SYSTEM AND METHOD FOR WASTE HEAT UTILIZATION IN CARBON DIOXIDE CAPTURE SYSTEMS IN POWER PLANTS

Disclosed herein is a system comprising an absorber; the absorber permitting contact between a flue gas stream that comprises carbon dioxide and a solvent to produce a carbon dioxide rich solvent; a regenerator disposed downstream of the absorber; the regenerator being operative to dissociate the carbon dioxide from the solvent; and a compression system disposed downstream of the regenerator comprising a plurality of compression stages; where each compression stage comprises a compressor that is operative to pressurize the carbon dioxide that is dissociated from the solvent; and where at least some of the compression stages comprise a knockout tank disposed upstream of the compressor and an intercooling heat exchanger disposed downstream of the compressor; where the knockout tank is operative to remove liquid present in the carbon dioxide and where the intercooling heat exchanger is operative to remove heat generated during the pressurizing of the carbon.

ABSTRACT
SYSTEM AND METHOD FOR WASTE HEAT UTILIZATION IN CARBON DIOXIDE CAPTURE SYSTEMS IN POWER PLANTS

TECHNICAL FIELD

[0001] This disclosure relates to a system and to a method for capturing waste heat in a carbon dioxide capture system in a power plant. In particular, this disclosure relates to a system and to a method for capturing waste heat in a carbon dioxide capture system in a power plant without any modifications to the stripper or to the reboiler.

BACKGROUND

[0002] In the combustion of a fuel (e.g., coal, oil, peat, waste, biofuel, natural gas, or the like used for the generation of power or for the production of materials such as cement, steel or glass, or the like, a stream of hot flue gas (also sometimes known as process gas) is generated. Such a hot flue gas contains, among other components, carbon dioxide (CO2).

[0003] The negative environmental effects of releasing carbon dioxide to the atmosphere have been recognized, and have resulted in the development of processes adapted for removing or reducing the amount of carbon dioxide from the flue gas streams. Solvents can efficiently remove carbon dioxide as well as other contaminants, such as sulfur dioxide and hydrogen chloride, from a flue gas stream.

[0004] A typical system for treating solvents comprises an absorber, a solvent stripper (hereinafter termed “regenerator”), and a compression system that is operative to pressurize the carbon dioxide. While the solvent is generally an amine, other solvents can also be used (e.g., methanol, ethanol, ammonia, water, or mixtures thereof). FIG. 1 is a prior art depiction of a system 100 for removing carbon dioxide from a flue gas stream by utilizing solvents (e.g., aqueous amine solution as just one of the other possibilities). The system 100 comprises an absorber 102; a regenerator 104; a partial condenser 106; a reboiler 118; and a compression system 110 (that comprises at least a compressor 114, a knockout tank 112, and a heat exchanger 116).

[0005] A flue gas stream 101 comprising carbon dioxide emanating from a source of combustion (e.g., a power plant) is directed to an absorber 102 where it is contacted with a solvent (e.g., aqueous amine solution—hereinafter solvent) stream 111. The solvent absorbs carbon dioxide from the flue gas stream to form a carbon dioxide rich solvent stream 103 (hereinafter “rich solvent stream”). A treated flue gas stream that is free of partially free from carbon dioxide is discharged from the absorber 102 usually to atmosphere via a stack and/or via other pieces of equipment such as heat exchangers, filters, and the like. As shown in the FIG. 1, the carbon dioxide rich solvent stream 103 is directed to a regenerator 104, where the carbon dioxide gas is released either completely or partially from the solvent. Two streams emanate from the regenerator 104—a carbon dioxide rich stream 107 and a lean solvent stream 111 that contains the solvent and byproducts of the solvent and unreleased carbon dioxide. The carbon dioxide rich stream 107 emanating from the regenerator 104 is compressed to a high pressure in the compression system 110.

[0006] In the compression system 110, the carbon dioxide rich stream 107 is first fed to the knock out tank 112, where any liquids present are removed (this liquid can be water from any aqueous solution used as solvent or can be flue gas moisture). The vapors and solvents are condensed and removed from the bottom of the knock out tank 112. The carbon dioxide stream emanating from the top of the knock out tank 112 is fed to a compressor 114, where it is compressed to a high pressure for purposes of sequestering the carbon dioxide and/or enhanced oil recovery (EOR) and/or carbon dioxide capture and utilization (CCU) and/or other purposes.

[0007] During the compression in the compressor 114, the temperature of the carbon dioxide increases. The hot carbon dioxide stream 121 is then discharged to a heat exchanger 116, which extracts heat from the hot carbon dioxide gas thus cooling it. The carbon dioxide is then discharged from the heat exchanger 116 to a pipeline for sequestration and/or enhanced oil recovery (EOR) and/or carbon dioxide capture and utilization (CCU) and/or other purposes. The heat exchanger 116 is cooled by cooling water.

[0008] The regenerator 104 is in fluid communication with a partial condenser 106 and a reboiler 118. The partial condenser 106 functions to remove vaporized solvent and/or vaporized solvent components contained in the carbon dioxide stream emitting from the top of the regenerator 104 partially or almost completely. The partial condenser 106 receives cooling water (cold) from a cooling water supply to condense vapors contained in the carbon dioxide stream emitting from the top of the regenerator 104. Warm water from the partial condenser 106 then discharged to a cooling tower (not shown) and/or any other heat sink e.g. air cooled heat exchanger. The solvent and/or solvent components removed in the partial condenser is then discharged back into the regenerator 104.

[0009] The reboiler 118 is operative to heat up the solvent at the regenerator bottom. Therefore it uses heating steam from the power plant steam cycle. Condensate from the reboiler 118 is then discharged back to the power plant steam cycle. A solvent stream 111 collected in the reboiler is recycled to the top of the absorber 102 via a heat exchanger 120. Heat is transferred to the carbon rich solvent stream 103 from the solvent stream 111 in the heat exchanger 120.

[0010] It is generally desirable to reuse heat generated in the compressor 114. Improving heat utilization generated during compression is therefore desired. Previous attempts to achieve this have involved redesigning the reboiler or the regenerator. Attempts to redesign the reboiler or the regenerator have proven to be expensive, disturb chemical equilibrium in the regenerator and require additional maintenance of the system 100. For example, regenerator columns are modified by partially integrating compression into the regenerator to recover waste heat. This is not shown in FIG. 1. Since the compression is partially integrated into the regenerator columns, the pressure of the released carbon dioxide is increased which affects the chemical equilibrium and hence might require the regenerator vessel (104) redesign.

[0011] It is therefore desirable to redesign the compression system for efficient utilization of heat generated during compression while not changing either the structure of the reboiler and/or that of the stripper. It is also desirable to redesign the compression system so that it can be used in either a new plant or as a retrofit.

SUMMARY

[0012] Disclosed herein is a system comprising an absorber; the absorber permitting contact between a flue gas stream that comprises carbon dioxide and a solvent to pro-
duce a carbon dioxide rich solvent; a regenerator disposed downstream of the absorber, the regenerator being operative to dissociate the carbon dioxide from the solvent; and a compression system disposed downstream of the regenerator comprising a plurality of compression stages; where each compression stage comprises a compressor that is operative to pressurize the carbon dioxide that is dissociated from the solvent; and where at least some of the compression stages comprise a knockout tank disposed upstream of the compressor and an intercooling heat exchanger disposed downstream of the compressor, where the knockout tank is operative to remove liquids present in the carbon dioxide and where the intercooling heat exchanger is operative to remove heat generated during the pressurization of the carbon dioxide.

[0013] Disclosed herein too is a method comprising discharging a carbon dioxide stream into a compression system; pressurizing the carbon dioxide stream in the compression system; where the compression system comprises a plurality of compression stages; where each compression stage comprises a compressor that is operative to pressurize the carbon dioxide that is dissociated from the solvent; and where at least some of the compression stages comprise a knockout tank disposed upstream of the compressor and an intercooling heat exchanger disposed downstream of the compressor, where the knockout tank is operative to remove liquid (condensed) solvent and/or solvent components like water present in the carbon dioxide and where the intercooling heat exchanger is operative to remove heat generated during the pressurization of the carbon dioxide; removing residual liquid (condensed) solvent and/or solvent components like water in the knockout tank; cooling compressed carbon dioxide in the intercooling heat exchanger with a coolant which may be water among other possibilities; and discharging the pressurized carbon dioxide to a sequestration station and/or enhanced oil recovery (EOR) and/or carbon dioxide capture and utilization (CCU) and/or other purposes.

BRIEF DESCRIPTION OF THE FIGURES

[0014] FIG. 1 is a prior art depiction of a system for removing carbon dioxide from a flue gas stream by utilizing a solvent (e.g., an aqueous amine solution);

[0015] FIG. 2 depicts an exemplary system for compressing carbon dioxide using multistage compression;

[0016] FIG. 3 depicts another exemplary system for compressing carbon dioxide using multistage compression; and

[0017] FIG. 4 depicts an exemplary system for recovering heat from the compressed carbon dioxide by heat exchangers and reusing the heat in the regenerator.

DETAILED DESCRIPTION

[0018] Disclosed herein is a system for the compression of carbon dioxide prior to sequestration. The system advantageously comprises a compression system that comprises a plurality of compressor stages disposed downstream of a regenerator and upstream of a sequestration station. The plurality of compressors are used for sequentially compressing the carbon dioxide to a pressure desired for sequestration and/or enhanced oil recovery (EOR) and/or carbon dioxide capture and utilization (CCU) and/or other purposes. The heat generated during this compression is absorbed by cooling water in intercoolers or in an after-cooler.

[0019] The use of multistage compression is advantageous in that it permits energy savings in the form of efficient and improved power consumption. The demand for compression power (electricity) is reduced. The system disclosed herein does not require any modification of absorbers, regenerators or reboilers and can therefore be used in a new power plant system or advantageously in an existing power plant as a retrofit.

[0020] Disclosed herein too is a method comprising multiple compression stages arranged in series where carbon dioxide gas (removed from a flue gas stream) is successively compressed to a desired pressure for sequestration. Each compression stage successively compresses the carbon dioxide gas in a compression ratio of about 1.5:1 to 4:1 and discharges the compressed carbon dioxide to the next compression stage. The compressed carbon dioxide emanating from each compressor is fed to a knockout tank to remove liquid (condensed) solvent and/or solvent components like water entrained in the carbon dioxide. One or more intercoolers located downstream of one or more compressors in the various compression stages removes the heat generated during compression and discharges the cooling water to a mixer from which it is cooled in a heat exchanger and further in an optional cooling tower.

[0021] With reference now to the FIG. 2, an exemplary system 200 for efficiently utilizing the heat of compression comprises an absorber 202, a regenerator 204, and a compression system 300 (bounded by dotted lines). The absorber 202 lies upstream of the regenerator 204, which in turn lies upstream of the compression system 300. The compression system 300 comprises a plurality of compressor stages with intercooling and after cooling. The compression system 300 can comprise 2 or more compression stages, specifically 3 or more compression stages, specifically 4 or more compression stages and more specifically 5 or more compression stages disposed downstream of the regenerator 204 and upstream of a sequestration station (not shown). In an exemplary embodiment, a compression system 300 comprising at least 6 or more compression stages are disposed downstream of the regenerator 204. The regenerator 204 is also in fluid communication with a first partial condenser 406 and a reboiler 418. The partial condenser 406 and the reboiler 418 are each in recycle loops with the regenerator 204.

[0022] In one embodiment, with reference to the FIG. 2, a flue gas stream 201 containing carbon dioxide is discharged into the absorber 202 where it is absorbed by a solvent. The carbon dioxide rich solvent stream 203 is discharged to the regenerator 204 via a heat exchanger 520 and completely or partially (shown in FIG. 2 is the case for the former) the compression system 300. In the regenerator 204, the solvent is separated from the carbon dioxide gas. The carbon dioxide stream 205 is discharged to the compression system 300, where it undergoes compression for purposes of sequestration. This compression in the compression system 300 and the return of the solvent to the regenerator will be detailed in the FIGS. 3 and 4. The solvent stream 411 that is separated from the carbon dioxide rich solvent stream 203 in the regenerator 204 is recycled to the absorber 202 via the heat exchanger 520, where it exchanges heat with the carbon dioxide rich solvent stream 203 that emanates from the absorber 202.

[0023] In one embodiment, at least a portion of the compression stages comprises a knockout tank, a compressor and an intercooling heat exchanger. The knockout tank lies upstream of the compressor, which lies upstream of the intercooling heat exchanger. In each stage, the knockout tank lies upstream of the respective compressor, while the intercooling
heat exchanger lies downstream of the respective compressor. In an exemplary embodiment, for a compression system comprising at least 6 compression stages, at least 4 compression stages comprise an intercooling heat exchanger disposed downstream of the respective compressor, while one stage comprises an after-cooling heat exchanger disposed downstream of the respective compressor.

[0024] In an exemplary embodiment, depicted in the FIG. 3, the first compression stage of the compression system 300 comprises a first knockout tank 206, a first compressor 208, an after first intercooling heat exchanger 210 that lies downstream of the regenerator 204, the second compression stage comprises a second knockout tank 212, a second compressor 214 and a second intercooling heat exchanger 216 that lies downstream of the first compression stage; the third compression stage comprises a third knock out tank 218, a third compressor 220 and a third intercooling heat exchanger 222 that lies downstream of the third compression stage, and the fourth compression stage comprises a fourth knockout tank 224, a fourth compressor 226, and a fourth intercooling heat exchanger 228 that lies downstream of the third compression stage. The fifth compression stage comprises an absorber 230 for absorbing residual water present in the carbon dioxide and a fifth compressor 226, with the absorber 230 being disposed downstream of the compressor 226. The fifth compression stage lies downstream of the fourth compression stage. The sixth compression stage lies downstream of the fifth compression stage and comprises a sixth compressor 234 and a first after-cooling heat exchanger 236. The after-cooling heat exchanger lies downstream of the sixth compressor 234, which in this exemplary embodiment is the final compressor. The sixth compressor 234 lies upstream of the first after-cooling heat exchanger 236. The compressors 208, 214, 220, 226, 232 and 234 are in mechanical communication with at least a driver (i.e., motor) 242. The motor 242 does mechanical work in driving the compressors to compress the carbon dioxide to the desired pressure for sequestration.

[0025] In the first stage of compression, a carbon dioxide stream 205 emanating from the regenerator 204 at a temperature T1 and a pressure P1 is discharged to the first knockout tank 206, where solvent and/or solvent components like water moisture entrained in the carbon dioxide stream 205 is flashed off. The carbon dioxide stream 207 emanating from the knockout tank 206 at a temperature T2 and pressure P2 is then discharged to the compressor 208 where it is compressed. At this stage T2 is greater than T1 and P2 is greater than P1. The compressed carbon dioxide stream 209 is then discharged to the first intercooling heat exchanger 210 where it is cooled down by exchanging its heat with cooling water.

[0026] In the second stage of compression, the carbon dioxide stream 229 emanating from the second intercooling heat exchanger 210 is discharged to a second knockout tank 212 where additional liquid (e.g., condensed solvent and/or moisture from flue gases) is removed. The carbon dioxide stream 211 now at a temperature T3 and pressure P3 is then compressed in the second compressor 214 to a temperature T4 and pressure P4 prior to being discharged via stream 213 to the second intercooling heat exchanger 216 where it is subjected to cooling with cooling water.

[0027] In the third stage of compression, the carbon dioxide stream 231 emanating from the third intercooling heat exchanger 216 is discharged to a third knock out tank 218 where additional liquid (e.g., condensed solvent and/or moisture from flue gases) is removed. The carbon dioxide stream 215 now at a temperature T5 and pressure P5 is then compressed in the third compressor 220 to a temperature T5 and pressure P6 prior to being discharged via stream 217 to the third intercooling heat exchanger 222 where it is subjected to cooling with cooling water.

[0028] In the fourth stage of compression, the carbon dioxide stream 233 emanating from the third intercooling heat exchanger 222 is discharged to a fourth knock out tank 224 where additional liquid (e.g., condensed solvent and/or moisture from flue gases) is removed. The carbon dioxide stream 219 now at a temperature T7 and pressure P7 is then compressed in the fourth compressor 226 to a temperature T8 and pressure P8 prior to being discharged via stream 221 to the fourth intercooling heat exchanger 228 where it is subjected to cooling with cooling water.

[0029] After the fourth compression stage the carbon dioxide stream is directed to an absorber 230 (e.g., a moisture removal system) comprising a desiccant to remove liquid (e.g., moisture from solvents and/or water). Depending on the process conditions and the type of the moisture removal system, the moisture removal system can be at the downstream of any compressor in the compression system 300. Shown in FIG. 3 is just a selected case where the moisture removal system is at the downstream of the fourth compression stage. The carbon dioxide stream 239 at a pressure P9 and temperature T9 is then directed to the fifth compressor 232 (the fifth compression stage) where it is compressed further and directed to the sixth compressor 234 (the sixth compression stage) where it is further compressed to a temperature T10 and pressure P10. After the sixth compression stage, the carbon dioxide stream 241 is discharged to the first after cooler 236 where it is cooled down to a pressure P11 and temperature T11. The pressure P11 and the temperature T11 is the pressure and temperature at which the carbon dioxide stream is sequestered and after the first after cooler 236, the carbon dioxide stream 243 is sequestered.

[0030] The liquid (e.g., condensed solvent and/or moisture from flue gases) is separated out in each of the knockout tanks is collected in a single knockout tank and is then discharged. In one embodiment, the liquid collected in the fourth knockout tank 224 is discharged to the third knockout tank 218 where it is combined with liquid from the third knockout tank 218 and from which it is discharged to the second knockout tank 212 (to be combined with liquid present in the second knockout tank) and then discharged to the first knockout tank 206. All of the liquid is collected in the first knockout tank 206 and then discharged to the exterior.

[0031] Cooling water used in the first after-cooling heat exchanger 236, the fourth intercooling heat exchanger 228, the third intercooling heat exchanger 222, the second intercooling heat exchanger 216 and the first intercooling heat exchanger 210 is discharged to a mixer 238 where it is mixed and then discharged to a heat exchanger 240, where it is cooled to a desired temperature before being discharged to a cooling tower (not shown). Alternatively, the water may be discharged directly to a cooling tower after being mixed in the mixer 238.

[0032] In each compression stage the carbon dioxide stream emanating from the regenerator 204, has liquid extracted from it in the knockout tank following which the carbon dioxide stream is compressed in the compressor to a ratio of about 1.5:1 to about 4:1, about 1.5:1 to about 4:1, specifically about 1.6:1 to about 3:1, and more specifically about 1.7:1 to about 2.5:1 in the first compressor 208. In an
exemplary embodiment, the first compressor 208 compresses the carbon dioxide stream in an amount of about 2:1.

[0033] In an exemplary embodiment, the temperature in each compression stage is increased by a factor of about 1.5 to about 3.5, specifically about 1.75 to about 3.0, and more specifically 2.0 to about 2.75 from the temperature of the carbon dioxide stream prior to entering the first compressor. The compressed carbon dioxide, now at a higher pressure and temperature (than it was prior to the compression in each compressor) is then discharged from the compressor to the intercooling heat exchanger if desired in order to exchange heat with coolant (i.e. cooling water or any other cooling material). The cooling water heated up in the intercooling heat exchanger is discharged to a cooling tower for cooling. The temperature of the cooling water is generally increased by about 5 to about 15°C, specifically about 7 to about 12°C in each intercooling heat exchanger as the water absorbs heat from the compressed carbon dioxide. In extreme cases, the temperature of the cooling water can be increased by up to 50°C.

[0034] As detailed briefly above, in one manner of operating the system 200 of the FIG. 2, a flue gas stream 201 is contacted with a solvent to form a carbon dioxide rich solvent stream 203, which is then discharged to the regenerator 204. Carbon dioxide gas released from the solvent is then discharged and subjected to compression in the plurality of compression stages depicted in the FIGS. 2, 3 and 4.

[0035] The carbon dioxide gas stream 205 is first discharged from the regenerator 204 to the knockout tank 206 (see FIG. 3), where some of the moisture contained in the carbon dioxide gas stream is collected. The carbon dioxide gas stream 207 emanating from the first knockout tank 206 is then compressed in the first compressor 208 to a compression ratio of about 1.5:1 to about 4:1. In an exemplary embodiment, the first compressor 208 compresses the carbon dioxide stream in an amount of about 2:1.

[0036] The temperature of the carbon dioxide stream 209 exiting the first compressor is increased by a factor of about 2.0 to about 2.5 from the temperature of the carbon dioxide stream 207 prior to entering the first compressor 208. In an exemplary embodiment, the temperature T1 and pressure P1 of the carbon dioxide stream 207 prior to being compressed in the first compressor 208 is about 40°C and about 3.0 bar (3.05 kilograms per square centimeter) respectively, while the temperature T2 and pressure P2 after compression is about 112°C and 6.2 bar (6.10 kilograms per square centimeter) respectively.

[0037] The compressed carbon dioxide stream 209 is then discharged to the first intercooling heat exchanger 210, where the heat of compression is absorbed by cooling water. The temperature of the cooling water is increased by about 5 to about 15°C, specifically about 7 to about 12°C in the intercooling heat exchanger 210 as it absorbs heat from the compressed carbon dioxide. In an exemplary embodiment, the cooling water from the intercooling heat exchanger 210 is then discharged to a mixer 238, from which it is discharged to a heat exchanger 240 where it is cooled from about 23.1°C to about 13.1°C.

[0038] In an exemplary embodiment, the temperature T3 and pressure P3 of the carbon dioxide stream 211 after the second knockout tank 212 and prior to entering the second compressor is 39.5°C and 5.9 bar (6.0 kilograms per square centimeters). In summary, the temperature of the carbon dioxide stream after each stage of compression increases by a factor of about 2.0 to about 2.5 from the temperature of the carbon dioxide stream prior to compression. After being discharged to the respective knockout tanks in each stage of compression, the temperature of the carbon dioxide stream is substantially similar to the temperature of the carbon dioxide stream prior to undergoing compression.

[0040] In this manner, in a compression system comprising multiple stages of compression, the temperature of the carbon dioxide stream prior to each compression stage is almost identical to each other. For example with reference to the FIG. 3, T1=T3=T5=T7 (where the symbol “=” means approximately) and so one. In a similar manner, the temperature of the carbon dioxide stream after each compression stage is almost identical to each other. For example with reference to the FIG. 3, T2=T4=T6=T8 and so one. In one embodiment, there may be a slight decrease in the temperature of the carbon dioxide stream after each successive compression stage. Thus for example, T2 may be slightly greater than T4, which is slightly greater than T6, which is slightly greater than T8.

[0041] With regard to the pressure in each compression stage, the process of the first compression stage is repeated through the second compression stage, the third compression stage, the fourth compression stage, and so on. At each stage, the respective compressors 214, 220 and 226 subject the carbon dioxide gas to a compression ratio of about 1.5:1 to about 4:1, specifically about 1.6:1 to about 3:1, and more specifically about 1.7:1 to about 2.5:1 and most specifically about 2:1. Thus if the pressure of the carbon dioxide stream prior to the first compression stage is P1, the pressure prior to the second stage of compression P3=2P1, while the pressure prior the third stage of compression P5=2P3=4P1, while the pressure prior the fourth stage of compression is P4=2P3=4P2=8P1.

[0042] The fifth compression stage comprises a compressor 232, but does not contain a knockout tank or an intercooling heat exchanger. Instead after the fourth compression stage, the carbon dioxide gas stream is discharged to an absorber 230 that comprises a desiccant that absorbs the remaining water present in the carbon dioxide. An exemplary desiccant is triethylene glycol (TEG).

[0043] The carbon dioxide gas stream now devoid of moisture is discharged to the fifth compressor 232 and then to the sixth compressor 234. In the fifth and the sixth compressors, the carbon dioxide gas stream is once again pressurized to a compression ratio of about 1.5:1 to about 4:1 in each compressor, while the temperature is increased from about T1 prior to the fifth compressor to a temperature T5 of about 1.8 to about 2.0 T1 after compression in the fifth compressor 232. The pressure prior the sixth stage of compression is 9P9=32P1.

[0044] After the sixth compressor, the temperature T10 is increased to about 3.5 to about 4.0 T1 while the pressure P10 is about 35P1 to about 40P1. In an exemplary embodiment, the pressure of the carbon dioxide stream after compression in the sixth compression stage is about 110 bar (about 112 kilograms per square centimeters), which is the pressure desired for carbon dioxide sequestration. The carbon dioxide stream after compression in the sixth compression stage is
then discharged to the first after-cooling heat exchanger 236, where it is pressure is about 110 bar (about 112 kilograms per square centimeters). The temperature of the carbon dioxide stream after the fifth intercooler 236 is about 45 to about 55 °C., specifically about 50 °C.

[0045] The cooling water used in the respective intercoolers at each compression stage is mixed in a mixer and is discharged to a heat exchanger 240 at a temperature of about 20 to about 25 °C., specifically about 23 °C., while after the heat exchanger 240, the temperature of the cooling water is about 10 to about 15 °C., specifically about 13 °C. The heat exchanger 240 receives cooling water from a cooling tower or any other cooling water device. In a similar manner, the heat exchangers 210, 216, 222, 228 and 236 can receive cooling water from the cooling tower, any other cooling water device. The cooling fluid can be obtained from any other heat exchanger as well.

[0046] Table 1 depicts the temperatures and pressures at points A1 through A11 for the Fig. 3, where A1 refers to point at which the temperature T1 and the pressure P1 are measured, A2 refers to point at which the temperature T2 and the pressure P2 are measured, A3 refers to point at which the temperature T3 and the pressure P3 are measured, and so on.

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
<th>A7</th>
<th>A8</th>
<th>A9</th>
<th>A10</th>
<th>A11</th>
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<td>T (°C)</td>
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<td>111.9</td>
<td>39.5</td>
<td>108.3</td>
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<td>103.1</td>
<td>39.7</td>
<td>98.1</td>
<td>99.7</td>
<td>150.3</td>
<td>49</td>
</tr>
<tr>
<td>P (bar)</td>
<td>2.9</td>
<td>6.2</td>
<td>5.9</td>
<td>11.9</td>
<td>11.8</td>
<td>22.1</td>
<td>21.8</td>
<td>39.1</td>
<td>70.2</td>
<td>110.5</td>
<td>110.2</td>
</tr>
</tbody>
</table>

[0047] In one embodiment, with reference to the set-up in the Fig. 4, the electrical load on the compressor is about 22,000 to about 30,000 kilowatts, specifically about 25,000 to about 28,000 kilowatts. The heat recovered from the intercooling heat exchangers is about 20,000 to about 40,000 kilowatts, specifically about 37,000 to about 39,000 kilowatts.

[0048] In another exemplary embodiment, depicted in the Fig. 4, the intercooling heat exchangers of one or more compression stages can be removed from the system depicted in the Fig. 3. In another embodiment, some of the knockout tanks can be removed from the compression stage immediately following the compression stage where the intercooler has been removed. When an intercooling heat exchanger of a particular compression stage is removed, it may be replaced by an additional heat exchanger added downstream of the succeeding compression stage from where the intercooler has been removed.

[0049] For example, an intercooler removed in the first compression stage may be replaced by a heat exchanger located downstream of the compressor in the second stage. Thus the removal of three intercooling heat exchangers from various compression stages results in the utilization of at least three heat exchangers in the succeeding compression stages. In one exemplary embodiment, the heat exchangers can be used to remove carbon dioxide from the carbon dioxide rich solvent, thus saving energy that is used in the regenerator 204. This is depicted by stream 502 in the Fig. 4. This set-up can reduce the steam used in the reboiler (not shown). Depending upon the pressure level of the extracted steam, this can save electrical energy in an amount of about 4 to 4.4 megawatts if the saved low pressure steam is expanded in a steam turbine. This method is advantageous in that the power consumption is increased by about 5 to about 10%, specifically about 7 to about 9%. The cooling water demand is reduced by about 35 to about 45%, specifically about 36 to about 40%. The heat utilization by the regenerator column is increased in an amount by up to about 40%, specifically about 5 to about 37%.

[0050] With reference now to the Fig. 4, the carbon dioxide stream 207 emanating from the knockout chamber 206 at a temperature and pressure at point (A1) indicated by (T1, P1) is discharged to the first compressor 208 where it is compressed to A2(T2, P2). Here A2 refers to the point where T2 and P2 are measured in the Fig. 3. It is then directly discharged to the second compressor 214 where it is subjected to additional compression to reach temperature and pressure A3(T3, P3). After compression, the carbon dioxide stream is discharged to a first heat exchanger 206 and then to the first intercooling heat exchanger 216 and the first knockout tank 218. The carbon dioxide stream now at A4(T4, P4) is then discharged to the third compressor 220 to reach temperature and pressure A5(T5, P5) and to the fourth compressor 226 to reach temperature and pressure A6(T6, P6). After the fourth compressor the carbon dioxide stream is discharged to the second heat exchanger 304 and then to second intercooling heat exchanger 228 and then to absorber 230 where any residual water is removed. The carbon dioxide stream at A7(T7, P7) is then discharged to the fifth compressor 232 to reach temperature and pressure A8(T8, P8) and the sixth compressor 234 to reach temperature and pressure A9(T9, P9). After the sixth compressor 234 the carbon dioxide stream is discharged to the third heat exchanger 302 and then to the third intercooling heat exchanger 236 from which it is discharged to the sequestration station (not shown) at a temperature and pressure of A10(T10, P10).

[0051] In one embodiment, the water stream 502 used in the heat exchangers 302, 304 and 306 (to recover heat from the compressed carbon dioxide) can have heat recovered from them in a heat recovery steam generator. In another embodiment, the heat recovered from the heat exchangers 302, 304 and 306 is used in the regenerator to supply up to 16 megawatts of energy to the regenerator.

[0052] The Table 2 shows the various temperatures and pressures at the various points A1 to A10 for a system having 6 compression stages with 2 intercooling heat exchangers, 1 after-cooling heat exchanger and the 3 heat exchangers as depicted in the Fig. 4.
In the system depicted in the FIG. 4, the temperature prior to compression in each odd numbered compressor is substantially the same. Thus, for example, T1=T4=T7. The temperature after compression at stages A3, A6, A8 and A9 is substantially elevated when compared with the temperatures prior to compression. The compression at each stage compresses the carbon dioxide in a compression ratio of about 1:5:1 to about 4:1, specifically about 1.6:1 to about 3:1, and more specifically about 1.7:1 to about 2.5:1 and most specifically about 2:1. The pressure during the 6 stages of compression shown in the Table 2 follows that pattern reflected in the Table 1 (which represents data from the FIG. 1).

In one embodiment, with reference to the set-up in the FIG. 4, the electrical load on the compressor is about 22,000 to about 30,000 kilowatts, specifically about 25,000 to about 28,000 kilowatts. The heat recovered from the intercooling heat exchangers is about 20,000 to about 40,000 kilowatts, specifically about 22,000 to about 26,000 kilowatts.

In this embodiment, the heat recovered from the compression of the carbon dioxide is used to recover the carbon dioxide from the solvent. The reutilization of heat in this manner increases the power plant efficiency by up to about 2 percentage points. In an exemplary embodiment, the reutilization of heat in this manner increases the efficiency of the power plant by up to one percentage point. This reutilization of heat in the heat exchangers 302, 304, and 306 results in a reduction of the reboiler duty by an amount of up to 8%, specifically about 5% to about 7%.

The cooling water demand is reduced by up to 27%, specifically about 15 to about 25% by the use of the three heat exchangers 302, 304 and 306. In addition, there is a potential for using a smaller reboiler when the heat recovered from water is used in the regenerator. In addition, any additional power used in the multistage compression can be compensated for by a reduction in reboiler steam demand.

It will be understood that, although the terms “first,” “second,” “third,” etc. may be used herein to describe various elements, components, regions, layers and/or sections, these terms are used herein for the purpose of description only and are not intended to distinguish one element, component, region, layer or section from another element, component, region, layer or section. Thus, “a first element,” “a component,” “a region,” “a layer” or “a section” discussed below could be termed a second element, component, region, layer or section without departing from the teachings herein.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used herein, singular forms like “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” or “includes” and/or “including” when used in this specification, specify the presence of stated features, regions, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, regions, integers, steps, operations, elements, components, and/or groups thereof.

Furthermore, relative terms, such as “lower” or “bottom” and “upper” or “top,” may be used herein to describe one element’s relationship to another elements as illustrated in the Figures. It will be understood that relative terms are intended to encompass different orientations of the device in addition to the orientation depicted in the Figures. For example, if the device in one of the figures is turned over, elements described as being on the “lower” side of other elements would then be oriented on “upper” sides of the other elements. The exemplary term “lower,” can therefore, encompasses both an orientation of “lower” and “upper,” depending on the particular orientation of the figure. Similarly, if the device in one of the figures is turned over, elements described as “below” or “beneath” other elements would then be oriented “above” the other elements. The exemplary terms “below” or “beneath” can, therefore, encompass both an orientation of above and below.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and the present disclosure, and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

Exemplary embodiments are described herein with reference to cross section illustrations that are schematic illustrations of idealized embodiments. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, embodiments described herein should not be construed as limited to the particular shapes of regions as illustrated herein but are to include deviations in shapes that result, for example, from manufacturing. For example, a region illustrated or described as flat may, typically, have rough and/or nonlinear features. Moreover, sharp angles that are illustrated may be rounded. Thus, the regions illustrated in the figures are schematic in nature and their shapes are not intended to illustrate the precise shape of a region and are not intended to limit the scope of the present claims.

The term and/or is used herein to mean both “and” as well as “or”. For example, “A and/or B” is construed to mean A, B or A and B.

The transition term “comprising” is inclusive of the transition terms “consisting essentially of and “consisting of and can be interchangeably for “comprising”.

While this disclosure describes exemplary embodiments, it will be understood by those skilled in the art that various changes can be made and equivalents can be substituted for elements thereof without departing from the scope of the disclosed embodiments. In addition, many modifications can be made to adopt a particular situation or material to the teachings of this disclosure without departing from the

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What is claimed is:

1. A system comprising:
   an absorber; the absorber permitting contact between a flue gas stream that comprises carbon dioxide and a solvent to produce a carbon dioxide rich solvent; a regenerator disposed downstream of the absorber; the regenerator being operative to dissociate the carbon dioxide from the solvent; and
   a compression system disposed downstream of the regenerator comprising:
   a plurality of compression stages; where each compression stage comprises a compressor that is operative to pressurize the carbon dioxide that is dissociated from the solvent; and where at least some of the compression stages comprise a knockout tank disposed upstream of the compressor and an intercooling heat exchanger disposed downstream of the compressor; where the knockout tank is operative to remove liquid present in the carbon dioxide and where the intercooling heat exchanger is operative to remove heat generated during the pressurizing of the carbon dioxide.

2. The system of claim 1, where each compression stage comprises the knockout tank and the intercooling heat exchanger.

3. The system of claim 2, where the compression system comprises at least two compression stages that comprise the knockout tank and the intercooling heat exchanger.

4. The system of claim 2, where the compression system comprises at least four compression stages that comprise the knockout tank and the intercooling heat exchanger.

5. The system of claim 2, where the compression system further comprises a heat exchanger disposed downstream of the compressor and upstream of the intercooling heat exchanger.

6. The system of claim 1, where the intercooling heat exchanger lies downstream of a first compressor and upstream of a second compressor.

7. The system of claim 1, where at least one compression stage comprises an after-cooling heat exchanger; where the after-cooling heat exchanger lies downstream of a final compressor.

8. The system of claim 1, where cooling water from a plurality of intercooling heat exchangers is discharged to a mixer prior to being discharged to a heat exchanger.

9. The system of claim 1, where at least one compression stage comprises an absorber containing a desiccant.

10. The system of claim 5, where a heat transferring fluid from the heat exchanger is discharged to the regenerator; where the heat transferring fluid has received heat from the pressurized carbon dioxide.

11. A method comprising:
   - discharging a carbon dioxide stream into a compression system;
   - pressurizing the carbon dioxide stream in the compression system; where the compression system comprises:
     - a plurality of compression stages; where each compression stage comprises a compressor that is operative to pressurize the carbon dioxide that is dissociated from the solvent; and where at least some of the compression stages comprise a knockout tank disposed upstream of the compressor and an intercooling heat exchanger disposed downstream of the compressor; where the knockout tank is operative to remove liquid present in the carbon dioxide and where the intercooling heat exchanger is operative to remove heat generated during the pressurizing of the carbon dioxide;
     - removing residual liquid in the knockout tank;
     - cooling compressed carbon dioxide in the intercooling heat exchanger with water; and
     - discharging the pressurized carbon dioxide to a sequestration station.

12. The method of claim 11, further comprising additionally cooling the compressed carbon dioxide in a heat exchanger disposed downstream of the compressor and upstream of the intercooling heat exchanger.

13. The method of claim 12, where the additional cooling occurs in a plurality of heat exchangers each of which is disposed downstream of a compressor and upstream of an intercooling heat exchanger.

14. The method of claim 12, where the heat exchanger is cooled with solvent that is used in a regenerator.

15. The method of claim 11, where a heat transferring fluid used in the intercooling heat exchanger is discharged to a mixer and then discharged to a heat exchanger.

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