to affect about an 8 °C to about a 12 °C reduction in temperature of the flue gas flowing through the third stage 40.

[0056] The heat exchanger 16 receives water from the cooling tower 34 at a temperature of about 15 to 25°C, depending upon ambient temperature conditions. The heat exchanger 16 affects about a 5 °C to about a 15 °C reduction in temperature of water supplied to the heat exchanger from the cooling tower 34. Thus water is supplied to the third liquid distribution system 44, from the heat exchanger, at a temperature of about 10 °C to 15 °C. The flue gas is passed through a spray of water supplied to the third liquid distribution system 44.

[0057] An ammonium sulfate (AS) solution having a temperature of about 5 to 10°C is conveyed through the second side of the heat exchanger 16 from the fifth stage 60. Heat is transferred from the water in the first side of the heat exchanger 16 to the AS solution in the second side of the heat exchanger. The AS solution is heated to about 15 to 25°C in the heat

exchanger 16. Thus, the heat exchanger 16 affects about a 10 °C to 15 °C increase in temperature of the AS solution entering the second side of the heat exchanger at the inlet 61.

[0058] The flue gas is conveyed to the fourth stage 50 via the third flue gas passage 42. The flue gas is cooled in the fourth stage 50 from about 15 to 25 °C to about 5 °C $\pm$ 5 °C, by the first chiller system 19. For example, the flue gas is passed through a spray of water supplied to the fourth liquid distribution system 58. The water is supplied to the fourth liquid distribution system 58 at a temperature of about 5 °C $\pm$ 5 °C, via the inlet 57. The water supplied to the inlet 57 is supplied from the first chiller system 19 via the outlet 52. Thus, the first chiller system 19 affects about a 10 °C to 15 °C reduction in temperature of the flue gas flowing through the fourth stage 50. The flue gas is discharged from the fourth stage 50 to the CO₂ absorber 77, via a path through the fourth flue gas passage 54, the outlet 55 and the line 76. The flue gas is discharged from the fourth stage 50 at a temperature of about 5 °C $\pm$ 5 °C.

[0059] The CO₂ absorber 77 removes CO₂ from the flue gas, after which the CO₂ lean flue gas is conveyed to the NH₃ water wash system 78 for removal of ammonia from the flue gas. The flue gas is transported from the NH₃ water wash system 78 to the fifth stage 60 of the DCH at about 5 °C $\pm$ 5 °C. The flue gas is heated in the fifth stage 60 from about 5 °C $\pm$ 5 °C to about 15 to 25 °C. The fifth stage 60 is an ammonia polishing system that produces AS from a reaction between sulfuric acid and ammonia contained in the flue gas. The AS solution is circulated through the fifth stage 60 and the shell side of the heat exchanger 16 via the third pump 65. The AS solution is supplied from the second outlet 62 of the heat exchanger 16 at a temperature of about 17 to 25 °C to the liquid distribution system 67. The liquid distribution system 67 sprays the AS solution into the interior area of the fifth stage 60 for communication with the flue gas and removal of the NH₃ from the flue gas. The spraying of the AS solution increases the temperature of the flue gas to about 15 to 25 °C. The AS solution is heated in the heat exchanger from about 5 °C $\pm$ 5 °C to about 15 °C to 25 °C. The heating of the AS solution and evaporation of water in the flue gas increases the concentration of the AS solution. For example, the concentration of the AS solution is increased to about 40 weight % ($\pm$ 5 weight %). Increasing the concentration of the AS solution to about 40 weight % reduces the amount of AS purging required via the AS purge line 11. The concentration of the AS solution can be further controlled by conveying portions of the AS solution contained in the first stage 20 via the recirculation line 85. The flue gas is conveyed from the fifth stage 60 to the sixth stage 70 at a temperature of about 15 to 20 °C, via the fifth flue gas passage 69.

[0060] The flue gas is heated in the sixth stage from about 15 to 25 °C to about 40 to 60 °C by exposing the flue gas to a spray of water supplied from the outlet 80 of the second stage 30. The water is supplied from the outlet 80 of the second stage 30 at temperature of about 40 to 60 °C, via the fourth pump 81 and the line 82. The 40 to 60 °C water is conveyed to the liquid distribution system 87 which sprays the water into an interior area defined by the sixth stage 70. The flue gas is discharged from the sixth stage 70, via the outlet 75, to the stack. The water sprayed into the interior area of the sixth stage 70 is cooled to about 15 to 25 °C and is discharged from the sixth stage to the cooling tower 34, via the outlet 72, for further cooling, depending upon the ambient temperature.

[0061] The flue gas treatment system 110 of FIG. 2 is operated similar to the flue gas treatment system 10 described above, except for the notable exceptions described below. Since the flue gas treatment system 110 does not include a stage that corresponds to the third stage of the flue gas treatment system 10, the first inlet 171 of the heat exchanger 116 is not in fluid communication with the cooling tower 134 and the first outlet 141 is not in fluid communication with the third stage. Instead, since the heat exchanger 116 is in fluid communication with the CO₂ absorber 177, the heat exchanger cools a solution containing CO₂, supplied from the CO₂ absorber. About 85 to 90% of the solution discharged from the CO₂ absorber 177 is conveyed to the second chiller system 184 via a path through the second absorber outlet 192, the regenerator 183 and the second chiller inlet 186. About 10 to 15% of the solution discharged from the CO₂ absorber 177 is conveyed to the heat exchanger 116 via a path through the branch connection 188 and the first inlet 171. The solution is cooled in the tube side of the heat exchanger 116 from about at a temperature of about 30 °C $\pm$ 5 °C to about 15 °C to about 20 °C. Thus, the heat exchanger 116 affects about a 5 °C to about 20 °C reduction in temperature of the solution entering the first side 171 of the heat exchanger. The cooled solution is discharged from the heat exchanger 116 via the first outlet 141 into the CO₂ absorber 177 via the first absorber inlet 191. A portion of the cooled solution discharged from the heat exchanger 116 is discharged into the second chiller system 184 via the branch connection 141A. Discharge of the cooled solution into the second chiller system 184 or into the CO₂ absorber 177 reduces the amount of cooling required by the second chiller system 184, compared to comparable systems having no such heat exchanger.

[0062] During operation of the flue gas treatment system 210 of FIG. 3, the DCC cools hot flue gas supplied via the inlet 221 from a temperature of about 40 to 60 °C to about 5 to 10 °C. The cooling occurs in the first stage 230, the second stage 40 and the third stage

250. The DCH heats the flue gas from about 5 to 10 °C to about 40 to 60 °C. The heating occurs in the fourth stage 260 and the fifth stage 270.

[0063] The cooling in the first stage 230 is generally affected by cooling water from the cooling tower 234. The cooling in the second stage 240 is generally affected by cooling water from the heat exchanger 216. The heat exchanger 216 heats the flue gas in the fourth stage 260 with heat extracted from the flue gas in the second stage 240, thereby cooling the flue gas in the third stage 250. The cooling in the third stage 250 is affected by the first chiller system 219. Load on the chiller system 219 is reduced by the cooling provided by the heat exchanger 216. The heating in the fourth stage 260 is affected by the heat exchanger 216 as described above. Heating in the fifth stage 270 is affected by the flow of water from the first stage 230 which absorbs heat from the flue gas flowing therethrough.

[0064] The flue gas is cooled in the first stage 230 from about 40 to 60 °C to about 30 to 40 °C, by passing the flue gas through a spray of water supplied to the second liquid distribution system 233. The water is supplied to the liquid distribution system 233 at a temperature of about 15 to 25 °C, via the inlet 232. The water supplied to the inlet 232 is supplied from the cooling tower 234. Thus, the temperature of the water supplied to the second liquid distribution system 233 is dependent on ambient conditions, for example, the temperature of the air stream passing through the conduits 238 of the cooling tower 234.

[0065] The flue gas is conveyed to the second stage 240 via the first flue gas passage 231. The flue gas is cooled in the second stage 240 from about 30 to 40 °C to about 15 to 25 °C, by the heat exchanger 216. Thus, the heat exchanger is operable to affect about a 5 °C to about a 25 °C reduction in temperature of the flue gas flowing through the second stage 240. In one embodiment, the heat exchanger is operable to affect about an 8 °C to about a 12 °C reduction in temperature of the flue gas flowing through the second stage 240.

[0066] The heat exchanger 216 receives water from the cooling tower 234 at a temperature of about 15 to 25°C, depending upon ambient temperature conditions. The heat exchanger 216 affects about a 5 °C to about a 15 °C reduction in temperature of water supplied to the heat exchanger from the cooling tower 234. Thus water is supplied to the second liquid distribution system 244, from the heat exchanger 216, at a temperature of about 10 °C to 15 °C. The flue gas is passed through a spray of water supplied to the second liquid distribution system 244.

[0067] An ammonium sulfate (AS) solution having a temperature of about 5 to 10°C is conveyed through the second side of the heat exchanger 216 from the fourth stage 260. Heat is transferred from the water in the first side of the heat exchanger 216 to the AS

solution in the second side of the heat exchanger. The AS solution is heated to about 15 to 25°C in the heat exchanger 216. Thus, the heat exchanger 216 affects about a 10 °C to 15 °C increase in temperature of the AS solution entering the second side of the heat exchanger at the inlet 261.

[0068] The flue gas is conveyed to the third stage 250 via the second flue gas passage 242. The flue gas is cooled in the third stage 250 from about 15 to 25 °C to about 5 °C $\pm$ 5 °C, by the first chiller system 219. For example, the flue gas is passed through a spray of water supplied to the third liquid distribution system 258. The water is supplied to the third liquid distribution system 258 at a temperature of about 5 °C $\pm$ 5 °C, via the inlet 257. The water supplied to the inlet 257 is supplied from the first chiller system 219 via the outlet 252. Thus, the first chiller system 219 affects about a 10 °C to 15 °C reduction in temperature of the flue gas flowing through the third stage 250. The flue gas is discharged from the third stage 250 to the CO₂ absorber 277, via a path through the third flue gas passage 254, the outlet 255 and the line 276. The flue gas is discharged from the third stage 250 at a temperature of about 5 °C $\pm$ 5 °C.

[0069] The CO₂ absorber 277 removes CO₂ from the flue gas, after which the flue gas is conveyed to the NH₃ water wash system 278 for removal of ammonia from the flue gas. The flue gas is transported from the NH₃ water wash system 278 to the fourth stage 260 of the DCH at about 5 °C $\pm$ 5 °C. The flue gas is heated in the fourth stage 260 from about 5 °C $\pm$ 5 °C to about 15 to 25 °C. The fourth stage 260 is an ammonia polishing system that produces AS from a reaction between sulfuric acid and ammonia contained in the flue gas. The AS solution is circulated through the fourth stage 260 and the shell side of the heat exchanger 216 via the third pump 265. The AS solution is supplied from the second outlet 262 of the heat exchanger 216 at a temperature of about 17 to 25 °C to the liquid distribution system 267. The liquid distribution system 267 sprays the AS solution into the interior area of the fourth stage 260 for communication with the flue gas and removal of the NH₃ from the flue gas. The spraying of the AS solution increases the temperature of the flue gas to about 15 to 25 °C. The AS solution is heated in the heat exchanger from about 5 °C $\pm$ 5 °C to about 15 °C to 25 °C. The heating of the AS solution and evaporation of water in the flue gas increases the concentration of the AS solution. For example, the concentration of the AS solution is increased to about 40 weight % ($\pm$ 5 weight %). Increasing the concentration of the AS solution to about 40 weight % reduces the amount of AS purging required via the AS purge line 211. The flue gas is conveyed from the fourth stage 260 to the fifth stage 270 at a temperature of about 15 to 20 °C, via the fourth flue gas passage 269.

[0070] The flue gas is heated in the fifth stage from about 15 to 25 °C to about 40 to 60 °C by exposing the flue gas to a spray of water supplied from the outlet 280 of the first stage 230. The water is supplied from the outlet 280 of the first stage 230 at temperature of about 40 to 60 °C, via the fourth pump 281 and the line 282. The 40 to 60 °C water is conveyed to the liquid distribution system 287 which sprays the water into an interior area defined by the fifth stage 270. The flue gas is discharged from the fifth stage 270, via the outlet 275, to the stack. The water sprayed into the interior area of the fifth stage 270 is cooled to about 15 to 25 °C and is discharged from the fifth stage to the cooling tower 234, via the outlet 272, for further cooling, depending upon the ambient temperature.

[0071] The flue gas treatment system 310 of FIG. 4 is operated similar to the flue gas treatment system 110 described above. Since the flue gas treatment system 110 does not include a stage that corresponds to the third stage 30 of the flue gas treatment system 10 of FIG. 1, the first inlet 371 of the heat exchanger 316 is not in fluid communication with the cooling tower 334 and the first outlet 341 is not in fluid communication with the third stage. Instead, since the heat exchanger 316 is in fluid communication with the CO₂ absorber 377, the heat exchanger cools a solution containing CO₂, supplied from the CO₂ absorber. About 85 to 90% of the solution discharged from the CO₂ absorber 377 is conveyed to the second chiller system 384 via a path through the second absorber outlet 392, the regenerator 383 and the second chiller inlet 386. About 10 to 15% of the solution discharged from the CO₂ absorber 177 is conveyed to the heat exchanger 116 via a path through the branch connection 388 and the first inlet 371. The solution is cooled in the tube side of the heat exchanger 316 from about at a temperature of about 30 °C $\pm$ 5 °C to about 15 °C to about 20 °C. Thus, the heat exchanger 316 affects about a 5 °C to about 20 °C reduction in temperature of the solution entering the first side 371 of the heat exchanger. The cooled solution is discharged from the heat exchanger 316 via the first outlet 341 into the CO₂ absorber 377 via the first absorber inlet 391. A portion of the cooled solution discharged from the heat exchanger 316 is discharged into the second chiller system 384 via the branch connection 341A. Discharge of the cooled solution into the second chiller system 384 or into the CO₂ absorber 377 reduces the amount of cooling required by the second chiller system 384, compared to comparable systems having no such heat exchanger.

[0072] While the present disclosure has been described with reference to various exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a

particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS

What is claimed is:

1. A gas treatment system comprising:
a heat exchanger having a first side and a second side separated from one another, the first side defining a first inlet and a first outlet and the second side defining a second inlet and a second outlet;
at least one of a direct contact cooler in fluid communication with the first outlet, a direct contact heater in fluid communication with the first inlet and a CO₂ absorber in fluid communication with the first inlet and the first outlet; and
an ammonia polishing system in fluid communication with at least one of the second inlet and the second outlet.
2. The gas treatment system of claim 1, wherein the heat exchanger is operable to affect about a 5°C to about 25°C reduction in temperature of the gas flowing through the direct contact cooler.
3. The gas treatment system of claim 1, wherein the first inlet is in fluid communication with a cooling tower and the heat exchanger is operable to affect about a 5°C to about a 15°C reduction in temperature of a fluid received from the cooling tower.
4. The gas treatment system of claim 1, wherein the ammonia polishing system is operable to supply a fluid to the second inlet at a temperature of about 5°C to about 10°C.
5. The gas treatment system of claim 1, wherein the direct contact heater is in fluid communication with the ammonia polishing system.
6. The gas treatment system of claim 1, wherein the direct contact cooler is in fluid communication with at least one additional direct contact cooler.
7. The gas treatment system of claim 6, wherein the at least one additional direct contact cooler is in fluid communication with a refrigeration based chiller.
8. The gas treatment system of claim 7, wherein the refrigeration based chiller is operable to affect about a 10°C to about a 15°C reduction in temperature of the gas flowing through the at least one additional direct contact cooler.
9. The gas treatment system of claim 1, wherein the heat exchanger is operable to affect about a 10°C to about a 15°C temperature increase in a fluid entering the second side.
10. The gas treatment system of claim 9, wherein the heat exchanger is operable to affect about a 35 weight percent to about a 45 weight percent ammonium sulfate concentration of the fluid.

11. The gas treatment system of claim 1, comprising a gas polisher in fluid communication with the direct contact cooler and the gas polisher is operable to remove at least one of SO_2 , SO_3 and particulate matter from the gas.
12. The gas treatment system of claim 1, wherein the ammonia polishing system is operable to remove ammonia from the gas.
13. The gas treatment system of claim 1, comprising a refrigeration based chiller in communication with the CO_2 absorber.
14. The gas treatment system of claim 13, wherein the refrigeration based chiller is in fluid communication with the heat exchanger.
15. A gas treatment system comprising:
 - a first stage comprising a first direct contact cooler defining a first gas inlet and a first gas outlet;
 - a second stage comprising a second direct contact cooler defining a second gas inlet and a second gas outlet, the first gas outlet being in fluid communication with the second gas inlet;
 - a third stage comprising a third direct contact cooler defining a third gas inlet and a third gas outlet, the second gas outlet being in fluid communication with the third gas inlet;
 - a chiller in fluid communication with the third stage;
 - a fourth stage comprising a first direct contact heater defining a fourth gas inlet and a fourth gas outlet;
 - a fifth stage comprising a second direct contact heater defining a fifth gas inlet and a fifth gas outlet, the fourth gas outlet being in fluid communication with the fifth gas inlet;
 - a heat exchanger having a first side and a second side separated from one another, the first side defining a first fluid inlet and a first fluid outlet and the second side defining a second fluid inlet and a second fluid outlet; and
 - the first fluid inlet being in fluid communication with the fifth stage, the first fluid outlet being in fluid communication with the second stage and the second fluid inlet and the second fluid outlet being in fluid communication with the fourth stage.
16. The gas treatment system of claim 15, comprising an ammonium sulfate solution disposed in the fourth stage and the second side of the heat exchanger and the heat exchanger being operable to affect about a 10°C to about a 15°C temperature increase in the ammonium sulfate solution entering the second fluid inlet.
17. The gas treatment system of claim 15, further comprising a gas polisher positioned upstream of and in fluid communication with the first stage.

18. A gas treatment system comprising:
- a first stage comprising a first direct contact cooler defining a first gas inlet and a first gas outlet;
 - a second stage comprising a second direct contact cooler defining a second gas inlet and a second gas outlet, the first gas outlet being in fluid communication with the second gas inlet;
 - a chiller in fluid communication with the second stage;
 - a third stage comprising a first direct contact heater defining a third gas inlet and a third gas outlet;
 - a fourth stage comprising a second direct contact heater defining a fourth gas inlet and a fourth gas outlet, the third gas outlet being in fluid communication with the fourth gas inlet;
 - a heat exchanger having a first side and a second side separated from one another, the first side defining a first fluid inlet and a first fluid outlet and the second side defining a second fluid inlet and a second fluid outlet; and
 - the first fluid inlet and the first fluid outlet being in fluid communication with a CO₂ absorber and the second fluid inlet and the second fluid outlet being in fluid communication with the fourth stage.
19. The gas treatment system of claim 15, wherein the heat exchanger is operable to affect about a 5°C to about a 20°C temperature reduction of a fluid entering the first fluid inlet.
20. The gas treatment system of claim 18, further comprising a gas polisher positioned upstream of and in fluid communication with the first stage.

FIG. 1

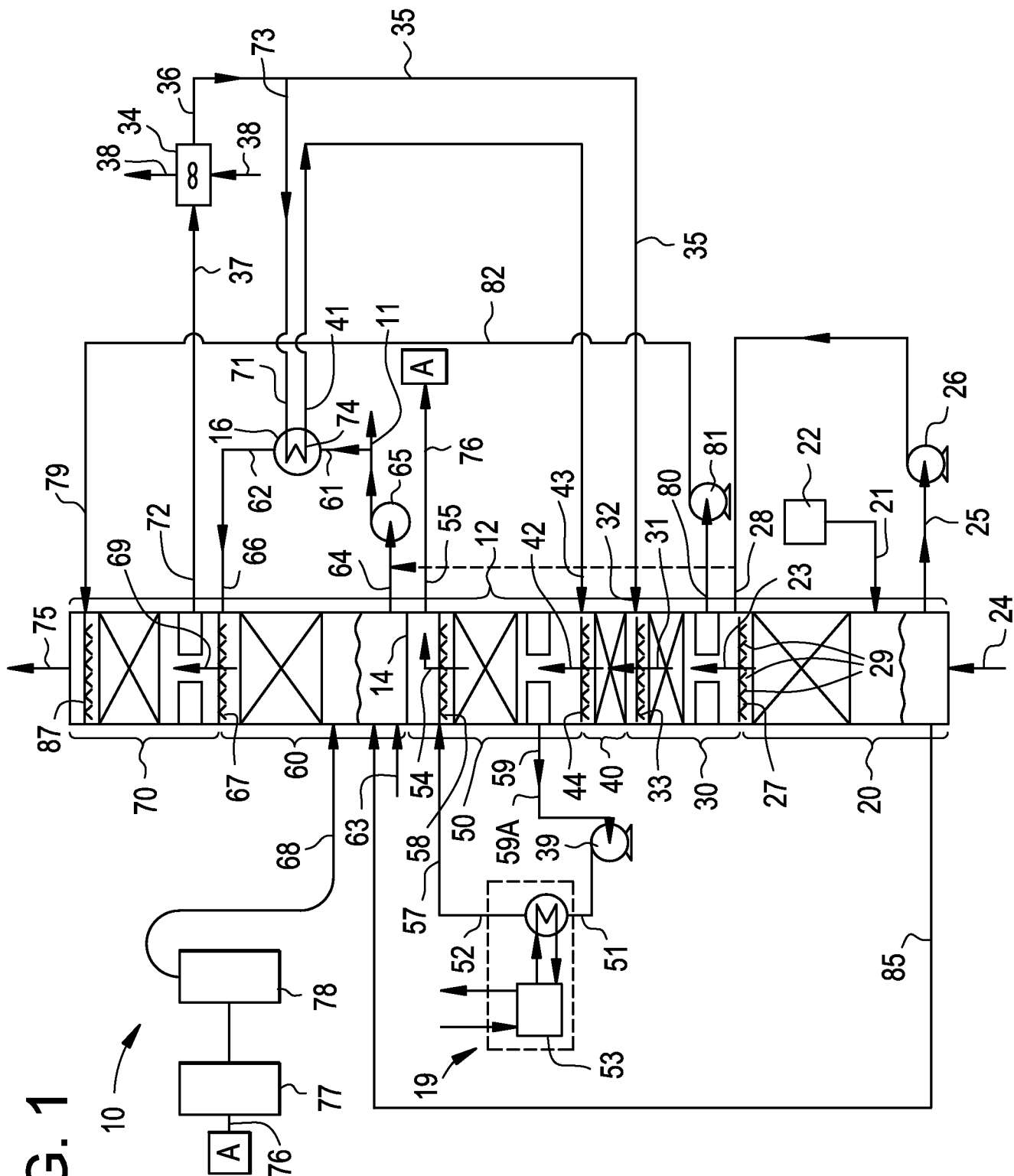


FIG. 2

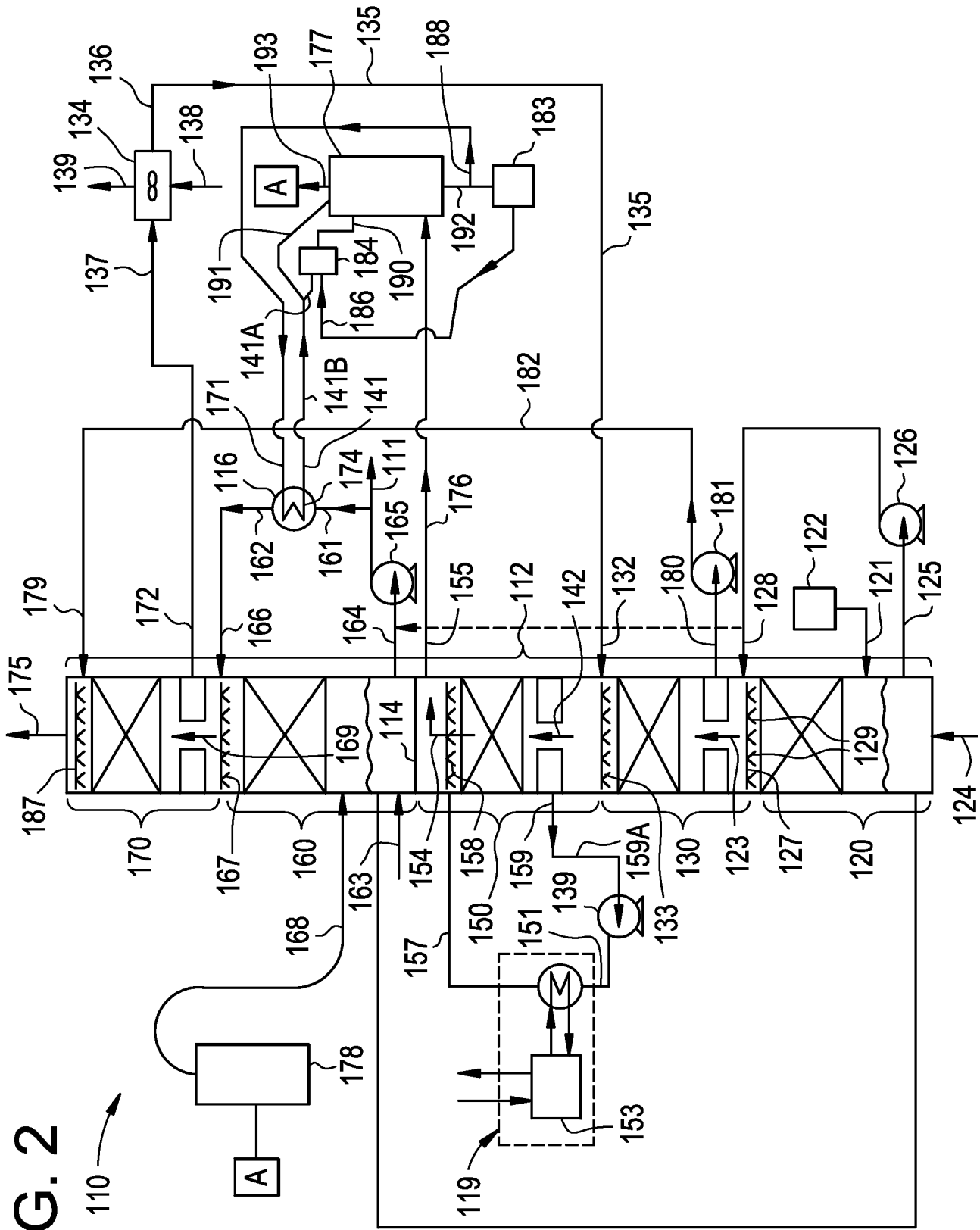


FIG. 3

