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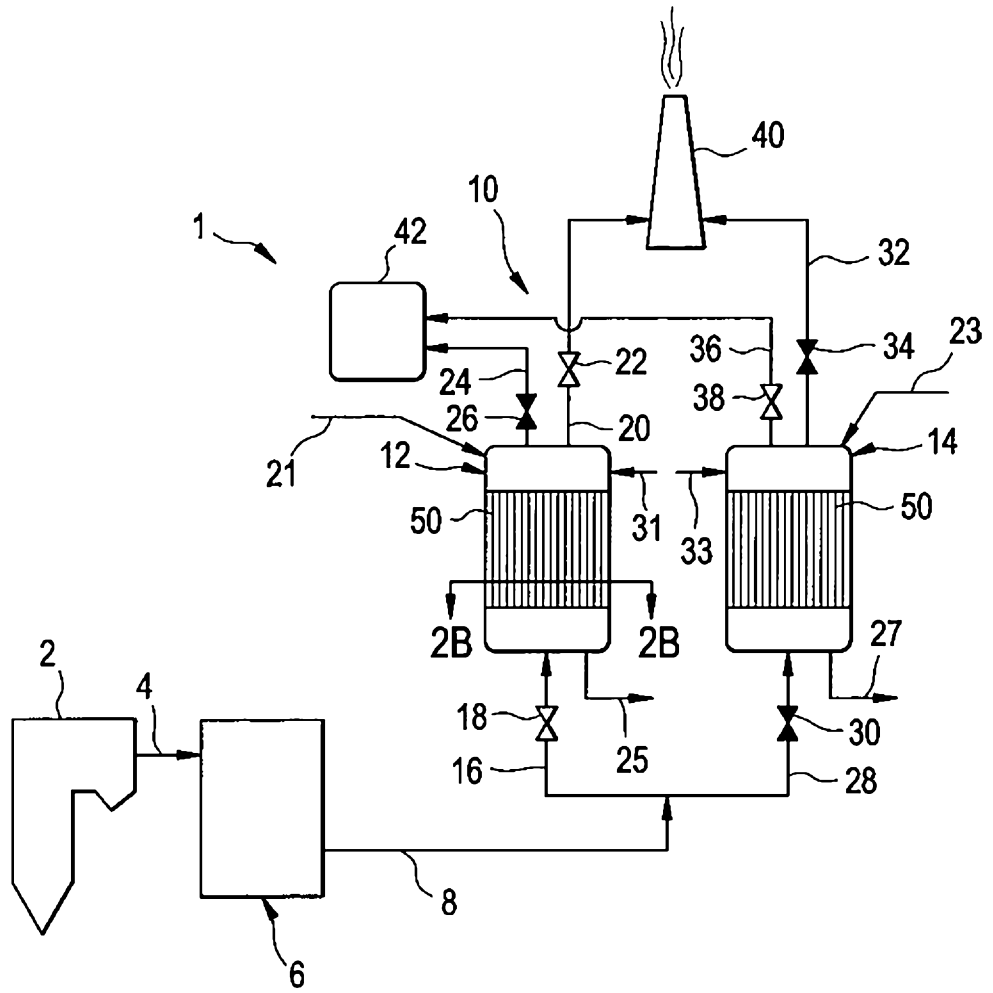
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ABSTRACT

A carbon dioxide capture system includes a solid sorbent material including an amine. A base solution is in communication with the sorbent material when the amine becomes deactivated. The base solution is removed from the sorbent material when the amine is regenerated by the base solution.

FIG. 1



A METHOD FOR REGENERATION OF SOLID AMINE CO₂ CAPTURE BEDSCROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 61/722,454; filed on November 5, 2012, entitled "A METHOD FOR REGENERATION OF SOLID AMINE CO₂ CAPTURE BEDS" which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure is generally directed to a system and method for regeneration of carbon dioxide (CO₂) capture beds comprising solid amines, and in particular is directed to treating deactivated solid amines in the CO₂ capture beds with a base solution to regenerate the amines for further CO₂ capture.

BACKGROUND

[0003] In the combustion of a fuel, such as coal, oil, natural gas, peat, waste, etc., in a combustion plant, such as those associated with boiler systems for providing steam to a power plant, a hot process gas (or flue gas) is generated. Such a flue gas will often contain, among other things, carbon dioxide (CO₂). The negative environmental effects of releasing CO₂ to the atmosphere have been widely recognized, and have resulted in the development of processes adapted for removing CO₂ from the hot process gas generated in the combustion of the above mentioned fuels. Systems and methods for removing CO₂ from a gas stream include CO₂ capture systems in which a flue gas is contacted with an aqueous absorbent solution such as, for example, a chilled ammonia based ionic solution.

[0004] Chemical adsorption with amines is also one such CO₂ capture technology being explored. Capturing CO₂ gas from a flue gas stream by subjecting the flue gas stream to an adsorbent that is coated onto a solid material or substrate is sometimes referred to as an adsorbent coated substrate (ACS). There are two types of these coated substrates – one in which amines are attached via adsorption and another in which amines are covalently attached to the substrate. Amines can be used as the adsorbent because they can be coated on the solid material and are useful for CO₂ capture because they can increase the capacity of the CO₂. However, the flue gases also contain strong acid gases such as sulfur dioxide (SO₂) and

sulfur trioxide (SO₃) which react with the amines and reduce the ability of the amine to react with and adsorb CO₂.

SUMMARY

[0005] According to aspects illustrated herein, there is provided a carbon dioxide capture system for removing carbon dioxide from a process gas, the system comprising at least a first absorber vessel having a solid sorbent material disposed therein; the first absorber vessel further comprising:

an inlet for supplying a base solution;

an outlet for discharging the base solution; and wherein

the solid sorbent material comprises an amine applied thereto via covalent bond linkages; and;

the base solution is supplied and is in communication with the sorbent material when the amine becomes deactivated; and

the base solution is removed from the sorbent material when the amine is regenerated by the base solution.

[0006] According to further aspects illustrated herein, there is provided a method for regenerating solid sorbent material in a carbon dioxide (CO₂) removal system. The method includes providing a solid sorbent layer having a deactivated amine that is incapable of capturing CO₂ applied thereto. A base solution is dispersed on the solid sorbent layer, thereby reacting the base solution with the deactivated amine. The deactivated amine is regenerated into an amine capable of capturing CO₂.

[0007] The above described and other features are exemplified by the following figures and in the detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Referring now to the figures, which are exemplary embodiments, and wherein the like elements are numbered alike:

[0009] FIG. 1 is a schematic diagram of a power plant comprising a system for removing carbon dioxide from a process gas.

2a

[0010] FIG. 2a is a schematic cross-section of a monolithic unit being operative for adsorption and desorption of carbon dioxide.

[0011] FIG. 2b is a schematic cross-section of the monolithic unit, as seen in the direction of the arrows 2b-2b of FIG. 2a.

[0012] FIG. 2c is an enlarged schematic cross-section of a wall of the monolithic unit of FIG. 2a.

[0013] FIG. 3 is a schematic diagram of the power plant of FIG. 1 shown in an alignment for regeneration of a sorbent material.

DETAILED DESCRIPTION

[0014] There is disclosed herein a system and method for carbon dioxide (CO₂) capture including a system and method for regeneration of CO₂ capture beds comprising solid amines. The system and method for regeneration of the CO₂ capture beds is directed to treating deactivated solid amines in the CO₂ capture beds with a base solution to regenerate the amines for further CO₂ capture. In one embodiment, the base solution is a dilute solution of NaOH which has a concentration thereof from 1wt% to 50 wt%, preferably from 1 wt % to 10 wt%. In one embodiment, the base solution is a dilute solution of KOH which has a concentration thereof from 1 wt % to 50 wt%, preferably from 1 wt% to 10 wt%. While, NaOH and KOH are described, solutions of Na₂CO₃ or K₂CO₃ or slurries of CaO can be employed without departing of the broader aspects disclosed herein.

[0015] FIG. 1 is a schematic view of a power plant generally designated by the numeral 1. The power plant 1 includes a boiler 2 in which a fuel, such as coal, oil, peat, or waste, is combusted under generation of heat. The combustion also generates a hot process gas, which is often referred to as a flue gas. The flue gas includes contaminants such as, but not limited to, CO₂, sulfur oxides (SO_x), nitrogen oxides (NO_x), fly ash, dust, soot, mercury, and the like. The boiler 2 is in communication with a gas cleaning system 6 via a duct 4. The gas cleaning system 6 includes a fly ash removal device, such as an electrostatic precipitator; a wet scrubber for removing sulfur dioxide (SO₂) and hydrochloric acid; and/or a selective catalytic reduction unit for removing nitrogen oxides.

[0016] As illustrated in FIG. 1, the gas cleaning system 6 is in communication with a carbon dioxide capture system 10 via the duct 8. The carbon dioxide capture system 10 includes a first adsorber vessel 12 and a second adsorber vessel 14. The first and second adsorber vessels 12, 14 are identical in design. The first adsorber vessel 12 is in communication with the duct 8 via a flue gas supply duct 16, which is provided with a shut off valve 18. The first adsorber 12 is in communication with a stack 40 via a flue gas disposal duct 20, which is provided with a shut off valve 22. The first adsorber 12 is in communication with a carbon dioxide storage tank 42 via a carbon dioxide disposal duct 24, which is provided with a shut off valve 26. Similarly, the second adsorber vessel 14 is in communication with the duct 8 via a flue gas supply duct 28, which is provided with a shut off valve 30. The second adsorber 14 is in communication with the stack 40 via a flue gas discharge duct 32, which is provided with a shut off valve 34. The second adsorber 14 is in

communication with the carbon dioxide storage tank 42 via a carbon dioxide disposal duct 36, which is provided with a shut off valve 38.

[0017] As shown in FIG. 1, the first adsorber vessel 12 has an inlet line 21 for supplying a base solution to the first adsorber vessel 12 for treatment of the sorbent material 50 as described herein. Likewise, the second adsorber vessel 14 has an inlet line 23 for supplying the base solution to the second adsorber vessel 14 for treatment of the sorbent material 50 as described herein. The first adsorber vessel 12 has a water inlet line 31 and the second adsorber vessel 14 has a water inlet line 33 for rinsing the base solution from the sorbent material 50. The first adsorber vessel 12 has an outlet line 25 for discharging the base solution and water from the first adsorber vessel. The second adsorber vessel 14 has an outlet line 27 for discharging the base solution from the second adsorber vessel.

[0018] Although the power plant 1 is shown and described as having the first and second adsorber vessels 12, 14, the present disclosure is not limited in this regard as the power plant may also be provided with three, four or even more adsorber vessels in parallel and/or series configurations. The number of adsorber vessels is determined by factors, such as, but not limited to the need for redundancy and the time for desorption of carbon dioxide versus the time for adsorption of carbon dioxide. It is also possible to operate with one single adsorber vessel. In the latter case the power plant would need to be shut down during the desorption mode, or the process gas would need to be released via a by-pass without any carbon dioxide being removed therefrom during the desorption mode.

[0019] In the embodiment illustrated in FIG. 1, the first adsorber vessel 12 is shown in an adsorption mode and is operative for adsorbing carbon dioxide from the flue gas. Hence, the valve 18 is open to allow flue gas from the duct 8 to enter the adsorber vessel 12 via the flue gas supply duct 16. Furthermore, the valve 22 is open, such that flue gas, from which carbon dioxide has been, at least partly, removed, may leave the first adsorber vessel 12 via the flue gas disposal duct 20, via which the flue gas may be emitted to the ambient air via a stack 40. The valve 26 is closed thereby isolating the first adsorber vessel 12 from the carbon dioxide storage tank 42.

[0020] In the embodiment illustrated in FIG. 1, the second adsorber vessel 14 is shown in a desorption mode, and is operative for desorption of carbon dioxide that has previously been removed from the flue gas. Hence, the valve 30 is closed, such that no flue gas can enter the adsorber vessel 14 via the flue gas supply duct 28. The valve 34 is also closed, such that no gas may leave the adsorber vessel 14 via the flue gas disposal duct 32.

Furthermore, the valve 38 is open, such that carbon dioxide, which has been released from the second adsorber vessel 14, may leave the vessel 14 via the carbon dioxide disposal duct 36. The carbon dioxide disposal duct 36 forwards the carbon dioxide to a carbon dioxide storage tank 42, in which the carbon dioxide is stored until it is finally used or disposed of.

[0021] Each adsorber vessel 12, 14 is provided with a solid sorbent material 50. FIG. 2a is an enlarged cross-sectional side view of the sorbent material 50. The sorbent material 50 comprises a monolithic unit 52 having a number of channels 54 defined by adjacent walls 56, through which the gas, illustrated as F in FIG. 2a, can flow. The walls 56 define a substrate 58 with a sorbent layer 60 adhered thereto, as described further below with reference to FIG. 2C. The monolithic unit 52 is of a flow-through type. In the adsorption mode the gas F is flue gas, and in the desorption mode the gas F is carbon dioxide.

[0022] FIG. 2a is a cross-section illustrating the monolithic unit 52 as seen along the line 2b-2b of FIG. 1. In the embodiment illustrated in FIG. 2b, the unit 52 has a square section. While the monolithic unit 52 is shown and described as having a square section, the present disclosure is not limited in this regard as, monolithic units having a circular section or another shape which is suitable for packing into the adsorber vessels 12 and 14, may be employed. In the embodiment shown in FIGS. 2a and 2b the channels 54 have a square section, with a width WC. As an alternative, the channels 54 may, for example, have a rectangular, triangular, or circular cross-section. The sorbent material 50 could comprise one single monolithic unit 52, but could comprise a number of monolithic units that have been packed together in the respective adsorber vessel 12, 14.

[0023] FIG. 2c illustrates an enlarged portion of one of the walls 56 of the monolithic unit 52. A central portion of the wall 56 is defined by a substrate 58. The substrate 58 contributes to the physical strength of the monolithic unit 52, and also provides a large surface area yielding an effective contact with the gas F. On both sides of the substrate 58 a solid sorbent layer 60 is provided. The sorbent layer 60 comprises an amine and a catalyst that have been applied to, solidified and immobilized on the substrate 58 via a covalent bond linkage.

[0024] While the sorbent material 50 is shown and described as comprising a flow-through type monolithic unit 52 the present disclosure is not limited in this regard as other configurations of the sorbent material may be employed, including, but not limited, to wall-flow type monolithic unit in which the flue gas flows through walls of the unit and

configurations in which the sorbent material is in a particulate form and supported on a stationary or moving bed or contained within a fluidized bed.

[0025] The amine may be any type that is suitable for adsorption and desorption of carbon dioxide. The amine may be a primary, a secondary, or a tertiary amine, or mixtures thereof. A primary amine has one of three hydrogen atoms in ammonia replaced by an organic substituent bound to the nitrogen atom. A secondary amine has two organic substituents bound to the nitrogen atom together with one hydrogen atom. In tertiary amines all three hydrogen atoms are replaced by organic substituents bonded to the nitrogen atom. The amine is preferably a secondary amine, or a mixture of a secondary amine together with a primary and/or a tertiary amine. Amines that are particularly suitable for incorporation in the sorbent layer 60 are amines that are secondary amines and/or amines that include alcohol (OH) functionality, examples of such amines being diethanolamine (DEA), diisopropanolamine (DIPA), and 2-hydroxyethyl piperazine (HEP).

[0026] Referring to FIG. 3, the carbon dioxide removal system 10 is shown in a regeneration alignment with the second adsorber vessel 14 configured for regeneration. In the regeneration configuration the second adsorber vessel 14 is: 1) isolated from the flue gas supply duct 28 by the shut off valve 30 being closed; 2) isolated from the stack 40 by shut off valve 34 being closed; and 3) isolated from the carbon dioxide storage tank 42 by shut off valve 28 being closed. While the second adsorber vessel 14 is shown and described as being in the regeneration alignment, the present disclosure is not limited in this regard as the first adsorber vessel 12 can also be configured in the regeneration alignment by closing shut off valves, 18, 22 and 26.

[0027] The first and second adsorber vessels 12, 14 are identical in design and operate in a parallel mode, with one of the adsorber vessels being in adsorption mode adsorbing carbon dioxide from the flue gas (e.g., the first adsorber vessel 12 as shown in FIG. 1), and the other adsorber vessel being in desorption mode releasing carbon dioxide (e.g., the second adsorber vessel 14 as shown in FIG. 1), such that the carbon dioxide removal capacity is regenerated. The first and second adsorber vessels 12, 14 are operated in an alternating manner, such that one adsorber vessel collects carbon dioxide from the flue gas, while the other adsorber vessel discharges CO₂ therefrom. Hence, when one adsorption vessel is full with carbon dioxide it is taken off-line for discharge of CO₂ therefrom, and the other adsorption vessel is put on-line.

[0028] When the flue gas passes, in the adsorption mode, through the channels 54 of the monolithic unit 52, the carbon dioxide present in the flue gas will be effectively adsorbed by the amine of the sorbent layer 60 due to the large surface area of the porous material of the sorbent layer 60 and the catalyst included in the sorbent layer 60 making such adsorption efficient. To remove the CO₂ from the sorbent layer 60, the sorbent layer is heated for example, by a steam source or via a heat exchanger (not shown). In one embodiment, in the desorption mode, the sorbent layer 60 is heated to about 60 to 150°C. When the temperature of the monolithic unit 52 is raised, in the desorption mode, the carbon dioxide will be effectively released from the amine of the sorbent layer 60 due in part to the large surface area of the porous material of the sorbent layer 60 and a carbon dioxide catalyst (e.g., organo-metallic complex catalysts, inorganic metal complex catalysts, metal oxides, and metal halides) included in the sorbent layer 60 and the thermally reversible nature of the chemical reaction of amine with CO₂. While the CO₂ is described as being removed from the sorbent layer 60 by heating, the present disclosure is not limited in this regard as the CO₂ can be removed from the sorbent layer 60 by other means including, but not limited to the use of inert gases or vacuum sources.

[0029] However, over time, the sorbent layer 60 can become deactivated when the amine group incorporated therein becomes incapable of reacting with CO₂. For example, the amine groups irreversibly react with acids stronger than CO₂ that are present in the flue gas. Such acidic gases present in the flue gas include, but are not limited to, SO₂, SO₃, HCL, HF and oxides of nitrogen. SO₂ is the most prevalent of these gases. In the presence of moisture in the flue gas SO₂ will react with the amine groups to form bisulfate salts thereby causing a reduction or termination of the ability of the amine group to react with CO₂. In general, the amine groups in the sorbent layer 60 react with moist acid gases according to the following equation:



[0031] Eq. 1 illustrates that the acid gas neutralizes the amine group by the protonation of the amine group and formation of the heat stable salt $\text{---NR}_2\text{H}^+\text{X}$ and renders the amine group incapable of reacting with CO₂, which is referred to as deactivated amine. The reaction illustrated in Eq. 1 is thermally irreversible.

[0032] Prior art methods and efforts have therefore been directed to reducing or eliminating SO₂ upstream of the carbon dioxide removal system 10, via wet and dry flue gas

desulfurization (FGD) systems. However, even small amounts of SO₂ entering the carbon dioxide removal system 10 can deactivate the amine groups in the sorbent layer 60 over time.

[0033] The present disclosure includes a method for regenerating the solid sorbent layer 60 in the CO₂ removal system 10. The method includes treating deactivated amine in the CO₂ sorbent layer 60 with a base solution to regenerate the amine for further CO₂ capture. In one embodiment, the method includes operating the first adsorber vessel 12 and/or the second adsorber vessel 14 in the regeneration alignment, wherein a base solution such as a dilute solution of sodium hydroxide (NaOH) or potassium hydroxide (KOH) is supplied to either the first adsorber vessel 12 and/or the second adsorber vessel 14.

[0034] For example, as shown in FIG. 3, the second adsorber vessel 14 is configured in a regeneration alignment with the shut off valves 30, 34 and 38 closed, after the CO₂ has been removed therefrom, for example by the addition of heat and transport of the CO₂ to the carbon dioxide storage tank 42. Another way to effect this regeneration is by using a sweep gas deficient in CO₂ such as nitrogen, air or steam. Thus regeneration of the deactivated amine in the sorbent layer 60 occurs in the absence of significant amounts of CO₂ and depends upon the amount heat input for regeneration and the flow of an inert gas. While the regeneration of the deactivated amine in the sorbent layer 60 is described as occurring after removal of the CO₂ from the adsorber vessel 14 and in the absence of significant amounts of CO₂, the present disclosure is not limited in this regard, as the regeneration of the deactivated amine in the sorbent layer 60 can also occur before the removal of the CO₂ from the adsorber vessel 14 and in the presence of CO₂.

[0035] During operation of the second adsorber vessel 14 in the regeneration alignment, a base solution such as a dilute solution of sodium hydroxide (NaOH) or potassium hydroxide (KOH) is supplied to the adsorber vessel 14 via the base solution inlet line 23. The base solution is dispersed on the sorbent material 50 and thereby communicating with the sorbent layer 60 which comprises the deactivated amine. A suitable amount (e.g., quantity and flow rate) of the base solution is supplied to the second adsorber vessel 14 so that enough hydroxide ions (OH⁻) are provided to chemically reverse the protonation of the deactivated amine (i.e., converting the thermally stable salts back into active amine groups that are capable of reacting with and capturing CO₂). When a sufficient amount of the thermal stable salts are converted back to active amine groups, the flow of base solution is terminated and the base solution discharged from the adsorber vessel 14 via the outlet line 27. Excess or unreacted base solution is washed from the sorbent layer 60 of the sorbent material

[0014] 50 by the introduction of a water wash via the water inlet line 33. The water and any unreacted or excess base solution is discharged from the adsorber vessel 14 via the outlet line 27. While the operation of the adsorber vessel 14 in the regeneration alignment is shown and described, the sorbent layer 60 of the sorbent material 50 in the adsorber vessel 12 can be regenerated in a manner similar to that described above for the adsorber vessel 14. Moreover, the adsorber vessel 12 and the adsorber vessel 14 can be operated in the regeneration alignment individually or simultaneously and can be operated in conjunction with any number of other adsorber vessels.

[0015] In one embodiment, the base solution is a dilute solution of NaOH which has a concentration thereof from 1-50 wt%, preferably from 1-10 wt%.

[0016] In one embodiment, the base solution is a dilute solution of KOH which has a concentration thereof from 1-50 wt%, preferably from 1-10 wt%.

[0017] While the present invention 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.

[0018] Comprises/comprising and grammatical variations thereof when used in this specification are to be taken to specify the presence of stated features, integers, steps or components or groups thereof, but do not preclude the presence or addition of one or more other features, integers, steps, components or groups thereof.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A carbon dioxide capture system for removing carbon dioxide from a process gas, the system comprising:
 - at least a first absorber vessel having a solid sorbent material disposed therein; the first absorber vessel further comprising:
 - an inlet for supplying a base solution;
 - an outlet for discharging the base solution; and wherein
 - the solid sorbent material comprises an amine applied thereto via covalent bond linkages; and;
 - the base solution is supplied and is in communication with the sorbent material when the amine becomes deactivated; and
 - the base solution is removed from the sorbent material when the amine is regenerated by the base solution.
2. The carbon dioxide capture system of claim 1, wherein the amine is selected from the group consisting of, a primary, a secondary, a tertiary amine, and combinations thereof.
3. The carbon dioxide capture system of claim 1 or claim 2, wherein the amine is selected from the group consisting of, diethanolamine (DEA), diisopropanolamine (DIPA), and 2-hydroxyethyl piperazine (HEP).
4. The carbon dioxide capture system of any one of claims 1 to 3, wherein the base solution is selected from the group consisting of solutions of NaOH, KOH, Na₂CO₃ and K₂CO₃ and slurries of CaO.
5. The carbon dioxide capture system of any one of claims 1 to 4, wherein the base solution comprises NaOH having a concentration of 1-50 wt%.
6. The carbon dioxide capture system of any one of claims 1 to 5, wherein the base solution comprises NaOH having a concentration of 1-10 wt%.

7. The carbon dioxide capture system of any one of claims 1 to 3, wherein the base solution comprises KOH having a concentration of 1-50 wt%.
8. The carbon dioxide capture system of any one of claims 1 to 4 and claim 7, wherein the base solution comprises KOH having a concentration of 1-10 wt%.
9. The carbon dioxide capture system of any one of claims 1 to 8, comprising a water supply in communication with the solid sorbent material when the amine group is regenerated by the base solution.
10. The carbon dioxide capture system of any one of claims 1 to 9, wherein the adsorber vessel includes an outlet for discharging at least one of the base solution and the water from the adsorber vessel.
11. A method for regenerating solid sorbent material in a carbon dioxide (CO₂) removal system, the method comprising:
 - providing a solid sorbent layer having a deactivated amine that is incapable of capturing CO₂ applied thereto;
 - dispersing a base solution on the solid sorbent layer;
 - reacting the base solution with the deactivated amine; and
 - regenerating the deactivated amine into an amine capable of capturing CO₂.
12. The method of claim 11, wherein the base solution comprises NaOH having a concentration of 1-50 wt%.
13. The method of claim 11, wherein the base solution comprises KOH having a concentration of 1-50 wt%.
14. The method of any one of claims 11 to 13, wherein the deactivated amine is a heat stable salt generated from reaction of the amine capable of capturing CO₂ with an acid gas.

15. The method of claim 14, wherein the acid gas is selected from the group consisting of SO₂, SO₃, HCl, HF and oxides of nitrogen.
16. The method of any one of claims 11 to 15, wherein the amine capable of capturing CO₂ is selected from the group consisting of, a primary, a secondary, a tertiary amine, and combinations thereof.
17. The method of any one of claims 11 to 16, wherein the amine capable of capturing CO₂ is selected from the group consisting of, diethanolamine (DEA), diisopropanolamine (DIPA), and 2-hydroxyethyl piperazine (HEP).
18. The method of any one of claims 11 to 17, wherein the base solution is dispersed on the solid sorbent layer in an amount sufficient to provide enough hydroxide ions to chemically reverse protonation of the deactivated amine.
19. The method of any one of claims 11 to 18, wherein after the regenerating the deactivated amine the sorbent layer is washed with water to remove excess or unreacted base solution therefrom.
20. The method of any one of claims 11 to 19, wherein the regenerating the deactivated amine occurs in the presence of a gas deficient in CO₂.
21. The system of any one of claims 1 to 10, wherein the at least first absorber vessel is operative in an adsorption mode, for adsorbing carbon dioxide from the process gas, is operative in a desorption mode for releasing the carbon dioxide and is operative in a regeneration mode, for regenerating the solid sorbent material.
22. The system of any one of claims 1 to 10, wherein the system further comprises at least a second absorber vessel, wherein the first and second absorbers are identical in design and operation and can be operated in parallel, alternating, or individual modes.

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FIG. 1

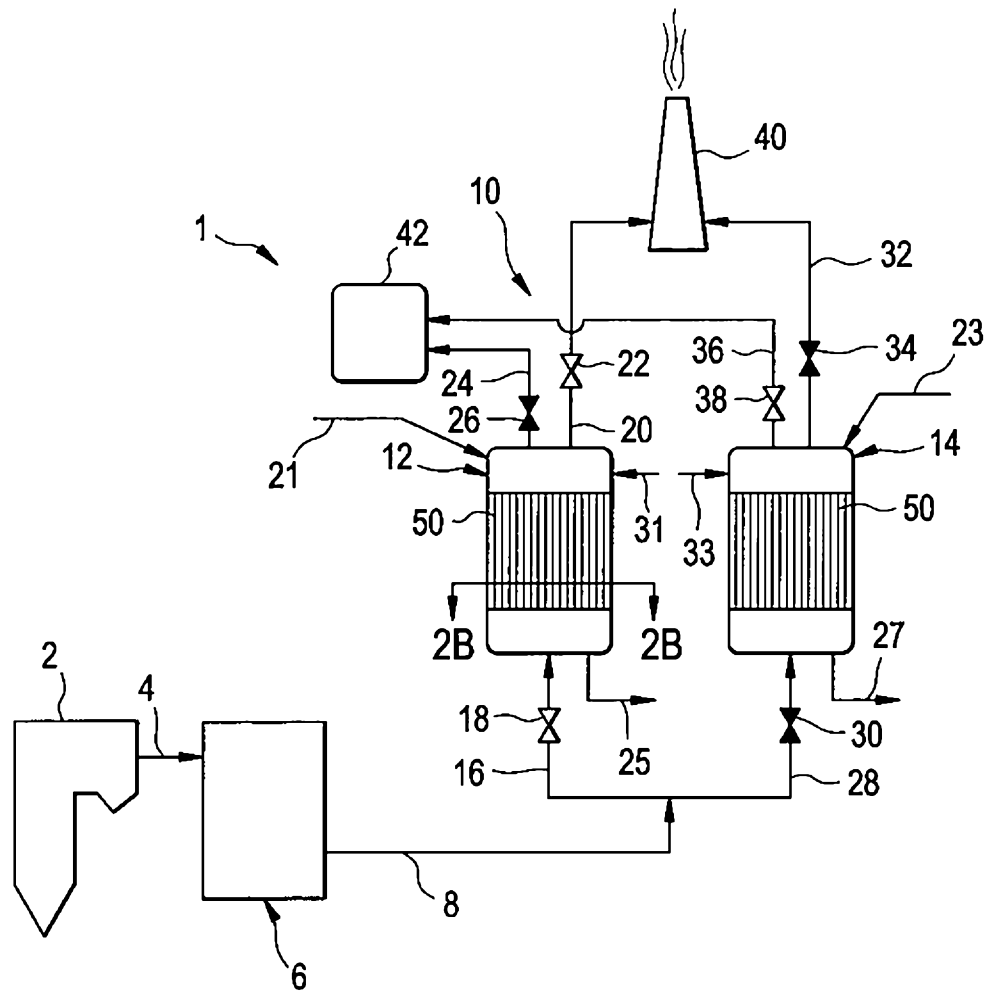


FIG. 2A

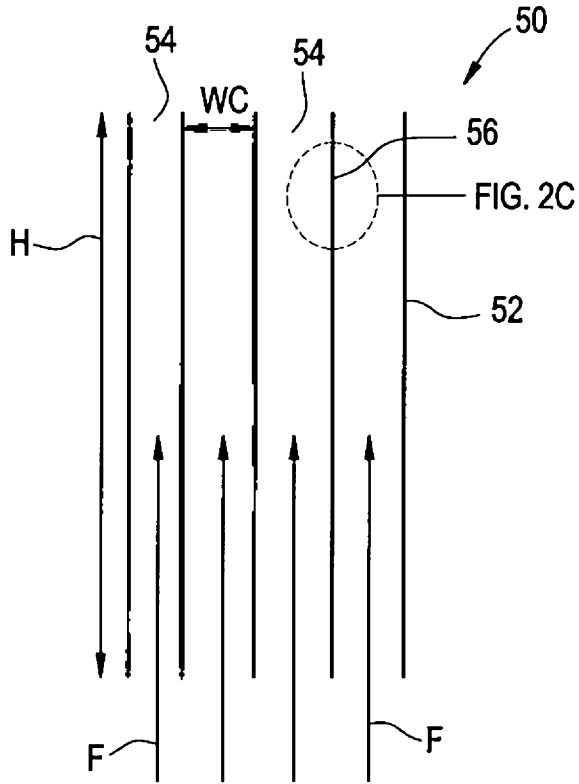


FIG. 2B

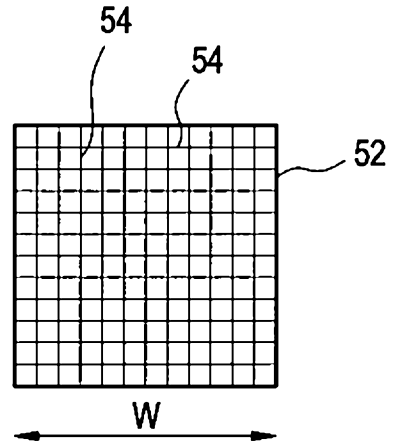


FIG. 2C

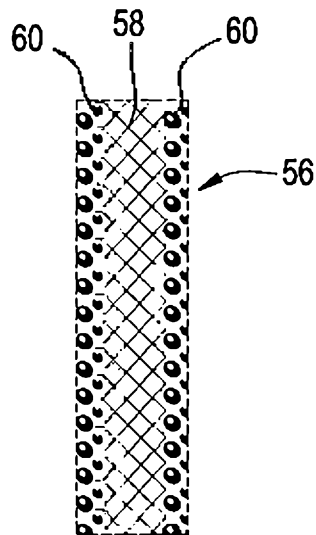


FIG. 3

