CLAIMS

1. A method of separating impurities from a natural gas stream, comprising:

separating carbon dioxide (CO_2) and hydrogen sulfide (H_2S) from the natural gas stream in a membrane separation system, thereby creating a partially-treated gas stream and a permeate gas stream, the permeate gas stream being comprised primarily of H_2S and CO_2 and the partially-treated gas stream being comprised primarily of natural gas, wherein the partially-treated gas stream and the permeate gas stream are at a lower temperature than the natural gas stream;

contacting the partially-treated gas stream with a first lean solvent stream comprising a hindered amine in a first contactor to separate H_2S from the partially-treated gas stream, thereby producing a first rich solvent stream and a fully-treated gas stream;

contacting the permeate gas stream with a second lean solvent stream comprising a hindered amine in a second contactor to separate H_2S therefrom to produce a second rich solvent stream and a CO_2 gas stream; and

removing H_2S and CO_2 from the first and second rich solvent streams, thereby producing the first and second lean solvent streams.

2. The method of claim 1, further comprising:

cooling the partially-treated gas stream prior to the partially-treated gas stream being contacted by the first lean solvent stream; and

cooling the permeate gas stream prior to the permeate gas stream being contacted by the second lean solvent stream.

3. The method of claim 2, wherein cooling the partially-treated gas stream and the permeate gas stream is accomplished using one or more coolers.

4. The method of any one of claims 1 to 3, further comprising cooling at least one of the first and second lean solvent streams to below ambient temperature after removing H_2S therefrom.

5. The method of any one of claims 1 to 4, wherein removing H_2S from the first and second rich solvent streams comprises separating H_2S from the first and second rich solvent streams in a regenerator and producing a regenerated solvent stream.

6. The method of claim 5, further comprising:

dividing the regenerated solvent stream to form the first and second lean solvent streams.

7. The method of claim 5, comprising:

forming the second lean solvent stream from the regenerated solvent stream; and

forming the first lean solvent stream from the second rich solvent stream.

8. The method of any one of claims 1 to 7, further comprising:

removing acid gas from the fully-treated gas stream; and

dehydrating the fully-treated stream.

9. The method of claim 8, wherein the acid gas comprises CO_2, and further comprising:

compressing the CO_2 removed from the fully-treated gas stream; and

combining the compressed CO_2 with the CO_2 gas stream.

10. The method of any one of claims 1-9, wherein at least one of the first and second contactors is a co-current contacting system, and further comprising:

receiving a gas stream, comprising one of the natural gas stream and the permeate gas stream, and a liquid stream, comprising one of the first and second lean solvent streams, in the co-current contacting system located in-line within a pipe, the co-current contacting system including a droplet generator and a mass transfer section;

using the droplet generator, generating droplets from the liquid stream and dispersing the droplets into the gas stream;

using the mass transfer section, providing a mixed, two-phase flow having a vapor phase and a liquid phase, wherein the liquid phase includes the liquid stream with H_2S and/or CO_2 absorbed from the gas stream, and wherein the vapor phase includes the gas stream; and

separating the vapor phase from the liquid phase.

11. The method of claim 10, wherein the droplet generator comprises:

an annular support ring securing the droplet generator in-line within the pipe;

a plurality of spokes extending from the annular support ring, the annular support ring having a plurality of liquid channels allowing the liquid stream to flow through the plurality of spokes and out of injection orifices disposed on the plurality of spokes; and

a gas entry cone supported by the plurality of spokes and allowing

a first portion of the gas stream to flow through a hollow section of the gas entry cone and through gas exit slots included in the plurality of spokes, and

a second portion of the gas stream to flow around the gas entry cone and between the plurality of spokes, wherein the second portion of the gas stream is separate from the first portion of the gas stream.

12. The method of claim 10 or 11, wherein the co-current contacting system is one of a plurality of co-current contacting systems connected in series, said plurality of co-current contacting systems including a last co-current contacting system;

wherein each of the plurality of co-current contacting system comprises

a co-current contactor including a droplet generator and a mass transfer section, the droplet generator generating droplets of the liquid stream and dispersing the droplets into a gas stream received from a previous co-current contacting system, and the mass transfer section providing a mixed, two-phase flow having a vapor phase and a liquid phase; and

a separation system that separates the vapor phase from the liquid phase, wherein the vapor phase includes a treated gas stream and the liquid phase includes the liquid from which droplets are generated in a co-current contactor of a previous co-current contacting system.

13. A system for separating impurities from a natural gas stream, comprising:

a membrane separation system configured to separate carbon dioxide (CO_2) and hydrogen sulfide (H_2S) from the natural gas stream, thereby creating a partially-treated gas stream and a permeate gas stream, the permeate gas stream being comprised primarily of H_2S and CO_2 and the partially-treated gas stream being comprised primarily of natural gas, wherein the partially-treated gas stream and the permeate gas stream are at a lower temperature than the natural gas stream;

a first contactor configured to contact the partially-treated gas stream with a first lean solvent stream comprising a hindered amine to separate H_2S from the partially-treated gas stream, thereby producing a first rich solvent stream and a fully-treated gas stream;

a second contactor configured to contact the permeate gas stream with a second lean solvent stream comprising a hindered amine to separate H_2S therefrom to produce a second rich solvent stream and a CO_2 gas stream; and

a regenerator configured to remove H_2S and CO_2 from the first and second rich solvent streams, thereby producing the first and second lean solvent streams.

14. The system of claim 13, further comprising:

a first cooler configured to cool the partially-treated gas stream prior to the partially-treated gas stream being contacted by the first lean solvent stream; and

a second cooler configured to cool the permeate gas stream prior to the permeate gas stream being contacted by the second lean solvent stream.

15. The system of claim 13 or 14, further comprising a refrigeration system configured to cool at least one of the first and second lean solvent streams to below ambient temperature after removing H_2S therefrom.

16. The system of any one of claims 13 to 15, further comprising:

a polisher configured to remove acid gas from the fully-treated gas stream; and

a dehydrator configured to remove moisture from the fully-treated stream.

17. The system of claim 16, wherein the acid gas comprises CO_2, and further comprising:

a compressor configured to compress the CO_2 removed from the fully-treated gas stream.

18. The system of any one of claims 13 to 17, wherein at least one of the first and second contactors is a co-current contacting system located in-line within a pipe, the co-current contacting system receiving a gas stream, comprising one of the natural gas stream and the permeate gas stream, and a liquid stream, comprising one of the first and second lean solvent streams, the co-current contacting system including

a co-current contactor including a droplet generator and a mass transfer section, the droplet generator configured to generate droplets from the liquid stream and to disperse the droplets into the gas stream, and the mass transfer section configured to provide a mixed, two-phase flow having a vapor phase and a liquid phase, wherein the liquid phase includes the liquid stream with H_2S and/or CO_2 absorbed from the gas stream, and wherein the vapor phase includes the gas stream; and

a separation system configured to separate the vapor phase from the liquid phase.

19. The system of claim 18, wherein the droplet generator comprises:

an annular support ring securing the droplet generator in-line within the pipe;

a plurality of spokes extending from the annular support ring, the annular support ring having a plurality of liquid channels allowing the liquid stream to flow through the plurality of spokes and out of injection orifices disposed on the plurality of spokes; and

a gas entry cone supported by the plurality of spokes and allowing

a first portion of the gas stream to flow through a hollow section of the gas entry cone and through gas exit slots included in the plurality of spokes, and

a second portion of the gas stream to flow around the gas entry cone and between the plurality of spokes, wherein the second portion of the gas stream is separate from the first portion of the gas stream.

20. The system of claim 18 or 19, wherein the co-current contacting system is one of a plurality of co-current contacting systems connected in series, said plurality of co-current contacting systems including a last co-current contacting system;

wherein each of the plurality of co-current contacting system comprises

a co-current contactor including a droplet generator and a mass transfer section, the droplet generator generating droplets of the liquid stream and dispersing the droplets into a gas stream received from a previous co-current contacting system, and the mass transfer section providing a mixed, two-phase flow having a vapor phase and a liquid phase; and

a separation system that separates the vapor phase from the liquid phase, wherein the vapor phase includes a treated gas stream and the liquid phase includes liquid from which droplets are generated in a co-current contactor of a previous co-current contacting system.