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NO_x REMOVAL FOR CRYOGENIC CARBON CAPTURE FROM FLUE GAS

Abstract

Processes for recovery of carbon dioxide from a flue gas stream and removal of NO_x compounds from the recovered carbon dioxide are described. The processes can recover gaseous, liquid, or supercritical carbon dioxide. The processes incorporate a NO_x stripping column after the CO₂ fractionation column to remove NO_x compounds formed in the CO₂ fractionation column.

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Background/Summary

RELATED APPLICATIONS [0001] This application claims priority to U.S. Provisional Patent Application Ser. No. 63/554,456, filed on Feb. 16, 2024, the entirety of which is incorporated herein by reference.

BACKGROUND

[0002] CO.sub.2 capture from flue gas is a key decarbonization strategy for various industries, such as steel, power and cement producers. Flue gas has contaminants that will cause the CO.sub.2 product to be off specification (e.g., NO.sub.2, SO.sub.2, etc.) or cause issues in the PSA-cryogenic system such as mercury issues with brazed aluminum exchanger, etc. The CO.sub.2 capture technologies need to handle the various contaminants in the feed while minimizing the corresponding energy usage and cost.

[0003] In cryogenic carbon capture from a flue gas or other source with NO_x compounds present, separation of NO_x from the captured CO.sub.2 for sequestration or utilization is highly important. Under certain circumstances and for tight product specifications, the removal of NO.sub.2 upstream of the cryogenic fractionation column may be inadequate to remove NO.sub.2 to the levels required due to the continued reaction of NO and O.sub.2 to form NO.sub.2 in the cryogenic fractionation column and overhead system.

[0004] There is a need for processes which efficiently capture CO.sub.2 in gas feed streams, as well as remove impurities from the feed streams and from the CO.sub.2 product streams.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 illustrates one embodiment of a process producing a vapor phase carbon dioxide product according to the present invention.

[0006] FIG. 2 illustrates another embodiment of process producing a vapor phase carbon dioxide product according to the present invention.

[0007] FIG. 3 illustrates one embodiment of process producing a liquid or supercritical phase carbon dioxide product according to the present invention.

[0008] FIG. 4 illustrates another embodiment of a process producing a liquid or supercritical phase carbon dioxide product according to the present invention.

DESCRIPTION

[0009] This present invention provides processes to remove additional NO_x compounds after the cryogenic CO.sub.2 fractionation column. It addresses situations where removing the NO_x compounds upstream of the CO.sub.2 fractionation column is inadequate to remove NO_x compounds to the levels required to meet the product specification. This is done while avoiding significant CO.sub.2 product losses. The processes incorporate non-catalytic means of removing NO_x while maintaining a vapor, liquid, or supercritical CO.sub.2 product. NO_x compounds include one or more of NO, NO.sub.2, N.sub.2O, N.sub.2O.sub.3, and N.sub.2O.sub.4.

[0010] This invention is embodied in two ways, depending on the desired CO.sub.2 product phase. For both implementations, a NO_x stripper column is added to strip off NO_x from the CO.sub.2 product from the bottom of the cryogenic fractionation column.

[0011] The liquid/supercritical product utilizes a higher pressure NO_x stripper column (one or more) to increase the boiling point of the CO.sub.2. The increased pressure allows the CO.sub.2

feed to the NO_x stripper column to be used as a condensing medium, saving on refrigeration system load. A pump and compressor are placed after a flash drum to increase the pressure accordingly. The CO₂ is then stripped in a NO_x stripper column with the feed on the bottom tray and a liquid product is taken on the overhead to be sent to cooling or additional pumping as needed. The bottom stream is rich in NO_x and is sent to the upstream NO_x removal zone or a flue gas generating unit.

[0012] The vapor phase product implementation uses the same scheme, but the CO₂ feed from the CO₂ fractionation column (one or more) is sent directly to the NO_x stripper column without an increase in pressure. The refrigeration system is used to condense the overhead, and a vapor only product is taken from the top. The bottoms stream is treated in the same manner as the liquid phase case.

[0013] In both cases, the reboiler is heated using either recirculating quench water from the quench column or warm refrigerant from the compressor discharge in the refrigeration loop.

[0014] Additionally, this process allows for low loss of CO₂ by recycling the significant amount of CO₂ purged with NO_x to the NO_x removal zone in the process where greater purification can take place at lower energy usage levels.

[0015] FIG. 1 illustrates one embodiment of a process 100 for producing a carbon dioxide vapor stream with reduced level of NO_x compounds. A flue gas (or other gas) feed stream 105 comprises carbon dioxide, one or more NO_x compounds, and one or more of nitrogen, oxygen, water and argon. The flue gas feed stream 105 may be sent to a quench column 110 where it is cooled with quench stream 115 in a quench column. The quench stream 115 can be any suitable quench stream as known to those of skill in the art. Suitable quench streams include, but are not limited to, water, caustic (to remove acidic impurities such as HCl and SO₂), or combinations thereof.

[0016] The quenched flue gas stream 120 is sent to a flue gas compressor and drier 125 where it is compressed and dried to form compressed flue gas stream 130. The quenched flue gas stream 120 is compressed from a pressure in a range of 75 to 150 kPa to a pressure in the range of 2500 to 5000 kPa for the compressed flue gas stream 130.

[0017] The compressed flue gas stream 130 is sent to the main heat exchanger 135 where it is cooled with a chilled refrigerant stream 140 from refrigeration system 145. The warmed refrigerant stream 150 is returned to the refrigeration system 145.

[0018] The cooled compressed flue gas stream 155 is sent to the NO_x removal zone 160 comprising one or more NO_x removal columns where the majority of the NO_x compounds other than NO and N₂O are removed from the cooled compressed flue gas stream 155. The reduced contaminant stream 165 comprises carbon dioxide and a reduced level of NO_x compounds compared to the cooled compressed flue gas stream 155 entering the NO_x removal zone 160.

[0019] The NO_x-enriched bottom stream 170 is highly concentrated in NO_x compounds, typically 25-75 percent by mole. The NO_x-enriched bottom stream 170 may be sent for treatment including, but not limited to, nitric acid production or fertilizer production. Alternatively, it may be combined with stream 190 and be discharged to the atmosphere, sent to further contaminant treating or a pressure swing adsorption unit.

[0020] The reduced contaminant stream 165 is sent to the CO₂ fractionation column 175 where it is separated into an overhead gas stream 180 comprising light components including, but not limited to, one or more of N₂, O₂, or NO, and a carbon dioxide-enriched bottom stream 185.

[0021] The overhead gas stream 180 may be warmed in the main heat exchanger 135, and the warmed overhead gas stream 190 may be sent to atmosphere, further flue gas contaminant treating, or a pressure swing adsorption unit.

[0022] During fractionation in the CO₂ fractionation column 175, a portion of the NO may be converted to NO₂, which leaves with the carbon dioxide-enriched bottom stream 185.

[0023] The carbon dioxide-enriched bottom stream 185 from the CO₂ fractionation column

175 is sent to the NOx stripping column **195** where the remaining NOx compounds are stripped from the carbon dioxide-enriched bottom stream **185**. The stripping column overhead stream **200** comprises gaseous carbon dioxide and is depleted of NOx compounds. It is the gaseous carbon dioxide product stream. In some situations, it can be used to cool the upstream process if the temperature specification for the gaseous carbon dioxide product is sufficiently high.

[0024] The stripping column bottom stream **205**, which is enriched in NOx compounds, is typically 0.1-5 mole percent NOx, and more often 0.2-1 mole % NOx. This stream may be recycled to the NOx removal zone **160** for concentration of the NOx and recovery of the CO.sub.2, or to a flue gas generation unit (not shown) for destruction of the NOx and recovery of the CO.sub.2.

[0025] FIG. 2 illustrates a second embodiment of a process **300** for producing a carbon dioxide vapor stream with reduced level of NOx compound. The flue gas (or other gas) feed stream **305** comprises carbon dioxide, one or more NOx compounds, and one or more of nitrogen, oxygen, water and argon. The flue gas feed stream **305** may be sent to a quench column **310** where it is cooled with quench stream **315**, as described above.

[0026] The quenched flue gas stream **320** is sent to a flue gas compressor **325** where it is compressed from a pressure in a range of 75 to 150 kPa to a pressure in the range of 800 to 2500 kPa.

[0027] The compressed flue gas stream **330** is sent to a CO.sub.2 pressure swing adsorption (PSA) unit **335**, which can be a standard CO.sub.2 PSA unit or a CO.sub.2 vacuum pressure swing adsorption (VPSA) unit. The compressed flue gas stream **330** is separated into a CO.sub.2-enriched stream **340** and an off gas stream **345**.

[0028] The CO.sub.2-enriched stream **340** is sent to a compressor and dehydration unit **350** where it is compressed to a pressure in the range of 2500 to 5000 kPa and dried forming dried CO.sub.2-enriched stream **355**. The dehydration unit may comprise any suitable dehydration unit including, but not limited to, a triethylene glycol unit, an activated alumina or a silica gel or a molecular sieve (zeolite A or X) or a combination thereof-based temperature swing adsorption process.

[0029] The dried CO.sub.2-enriched stream **355** is sent to the main heat exchanger **360** where it is cooled with a chilled refrigerant stream **365** from refrigeration system **370** forming cooled CO.sub.2-enriched stream **380**. The warmed refrigerant stream **375** is returned to the refrigeration system **370**.

[0030] The cooled CO.sub.2-enriched stream **380** is sent to the NOx removal zone **385** comprising one or more NOx removal columns where the majority of the NOx compounds other than NO and N.sub.2O are removed from the cooled CO.sub.2-enriched stream **380**. The reduced contaminant stream **390** comprises carbon dioxide and a reduced level of NOx compounds compared to the cooled CO.sub.2-enriched stream **380** entering the NOx removal zone **385**.

[0031] The NOx-enriched bottom stream **395** is highly concentrated in NOx compounds, typically 25-75 percent by mole. The NOx-enriched bottom stream **395** may be sent for treatment including, but not limited to, nitric acid production or fertilizer production. Alternatively, it may be combined with stream **445** and be discharged to the atmosphere, sent to further contaminant treating or a pressure swing adsorption unit.

[0032] The reduced contaminant stream **390** is sent to the CO.sub.2 fractionation column **400** where it is separated into an overhead gas stream **405** comprising light components including, but not limited to, one or more of N.sub.2, O.sub.2, or NO, and a carbon dioxide-enriched bottom stream **410**.

[0033] The overhead gas stream **405** may be warmed in the main heat exchanger **360**, and the warmed overhead gas stream **415** may be sent to the PSA unit **335**. Alternatively, it could be sent to atmosphere, or further flue gas contaminant treating.

[0034] As discussed above, during fractionation in the CO.sub.2 fractionation column **400**, a portion of the NO may be converted to NO.sub.2, which leaves with the carbon dioxide-enriched bottom stream **410**.

[0035] The carbon dioxide-enriched bottom stream **410** from the CO.sub.2 fractionation column **400** is sent to the NOx stripping column **420** where the remaining NOx compounds are stripped from the carbon dioxide-enriched bottom stream **410**. The stripping column overhead stream **425** comprises gaseous carbon dioxide and is depleted of NOx compounds. It is the gaseous carbon dioxide product stream. As discussed above, it can be used to cool the upstream process if the temperature specification for the gaseous carbon dioxide product is sufficiently high.

[0036] The stripping column bottom stream **430**, which is enriched in NOx compounds, is typically 0.1-5 mole percent NOx, and more often 0.2-1 mole % NOx. This stream may be recycled to the NOx removal zone **385** for concentration of the NOx and recovery of the CO.sub.2, or to a flue gas generation unit (not shown) for destruction of the NOx and recovery of the CO.sub.2.

[0037] The off gas stream **345** from the PSA unit **335** is sent to a flue gas expander **435**, and the cooled expanded flue gas stream **440** is sent to the main heat exchanger **360**. The warmed expanded flue gas stream **445** can be further treated and/or released to the atmosphere.

[0038] FIG. **3** illustrates one embodiment of a process **500** for producing a liquid carbon dioxide stream with reduced level of NOx compounds. A flue gas (or other gas) feed stream **505** comprises carbon dioxide, one or more NOx compounds, and one or more of nitrogen, oxygen, water and argon. The flue gas feed stream **505** may be sent to a quench column **510** where it is cooled with quench stream **515** in a quench column. The quench stream **515** can be any suitable quench stream as known to those of skill in the art. Suitable quench streams include, but are not limited to, water, caustic, or combinations thereof.

[0039] The quenched flue gas stream **520** is sent to a flue gas compressor and drier **525** where it is compressed and dried to form compressed flue gas stream **530**. The quenched flue gas stream **520** is compressed from a pressure in a range of 75 to 150 kPa to a pressure in the range of 2500 to 5000 kPa for the compressed flue gas stream **530**.

[0040] The compressed flue gas stream **530** is sent to the main heat exchanger **535** where it is cooled with a chilled refrigerant stream **540** from refrigeration system **545**. The warmed refrigerant stream **550** is returned to the refrigeration system **545**.

[0041] The cooled compressed flue gas stream **555** is sent to the NOx removal zone **560** comprising one or more NOx removal columns where the majority of the NOx compounds other than NO and N.sub.2O are removed from the cooled compressed flue gas stream **555**. The reduced contaminant stream **565** comprises carbon dioxide and a reduced level of NOx compounds compared to the cooled compressed flue gas stream **555** entering the NOx removal zone **560**.

[0042] The NOx-enriched bottom stream **570** is highly concentrated in NOx compounds, typically 25-75 percent by mole. The NOx-enriched bottom stream **570** may be sent for treatment including, but not limited to, nitric acid production or fertilizer production. Alternatively, it may be combined with stream **590** and be discharged to the atmosphere, sent to further contaminant treating or a pressure swing adsorption unit.

[0043] The reduced contaminant stream **565** is sent to the CO.sub.2 fractionation column **575** where it is separated into an overhead gas stream **580** comprising light components including, but not limited to, one or more of N.sub.2, O.sub.2, or NO, and a carbon dioxide-enriched bottom stream **585**.

[0044] The overhead gas stream **580** may be warmed in the main heat exchanger **535**, and the warmed overhead gas stream **590** may be sent to atmosphere, further flue gas contaminant treating, or a pressure swing adsorption unit.

[0045] During fractionation in the CO.sub.2 fractionation column **575**, a portion of the NO may be converted to NO.sub.2, which leaves with the carbon dioxide-enriched bottom stream **585**.

[0046] The carbon dioxide-enriched bottom stream **585** from the CO.sub.2 fractionation column **575** is warmed in heat exchanger **592** with the stripping column overhead stream **595**. The warmed carbon dioxide-enriched bottom stream **600** is sent to flash drum **605** where it is separated into carbon dioxide-enriched bottom vapor stream **610** and carbon dioxide-enriched bottom liquid

stream **615**.

[0047] The carbon dioxide-enriched bottom vapor stream **610** is compressed in compressor **620** forming compressed carbon dioxide-enriched bottom vapor stream **625**. The carbon dioxide-enriched bottom liquid stream **615** is pumped in pump **630** forming pumped carbon dioxide-enriched bottom liquid stream **635**.

[0048] The compressed carbon dioxide-enriched bottom vapor stream **625** and the pumped carbon dioxide-enriched bottom liquid stream **635** can be combined, and the combined carbon dioxide-enriched bottom stream **640** is sent to the NOx stripping column **645**. Alternatively, the compressed carbon dioxide-enriched bottom vapor stream **625** and the pumped carbon dioxide-enriched bottom liquid stream **635** can be sent to the NOx stripping column **645** separately.

[0049] The stripping column overhead stream **595** is heat exchanged with the carbon dioxide-enriched bottom stream **585** from the CO.sub.2 fractionation column **575**. The cooled stripping column overhead **650** is sent to overhead receiver **655**.

[0050] The liquid stripping column overhead from the overhead receiver **655** can be split into first portion **660**, which can be refluxed to the NOx stripping column **645**, and a second portion **665**, which is the carbon dioxide product stream. It can be further chilled, or it can be pumped to form supercritical carbon dioxide.

[0051] The stripping column bottom stream **670**, which is enriched in NOx compounds, is typically 0.1-5 mole percent NOx, and more often 0.2-1 mole % NOx. This stream may be recycled to the NOx removal zone **560** for concentration of the NOx and recovery of the CO.sub.2, or to a flue gas generation unit (not shown) for destruction of the NOx and recovery of the CO.sub.2.

[0052] FIG. 4 illustrates a second embodiment of a process **700** for producing a carbon dioxide liquid stream with reduced level of NOx compound. The flue gas (or other gas) feed stream **705** comprises carbon dioxide, one or more NOx compounds, and one or more of nitrogen, oxygen, water and argon. The flue gas feed stream **705** may be sent to a quench column **710** where it is cooled with quench stream **715**, as described above.

[0053] The quenched flue gas stream **720** is sent to a flue gas compressor **725** where it is compressed from a pressure in a range of 75 to 150 kPa to a pressure in the range of 800 to 2500 kPa.

[0054] The compressed flue gas stream **730** is sent to a CO.sub.2 pressure swing adsorption (PSA) unit **735**, which can be a standard CO.sub.2 PSA unit or a CO.sub.2 vacuum pressure swing adsorption (VPSA) unit, as discussed above. The compressed flue gas stream **730** is separated into a CO.sub.2-enriched stream **740** and an off gas stream **745**.

[0055] The CO.sub.2-enriched stream **740** is sent to a compressor and dehydration unit **750** where it is compressed to a pressure in the range of 2500 to 5000 kPa and dried forming dried CO.sub.2-enriched stream **755**. Suitable dehydration units are described above.

[0056] The dried CO.sub.2-enriched stream **755** is sent to the main heat exchanger **760** where it is cooled with a chilled refrigerant stream **765** from refrigeration system **770** forming cooled CO.sub.2-enriched stream **780**. The warmed refrigerant stream **775** is returned to the refrigeration system **770**.

[0057] The cooled CO.sub.2-enriched stream **780** is sent to the NOx removal zone **785** comprising one or more NOx removal columns where the majority of the NOx compounds other than NO and N.sub.2O are removed. The reduced contaminant stream **790** comprises carbon dioxide and a reduced level of NOx compounds compared to the cooled CO.sub.2-enriched stream **780** entering the NOx removal zone **785**.

[0058] The NOx-enriched bottom stream **795** is highly concentrated in NOx compounds, typically 25-75 percent by mole. The NOx-enriched bottom stream **795** may be sent for treatment including, but not limited to, nitric acid production or fertilizer production. Alternatively, it may be combined with stream and sent to further contaminant treating or a pressure swing adsorption unit.

[0059] The reduced contaminant stream **790** is sent to the CO.sub.2 fractionation column **800**

where it is separated into an overhead gas stream **805** comprising light components including, but not limited to, one or more of N.sub.2, O.sub.2, or NO, and a carbon dioxide-enriched bottom stream **810**.

[0060] The overhead gas stream **805** may be warmed in the main heat exchanger **760**, and the warmed overhead gas stream **815** may be sent to the PSA unit **735**. Alternatively, it could be sent to atmosphere, or further flue gas contaminant treatment.

[0061] As discussed above, during fractionation in the CO.sub.2 fractionation column **800**, a portion of the NO may be converted to NO.sub.2, which leaves with the carbon dioxide-enriched bottom stream **810**.

[0062] The carbon dioxide-enriched bottom stream **810** from the CO.sub.2 fractionation column **800** is warmed in heat exchanger **817** with the stripping column overhead stream **820**. The warmed carbon dioxide-enriched bottom stream **825** is sent to flash drum **830** where it is separated into carbon dioxide-enriched bottom vapor stream **835** and carbon dioxide-enriched bottom liquid stream **840**.

[0063] The carbon dioxide-enriched bottom vapor stream **835** is compressed in compressor **845** forming compressed carbon dioxide-enriched bottom vapor stream **850**. The carbon dioxide-enriched bottom liquid stream **840** is pumped in pump **855** forming pumped carbon dioxide-enriched bottom liquid stream **860**.

[0064] The compressed carbon dioxide-enriched bottom vapor stream **850** and the pumped carbon dioxide-enriched bottom liquid stream **860** can be combined, and the combined carbon dioxide-enriched bottom stream **865** is sent to the NOx stripping column **870**. Alternatively, the compressed carbon dioxide-enriched bottom vapor stream **850** and the pumped carbon dioxide-enriched bottom liquid stream **860** can be sent to the NOx stripping column **870** separately.

[0065] The stripping column overhead stream **820** is heat exchanged with the carbon dioxide-enriched bottom stream **810** from the CO.sub.2 fractionation column **800**. The cooled stripping column overhead **875** is sent to overhead receiver **880**.

[0066] The liquid stripping column overhead from the overhead receiver **880** can be split into first portion **885**, which can be refluxed to the NOx stripping column **870**, and a second portion **890**, which is the liquid carbon dioxide product stream. It can be further chilled, or it can be pumped to form supercritical carbon dioxide.

[0067] The stripping column bottom stream **895**, which is enriched in NOx compounds, is typically 0.1-5 mole percent NOx, and more often 0.2-1 mole % NOx. This stream may be recycled to the NOx removal zone **785** for concentration of the NOx and recovery of the CO.sub.2, or to a flue gas generation unit (not shown) for destruction of the NOx and recovery of the CO.sub.2.

[0068] The off gas stream **745** from the PSA unit **735** is sent to a flue gas expander **905**, and the cooled expanded flue gas stream **910** is sent to the main heat exchanger **760**. The warmed expanded flue gas stream **920** can be further treated and/or released to the atmosphere.

SPECIFIC EMBODIMENTS

[0069] While the following is described in conjunction with specific embodiments, it will be understood that this description is intended to illustrate and not limit the scope of the preceding description and the appended claims.

[0070] A first embodiment of the invention is a process for recovery of carbon dioxide from a flue gas stream and removal of NOx compounds from the recovered carbon dioxide comprising compressing a flue gas feed stream forming a compressed flue gas stream, wherein the flue gas feed stream comprises carbon dioxide and a NOx compound; removing at least a portion of the NOx compound from the compressed flue gas feed stream in a NOx removal zone comprising a NOx removal column forming a reduced contaminant stream wherein a level of the NOx compound in the reduced contaminant stream is less than a level of the NOx compound in the compressed flue gas stream; fractionating the reduced contaminant stream in a CO.sub.2 fractionation column into a carbon dioxide-enriched bottom stream comprising carbon dioxide and

the NO_x compound and an overhead gas stream enriched in light components comprising one or more of N₂, O₂, N₂O or NO; stripping at least a portion of the NO_x compound from the carbon dioxide-enriched bottom stream from the CO₂ fractionation column in a NO_x stripping column forming a stripping column overhead stream comprising carbon dioxide and depleted of the NO_x compound and a stripping column bottom stream enriched in the NO_x compound. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising separating the stripping column overhead stream into an overhead liquid stream and an overhead gas stream; and refluxing the overhead liquid stream to the NO_x stripping column; wherein the overhead gas stream comprises a gaseous carbon dioxide product stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising compressing at least a portion of the carbon dioxide-enriched bottom stream from the CO₂ fractionation column before introducing the carbon dioxide-enriched bottom stream to the NO_x stripping column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising heat exchanging the carbon dioxide-enriched bottom stream from the CO₂ fractionation column with the stripping column overhead stream from the NO_x stripping column forming a warmed carbon dioxide-enriched bottom stream and a cooled stripping column overhead stream before compressing the at least the portion of the carbon dioxide-enriched bottom stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising separating the warmed carbon dioxide-enriched bottom stream into a liquid carbon dioxide-enriched bottom stream and a vapor carbon dioxide-enriched bottom stream; and wherein compressing the at least the portion of the carbon dioxide-enriched bottom stream comprises compressing the vapor carbon dioxide-enriched bottom stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising introducing the liquid carbon dioxide-enriched bottom stream and the compressed carbon dioxide-enriched bottom stream to the NO_x stripping column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising pumping the liquid carbon dioxide-enriched bottom stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising heat exchanging the carbon dioxide-enriched bottom stream from the CO₂ fractionation column with the stripping column overhead stream from the NO_x stripping column forming a warmed carbon dioxide-enriched bottom stream and a cooled stripping column overhead stream before compressing the at least the portion of the carbon dioxide-enriched bottom stream; refluxing a first portion of the cooled stripping column overhead stream from the NO_x stripping column to the NO_x stripping column; and wherein a second portion of the cooled stripping column overhead stream comprises a liquid carbon dioxide product stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising cooling the stripping column overhead stream from the NO_x stripping column forming a cooled stripping column overhead stream; and wherein the cooled stripping column overhead stream comprises a liquid carbon dioxide product stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising chilling the liquid carbon dioxide product stream; or pumping the liquid carbon dioxide product stream to form a supercritical carbon dioxide product stream; or both. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising recycling the stripping column bottom stream to the NO_x removal zone or a flue gas generation unit. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph wherein the CO₂ removal zone

comprises a CO.sub.2 pressure swing adsorption (PSA) unit and further comprising separating the compressed flue gas feed stream in a CO.sub.2 pressure swing adsorption (PSA) unit to form a CO.sub.2-enriched stream, and an off gas stream before removing the at least a portion of the NOx compound from the compressed flue gas feed stream; and compressing the CO.sub.2-enriched stream in a compressor forming a compressed CO.sub.2-enriched stream; wherein removing the at least a portion of the NOx compound from the compressed flue gas feed stream comprises removing the at least a portion of the NOx compound from the compressed CO.sub.2-enriched stream.

[0071] A second embodiment of the invention is a process for recovery of carbon dioxide from a flue gas stream and removal of NOx compounds from the recovered carbon dioxide comprising compressing a flue gas feed stream forming a compressed flue gas stream, wherein the flue gas feed stream comprises carbon dioxide and a NOx compound; removing at least a portion of the NOx compound from the compressed flue gas feed stream in a NOx removal zone comprising a NOx removal column forming a reduced contaminant stream wherein a level of the NOx compound in the reduced contaminant stream is less than a level of the NOx compound in the compressed flue gas stream and a NOx-enriched bottom stream; fractionating the reduced contaminant stream in a CO.sub.2 fractionation column into a carbon dioxide-enriched bottom stream comprising carbon dioxide and the NOx compound and an overhead gas stream enriched in light components comprising one or more of N.sub.2, N.sub.2O, O.sub.2, or NO; stripping at least a portion of the NOx compound from the carbon dioxide-enriched bottom stream from the CO.sub.2 fractionation column in a NOx stripping column forming a stripping column overhead stream comprising carbon dioxide and depleted of the NOx compound and a stripping column bottom stream enriched in the NOx compound; treating the NOx-enriched bottom stream from the NOx removal zone; and recycling the stripping column bottom stream to the NOx removal zone or a flue gas generation unit. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising separating the stripping column overhead stream into an overhead liquid stream and an overhead gas stream; and refluxing the overhead liquid stream to the NOx stripping column; wherein the overhead gas stream comprises a gaseous carbon dioxide product stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising compressing at least a portion of the carbon dioxide-enriched bottom stream from the CO.sub.2 fractionation column before introducing the carbon dioxide-enriched bottom stream to the NOx stripping column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising heat exchanging the carbon dioxide-enriched bottom stream from the CO.sub.2 fractionation column with the stripping column overhead stream from the NOx stripping column forming a warmed carbon dioxide-enriched bottom stream and a cooled stripping column overhead stream; separating the warmed carbon dioxide-enriched bottom stream into a liquid carbon dioxide-enriched bottom stream and a vapor carbon dioxide-enriched bottom stream, and compressing the vapor carbon dioxide-enriched bottom stream; introducing the liquid carbon dioxide-enriched bottom stream and the compressed carbon dioxide-enriched bottom stream to the NOx stripping column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising pumping the liquid carbon dioxide-enriched bottom stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising heat exchanging the carbon dioxide-enriched bottom stream from the CO.sub.2 fractionation column with the stripping column overhead stream from the NOx stripping column forming a warmed carbon dioxide-enriched bottom stream and a cooled stripping column overhead stream before compressing the at least the portion of the carbon dioxide-enriched bottom stream; refluxing a first portion of the cooled stripping column overhead

stream from the NO_x stripping column to the NO_x stripping column; and wherein a second portion of the cooled stripper column overhead stream comprises a liquid carbon dioxide product stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising chilling the liquid carbon dioxide product stream; or pumping the liquid carbon dioxide product stream to form a supercritical carbon dioxide product stream; or both. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph wherein the CO₂ removal zone comprises a CO₂ pressure swing adsorption (PSA) unit and further comprising separating the compressed flue gas feed stream in a CO₂ pressure swing adsorption (PSA) unit to form a CO₂-enriched stream, and an off gas stream before removing the at least a portion of the NO_x compound from the compressed flue gas feed stream; and compressing the CO₂-enriched stream in a compressor forming a compressed CO₂-enriched stream; wherein removing the at least a portion of the NO_x compound from the compressed flue gas feed stream comprises removing the at least a portion of the NO_x compound from the compressed CO₂-enriched stream.

[0072] Without further elaboration, it is believed that using the preceding description that one skilled in the art can utilize the present invention to its fullest extent and easily ascertain the essential characteristics of this invention, without departing from the spirit and scope thereof, to make various changes and modifications of the invention and to adapt it to various usages and conditions. The preceding preferred specific embodiments are, therefore, to be construed as merely illustrative, and not limiting the remainder of the disclosure in any way whatsoever, and that it is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims.

[0073] In the foregoing, all temperatures are set forth in degrees Celsius and, all parts and percentages are by weight, unless otherwise indicated.

Claims

1. A process for recovery of carbon dioxide from a flue gas stream and removal of NO_x compounds from the recovered carbon dioxide comprising: compressing a flue gas feed stream forming a compressed flue gas stream, wherein the flue gas feed stream comprises carbon dioxide and a NO_x compound; removing at least a portion of the NO_x compound from the compressed flue gas feed stream in a NO_x removal zone comprising a NO_x removal column forming a reduced contaminant stream wherein a level of the NO_x compound in the reduced contaminant stream is less than a level of the NO_x compound in the compressed flue gas stream; fractionating the reduced contaminant stream in a CO₂ fractionation column into a carbon dioxide-enriched bottom stream comprising carbon dioxide and the NO_x compound and an overhead gas stream enriched in light components comprising one or more of N₂, O₂, N₂O or NO; and stripping at least a portion of the NO_x compound from the carbon dioxide-enriched bottom stream from the CO₂ fractionation column in a NO_x stripping column forming a stripping column overhead stream comprising carbon dioxide and depleted of the NO_x compound and a stripping column bottom stream enriched in the NO_x compound.

2. The process of claim 1 further comprising: separating the stripping column overhead stream into an overhead liquid stream and an overhead gas stream; and refluxing the overhead liquid stream to the NO_x stripping column; wherein the overhead gas stream comprises a gaseous carbon dioxide product stream.

3. The process of claim 1 further comprising: compressing at least a portion of the carbon dioxide-enriched bottom stream from the CO₂ fractionation column before introducing the carbon dioxide-enriched bottom stream to the NO_x stripping column.

4. The process of claim 3 further comprising: heat exchanging the carbon dioxide-enriched bottom

stream from the CO.sub.2 fractionation column with the stripping column overhead stream from the NOx stripping column forming a warmed carbon dioxide-enriched bottom stream and a cooled stripping column overhead stream before compressing the at least the portion of the carbon dioxide-enriched bottom stream.

5. The process of claim 4 further comprising: separating the warmed carbon dioxide-enriched bottom stream into a liquid carbon dioxide-enriched bottom stream and a vapor carbon dioxide-enriched bottom stream; and wherein compressing the at least the portion of the carbon dioxide-enriched bottom stream comprises compressing the vapor carbon dioxide-enriched bottom stream.

6. The process of claim 5 further comprising: introducing the liquid carbon dioxide-enriched bottom stream and the compressed carbon dioxide-enriched bottom stream to the NOx stripping column.

7. The process of claim 5 further comprising: pumping the liquid carbon dioxide-enriched bottom stream.

8. The process of claim 3 further comprising: heat exchanging the carbon dioxide-enriched bottom stream from the CO.sub.2 fractionation column with the stripping column overhead stream from the NOx stripping column forming a warmed carbon dioxide-enriched bottom stream and a cooled stripping column overhead stream before compressing the at least the portion of the carbon dioxide-enriched bottom stream; refluxing a first portion of the cooled stripping column overhead stream from the NOx stripping column to the NOx stripping column; and wherein a second portion of the cooled stripper column overhead stream comprises a liquid carbon dioxide product stream.

9. The process of claim 3 further comprising: cooling the stripping column overhead stream from the NOx stripping column forming a cooled stripping column overhead stream; and wherein the cooled stripping column overhead stream comprises a liquid carbon dioxide product stream.

10. The process of claim 9 further comprising: chilling the liquid carbon dioxide product stream; or pumping the liquid carbon dioxide product stream to form a supercritical carbon dioxide product stream; or both.

11. The process of claim 1 further comprising: recycling the stripping column bottom stream to the NOx removal zone or a flue gas generation unit.

12. The process of claim 1 wherein the CO.sub.2 removal zone comprises a CO.sub.2 pressure swing adsorption (PSA) unit and further comprising: separating the compressed flue gas feed stream in a CO.sub.2 pressure swing adsorption (PSA) unit to form a CO.sub.2-enriched stream, and an off gas stream before removing the at least a portion of the NOx compound from the compressed flue gas feed stream; and compressing the CO.sub.2-enriched stream in a compressor forming a compressed CO.sub.2-enriched stream; wherein removing the at least a portion of the NOx compound from the compressed flue gas feed stream comprises removing the at least a portion of the NOx compound from the compressed CO.sub.2-enriched stream.

13. A process for recovery of carbon dioxide from a flue gas stream and removal of NOx compounds from the recovered carbon dioxide comprising: compressing a flue gas feed stream forming a compressed flue gas stream, wherein the flue gas feed stream comprises carbon dioxide and a NOx compound; removing at least a portion of the NOx compound from the compressed flue gas feed stream in a NOx removal zone comprising a NOx removal column forming a reduced contaminant stream wherein a level of the NOx compound in the reduced contaminant stream is less than a level of the NOx compound in the compressed flue gas stream and a NOx-enriched bottom stream; fractionating the reduced contaminant stream in a CO.sub.2 fractionation column into a carbon dioxide-enriched bottom stream comprising carbon dioxide and the NOx compound and an overhead gas stream enriched in light components comprising one or more of N.sub.2, N.sub.2O, O.sub.2, or NO; stripping at least a portion of the NOx compound from the carbon dioxide-enriched bottom stream from the CO.sub.2 fractionation column in a NOx stripping column forming a stripping column overhead stream comprising carbon dioxide and depleted of the NOx compound and a stripping column bottom stream enriched in the NOx compound; treating the

NOx-enriched bottom stream from the NOx removal zone; and recycling the stripping column bottom stream to the NOx removal zone or a flue gas generation unit.

14. The process of claim 13 further comprising: separating the stripping column overhead stream into an overhead liquid stream and an overhead gas stream; and refluxing the overhead liquid stream to the NOx stripping column; wherein the overhead gas stream comprises a gaseous carbon dioxide product stream.

15. The process of claim 13 further comprising: compressing at least a portion of the carbon dioxide-enriched bottom stream from the CO.sub.2 fractionation column before introducing the carbon dioxide-enriched bottom stream to the NOx stripping column.

16. The process of claim 13 further comprising: heat exchanging the carbon dioxide-enriched bottom stream from the CO.sub.2 fractionation column with the stripping column overhead stream from the NOx stripping column forming a warmed carbon dioxide-enriched bottom stream and a cooled stripping column overhead stream; separating the warmed carbon dioxide-enriched bottom stream into a liquid carbon dioxide-enriched bottom stream and a vapor carbon dioxide-enriched bottom stream; compressing the vapor carbon dioxide-enriched bottom stream; and introducing the liquid carbon dioxide-enriched bottom stream and the compressed carbon dioxide-enriched bottom stream to the NOx stripping column.

17. The process of claim 16 further comprising: pumping the liquid carbon dioxide-enriched bottom stream.

18. The process of claim 13 further comprising: heat exchanging the carbon dioxide-enriched bottom stream from the CO.sub.2 fractionation column with the stripping column overhead stream from the NOx stripping column forming a warmed carbon dioxide-enriched bottom stream and a cooled stripping column overhead stream before compressing the at least the portion of the carbon dioxide-enriched bottom stream; and refluxing a first portion of the cooled stripping column overhead stream from the NOx stripping column to the NOx stripping column; wherein a second portion of the cooled stripper column overhead stream comprises a liquid carbon dioxide product stream.

19. The process of claim 18 further comprising: chilling the liquid carbon dioxide product stream; or pumping the liquid carbon dioxide product stream to form a supercritical carbon dioxide product stream; or both.

20. The process of claim 13 wherein the CO.sub.2 removal zone comprises a CO.sub.2 pressure swing adsorption (PSA) unit and further comprising: separating the compressed flue gas feed stream in a CO.sub.2 pressure swing adsorption (PSA) unit to form a CO.sub.2-enriched stream, and an off gas stream before removing the at least a portion of the NOx compound from the compressed flue gas feed stream; and compressing the CO.sub.2-enriched stream in a compressor forming a compressed CO.sub.2-enriched stream; wherein removing the at least a portion of the NOx compound from the compressed flue gas feed stream comprises removing the at least a portion of the NOx compound from the compressed CO.sub.2-enriched stream.
