CLAIMS

1. A method of liquefaction using a closed loop refrigeration system, the method comprising the steps of:

(a) compressing a gaseous refrigerant stream in at least one compressor;

(b) cooling at least a portion of the compressed gaseous refrigerant stream in a first heat exchanger;

(c) expanding a first portion of the cooled, compressed gaseous refrigerant stream from the first heat exchanger in a first expander to provide a first expanded gaseous refrigerant stream;

(d) cooling and substantially liquefying a feed gas stream to form a substantially liquefied feed gas stream in a second heat exchanger through indirect heat exchange against the first portion of the first expanded gaseous refrigerant stream from the first expander; and

(e) further cooling a second portion of the cooled, compressed gaseous refrigerant stream from the first heat exchanger in a third heat exchanger by indirect heat exchange with a second portion of the first expanded gaseous refrigerant stream from the first expander,

wherein the first expanded gaseous refrigerant stream exiting the first expander is substantially vapor.

2. The method of claim 1, further comprising subcooling the cooled and substantially liquefied feed gas stream through indirect heat exchange in a subcooler exchanger against a second expanded gaseous refrigerant stream exiting a second expander.

3. The method of claim 2, wherein the second portion of the cooled, compressed gaseous refrigerant stream, after being further cooled in the third heat exchanger, is fed to the second expander to provide the second expanded gaseous refrigerant stream.

4. The method of claim 3, wherein the second expanded gaseous refrigerant stream exiting the second expander is substantially vapor.

5. The method of claim 4, wherein the second expanded gaseous refrigerant stream exiting the subcooler exchanger is compressed in a low pressure compressor; combined with the first portion of the first expanded gaseous refrigerant stream exiting the second heat exchanger and the second portion of the first expanded gaseous refrigerant stream exiting the third heat exchanger; and the mixed stream further compressed in a high pressure compressor.

6. The method of claim 1, further comprising warming at least a portion of the first portion of the first expanded gaseous refrigerant stream exiting the second heat exchanger in the first heat exchanger.

7. The method of claim 1, further comprising warming the second portion of the first expanded gaseous refrigerant stream exiting the third heat exchanger in the first heat exchanger.

8. The method of claim 1, further comprising splitting the compressed gaseous refrigerant stream exiting the at least one compressor into a first portion and a second portion, cooling said first portion in a supplemental refrigeration system that comprises at least one stage of a vaporizing liquid refrigerant, cooling said second portion in the first heat exchanger in step (b) of claim 1, and combining the cooled first portion with a portion of the cooled second portion for expansion in the first expander in step (c) of claim 1.

9. The method of claim 1, further comprising splitting the compressed gaseous refrigerant stream exiting the at least one compressor into a first portion and a second portion, expanding said first portion in a third expander, warming the resultant expanded first portion in the first heat exchanger, and cooling said second portion in the first heat exchanger in step (b) of claim 1.

10. The method of claim 1, wherein the feed gas stream for liquefaction is a natural gas stream.

11. The method of claim 1, wherein the gaseous refrigerant stream is a nitrogen stream.

12. A closed loop system for liquefaction comprising:

a refrigeration circuit, the refrigeration circuit comprising:

a first compressor;

a first heat exchanger fluidly coupled to the first compressor and adapted to accept a gaseous refrigerant stream from the first compressor;

a first expander fluidly coupled to the first heat exchanger and adapted to accept a first stream of refrigerant from the first heat exchanger;

a second heat exchanger fluidly coupled to the first expander and adapted to accept a first expanded gaseous refrigerant stream from the first expander and a feed gas stream;

a third heat exchanger fluidly coupled to the first heat exchanger and to the first expander and adapted to accept a second stream of refrigerant from the first heat exchanger and a second expanded gaseous refrigerant stream from the first expander;

a second expander fluidly coupled to the third heat exchanger and adapted to accept a stream of refrigerant from the third heat exchanger; and

a subcooler exchanger fluidly coupled to the second heat exchanger and the second expander and adapted for acceptance of the feed gas stream from the second heat exchanger and an expanded gaseous refrigerant stream from the second expander,

wherein the first heat exchanger and the third heat exchanger may be combined into one heat exchanger, and

wherein the second heat exchanger and the subcooler exchanger may be combined into one heat exchanger.

13. A method of liquefaction using a closed loop refrigeration system, the method comprising the steps of:

(a) compressing a gaseous refrigerant stream in at least one compressor;

(b) cooling at least a portion of the compressed gaseous to refrigerant stream in a first heat exchanger;

(c) removing from an intermediate section of the first heat exchanger a cooled, compressed gaseous refrigerant stream and expanding said portion of the cooled, compressed gaseous refrigerant stream from the first heat exchanger in a first expander to provide a first expanded gaseous refrigerant stream;

(d) cooling and substantially liquefying a feed gas stream to form a substantially liquefied feed gas stream in a second heat exchanger through indirect heat exchange against the first portion of the first expanded gaseous refrigerant stream from the first expander; and

(e) further cooling a second portion of the cooled, compressed gaseous refrigerant stream in the first heat exchanger by indirect heat exchange with a second portion of the first expanded gaseous refrigerant stream from the first expander,

wherein the first expanded gaseous refrigerant stream exiting the first expander is substantially vapor.

14. The method of claim 13, further comprising subcooling the cooled and substantially liquefied feed gas stream through indirect heat exchange in the second exchanger against a second expanded gaseous refrigerant stream exiting a second expander.

15. The method of claim 14, wherein the second portion of the cooled, compressed gaseous refrigerant stream, after being further cooled in the first heat exchanger, is fed to the second expander to provide the second expanded gaseous refrigerant stream.

16. The method of claim 15, wherein the second expanded gaseous refrigerant stream exiting the second expander is substantially vapor.

17. The method of claim 13, further comprising subcooling the cooled and substantially liquefied feed gas stream through indirect heat exchange in a subcooler exchanger against a second expanded gaseous refrigerant stream exiting a second expander.

18. The method of claim 13, wherein the feed gas stream for liquefaction is a natural gas stream.

19. The method of claim 13, wherein the gaseous refrigerant stream is a nitrogen stream.

20. A closed loop system for liquefaction, comprising:

a refrigeration circuit, the refrigeration circuit comprising:

a first compressor;

a first heat exchanger fluidly coupled to the first compressor and adapted to accept a compressed gaseous refrigerant stream from the first compressor;

a first expander fluidly coupled to the first heat exchanger and adapted to accept a first portion of the cooled, compressed gaseous refrigerant stream from an intermediate location of the first heat exchanger;

a second heat exchanger fluidly coupled to the first expander and adapted to accept a first expanded gaseous refrigerant stream from the first expander and a feed gas stream;

a second expander fluidly coupled to the first heat exchanger and adapted to accept a second portion of the cooled, compressed gaseous refrigerant stream from the first heat exchanger;

wherein the first heat exchanger is adapted to accept a second expanded gaseous refrigerant stream from the first expander, and wherein the second heat exchanger is adapted to receive an expanded gaseous refrigerant stream from the second expander.

CLAIMS

1. A method of liquefaction using a closed loop refrigeration system, the method comprising the steps of:

(a) compressing a gaseous refrigerant stream in at least one compressor;

(b) cooling the compressed gaseous refrigerant stream in a first heat exchanger;

(c) expanding at least a first portion of the cooled, compressed gaseous refrigerant stream from the first heat exchanger in a first expander to provide a first expanded gaseous refrigerant stream; and

(d) cooling and substantially liquefying a feed gas stream to form a substantially liquefied feed gas stream in a second heat exchanger through indirect heat exchange against at least a first portion of the first expanded gaseous refrigerant stream from the first expander,

wherein the first expanded gaseous refrigerant stream exiting the first expander is substantially vapor.

2. The method of claim 1, further comprising subcooling the cooled and substantially liquefied feed gas stream through indirect heat exchange in a subcooler exchanger against a second expanded gaseous refrigerant stream exiting a second expander, wherein the second expanded gaseous refrigerant stream exiting the second expander is substantially vapor.

3. The method of claim 2, wherein the compressing of the gaseous refrigerant stream of step (a) of claim 1 occurs by:

(a)(1) compressing the gaseous refrigerant stream in a low pressure compressor; and

(a)(2) further compressing the gaseous refrigerant stream a high pressure compressor.

4. The method of claim 3, wherein the pressure of the second expanded gaseous refrigerant stream exiting the second expander is lower than the pressure of the first expanded gaseous refrigerant stream exiting the first expander.

5. The method of claim 1, wherein a first portion of the first expanded gaseous refrigerant stream from the first expander cools the feed gas stream through

indirect heat exchange in the second heat exchanger in step (d) of claim 1 and wherein a second portion of the first expanded gaseous refrigerant stream from the first expander cools a second portion of the cooled, compressed gaseous refrigerant stream from the first heat exchanger in a third heat exchanger.

6. The method of claim 1, further comprising providing supplemental cooling to the first heat exchanger through indirect heat exchange with a supplemental refrigeration system comprising at least one stage of a vaporizing liquid refrigerant.

7. The method of claim 6, wherein the vaporizing liquid refrigerant comprises CO_2, methane, propane, butane, iso-butane, propylene, ethane, ethylene, R22, HFC refrigerants including R410A, R134A, R507, R23, or combinations thereof.

8. The method of claim 1, wherein the feed gas stream for liquefaction is a natural gas stream.

9. The method of claim 8, wherein the natural gas liquefaction occurs on a Floating Production Storage and Offloading (FPSO) vessel.

10. The method of claim 1, wherein the gaseous refrigerant stream is a nitrogen stream.

11. The method of claim 3, further comprising warming a second portion of the first expanded gaseous refrigerant stream exiting the first expander in the third heat exchanger and the first heat exchanger to form a warmed gaseous refrigerant stream and combining the warmed gaseous refrigerant stream with the compressed gaseous refrigerant stream exiting the low pressure compressor between steps (a)(1) and (a)(2) of claim 3.

12. The method of claim 5, wherein a third portion of the first expanded gaseous refrigerant stream exiting the first expander is heated in the third heat exchanger prior to expansion in a second expander.

13. The method of claim 2, further comprising extracting a portion of the gaseous refrigerant stream descending the second heat exchanger from an intermediate location of the second heat exchanger, heating the extracted portion of the gaseous refrigerant stream in the first heat exchanger, and combining the warmed gaseous refrigerant stream with the compressed gaseous refrigerant stream exiting the low pressure compressor between steps (a)(1) and (a)(2) of claim 3.

14. The method of claim 1, wherein the first heat exchanger and the third heat exchanger are a single heat exchanger.

15. The method of claim 1, wherein the second heat exchanger and the subcooler exchanger are a single heat exchanger.

16. The method of claim 1, wherein the first heat exchanger and the third heat exchanger are plate-and-fin brazed aluminum (core) type heat exchangers.

17. The method of claim 1, wherein the second heat exchanger and the subcooler exchanger are wound-coil heat exchangers.

18. The method of claim 3, further comprising splitting the compressed gaseous refrigerant stream exiting the high pressure compressor, cooling a first portion of the compressed gaseous refrigerant stream exiting the high pressure compressor in a supplemental refrigeration system that comprises at least one stage of a vaporizing liquid refrigerant, and combining the cooled first portion of the compressed gaseous refrigerant stream with the first portion of the cooled, compressed gaseous refrigerant stream from the first heat exchanger for expansion in the first expander in step (c) of claim 1, and wherein a second portion of the compressed gaseous refrigerant stream exiting the high pressure compressor is cooled in the first heat exchanger in step (b) of claim 1.

19. The method of claim 18, further comprising precooling the feed gas stream in a supplemental refrigeration system that comprises at least one stage of a vaporizing liquid refrigerant prior to step (d) of claim 1.

20. The method of claim 19, wherein the supplemental refrigeration system for precooling the feed gas stream and the supplemental refrigeration system for cooling the first portion of the compressed gaseous refrigerant stream exiting the high pressure compressor is a single supplemental refrigeration system.

21. The method of claim 3, further comprising splitting the compressed gaseous refrigerant stream exiting the high pressure compressor, expanding a first portion of the compressed gaseous refrigerant stream exiting the at least one compressor in a third expander, warming the expanded first portion of the compressed gaseous refrigerant stream in the first heat exchanger, and then combining the warmed, expanded first portion of the compressed gaseous refrigerant stream with the compressed gaseous refrigerant stream exiting the low pressure compressor between steps (a)(1) and (a)(2) of claim 3, and cooling the second portion of the compressed

gaseous refrigerant stream exiting the high pressure compressor in the first heat exchanger in step (b) of claim 1.

22. The method of claim 4, further comprising splitting the compressed gaseous refrigerant stream exiting the high pressure compressor, expanding a first portion of the compressed gaseous refrigerant stream exiting the high pressure compressor in a third expander, warming the expanded first portion of the compressed gaseous refrigerant stream in the first heat exchanger, and then combining the warmed, expanded first portion of the compressed gaseous refrigerant stream with the compressed gaseous refrigerant stream exiting the low pressure compressor between steps (a)(1) and (a)(2) of claim 3, and cooling the second portion of the compressed gaseous refrigerant stream exiting the high pressure compressor in the first heat exchanger in step (b) of claim 1.

23. The method of claim 2, further comprising throttling the subcooled liquefied feed gas stream, separating the throttled subcooled liquefied feed gas stream in a phase separator into a liquid product and a flash vapor, wherein the flash vapor can be further compressed, warmed, and used as fuel for energy production.

24. The method of claim 1, further comprising storing the cooled and substantially liquefied feed gas stream in a high-pressure storage tank.

25. A method of liquefaction using a closed loop refrigeration system, the method comprising the steps of:

(a) compressing a gaseous refrigerant stream in a low pressure compressor;

(b) further compressing the compressed gaseous refrigerant stream in a high pressure compressor;

(c) cooling the compressed gaseous refrigerant stream in a first heat exchanger;

(d) expanding at least a first portion of the cooled, compressed gaseous refrigerant stream from the first heat exchanger in a first expander to provide a first expanded gaseous refrigerant stream, wherein the first expanded gaseous refrigerant stream from the first expander provides cooling to a second heat exchanger and the first heat exchanger;

(e) cooling and substantially liquefying a feed gas stream through indirect heat exchange against the first expanded gaseous refrigerant stream from the first expander in the second heat exchanger and the first heat exchanger; and

(f) subcooling the cooled and substantially liquefied feed gas stream through indirect heat exchange against a second expanded gaseous refrigerant stream exiting a second expander in a subcooler exchanger,

wherein the first expanded gaseous refrigerant stream exiting the first expander and the second expanded gaseous refrigerant stream exiting the second expander are substantially vapor, and wherein the pressure of the second expanded gaseous refrigerant stream is lower than the pressure of the first expanded gaseous refrigerant stream.

26. A closed loop system for liquefaction, comprising:

a refrigeration circuit, the refrigeration circuit comprising:

a first heat exchanger;

a second heat exchanger fluidly coupled to the first heat exchanger;

a first expander fluidly coupled to the first heat exchanger and adapted to accept a stream of refrigerant from the first heat exchanger;

a second expander fluidly coupled to the second heat exchanger and adapted to accept a stream of refrigerant from the second heat exchanger; and

a third heat exchanger fluidly coupled to the first expander and adapted to accept a first expanded gaseous refrigerant stream from the first expander and a feed gas stream,

wherein the first expanded gaseous refrigerant stream from the first expander and the second expanded gaseous refrigerant stream from the second expander are substantially a vapor stream.

27. The system of claim 26, further comprising a subcooler exchanger fluidly coupled to the third heat exchanger and the second expander and adapted for acceptance of the feed gas stream from the third heat exchanger.

28. The system of claim 26, further comprising:

(a) a low pressure refrigerant compressor fluidly coupled to the first heat exchanger; and

(b) a high pressure refrigerant compressor fluidly coupled to the first heat exchanger and the low pressure refrigerant compressor adapted for acceptance of a refrigerant stream from the first heat exchanger and the low pressure refrigerant compressor.

29. The system of claim 28, wherein the second expanded gaseous refrigerant stream from the second expander is lower in pressure than the first expanded gaseous refrigerant stream from the first expander.

30. The system of claim 28, further comprising a supplemental refrigeration system adapted to provide cooling to the first heat exchanger, wherein the supplemental refrigeration system comprises at least one stage of a vaporizing liquid refrigerant.

31. The system of claim 30, wherein the vaporizing liquid refrigerant comprises CO_2, methane, propane, butane, iso-butane, propylene, ethane, ethylene, R22, HFC refrigerants including R410A, R134A, R507, R23, or combinations thereof.

32. The system of claim 26, wherein the feed gas stream is a natural gas stream.

33. The system of claim 32, wherein the system is used on a Floating Production Storage and Offloading (FPSO) vessel.

34. The system of claim 26, wherein the stream of refrigerant is a nitrogen stream.

35. The system of claim 26, wherein the first heat exchanger and the second heat exchanger are a single heat exchanger.

36. The system of claim 27, wherein the third heat exchanger and the subcooler exchanger are a single heat exchanger.

37. The system of claim 26, wherein the first heat exchanger and the second heat exchanger are plate-and-fin brazed aluminum (core) type heat exchangers.

38. The system of claim 27, wherein the third heat exchanger and the subcooler exchanger 112 are wound-coil heat exchangers.

39. The system of claim 28, further comprising a supplemental refrigeration system fluidly coupled to the high pressure refrigerant compressor and adapted for

acceptance of a compressed gaseous refrigerant stream from the high pressure refrigerant compressor.

40. The system of claim 26, further comprising a supplemental refrigeration system fluidly coupled to the third heat exchanger and adapted to accept the feed gas stream.

41. The system of claim 28, further comprising a third expander fluidly coupled to the high pressure refrigerant compressor and adapted for accepting a portion of a compressed gaseous refrigerant stream from the high pressure refrigerant compressor.

42. The system of claim 27, further comprising:

a valve fluidly coupled to the subcooler exchanger adapted for acceptance of the feed gas stream from the subcooler exchanger;

a phase separator fluidly coupled to the valve and adapted for separation of the feed gas stream into a liquid product and a flash vapor.

43. The system of claim 26, further comprising:

a first low pressure refrigerant compressor fluidly coupled to the first heat exchanger; and

a second low pressure refrigerant compressor fluidly coupled to the third heat exchanger.

44. A method of liquefaction of a gaseous feed using a closed-loop vapor expansion cycle having at least two expanders, wherein the discharge pressure of a second expander is lower than the discharge pressure of a first expander, and wherein the first expander provides at least a portion of the refrigeration required to liquefy the gaseous feed.

45. The method of claim 44, wherein the gaseous feed comprises natural gas.

46. The method of claim 44, wherein a resultant expanded stream from the second expander is warmed to near ambient temperature, compressed, and combined with a warmed resultant expanded stream from the first expander.

47. The method of claim 46, wherein the combined streams from the first expander and the second expander are further compressed and then cooled for further expansion.

48. The method of claim 44, wherein a resultant expanded stream from the first expander is split such that a first portion of the resultant expanded stream is used to cool the gaseous feed through indirect heat exchange and a second portion of the resultant expanded stream is used to provide cooling in a heat exchanger.