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(54) METHOD FOR THE PRODUCTION OF LIQUEFIED NATURAL GAS AND NITROGEN

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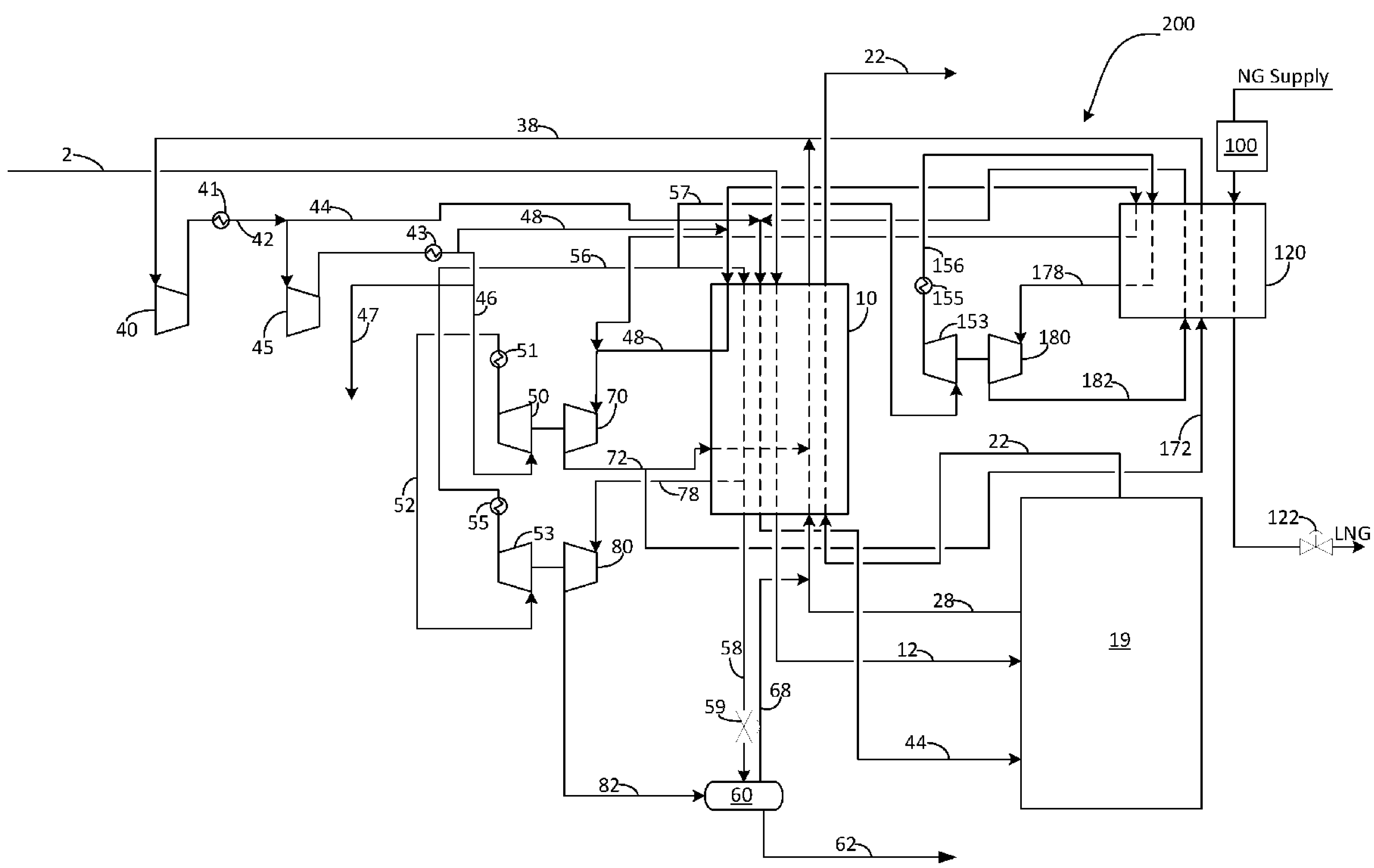
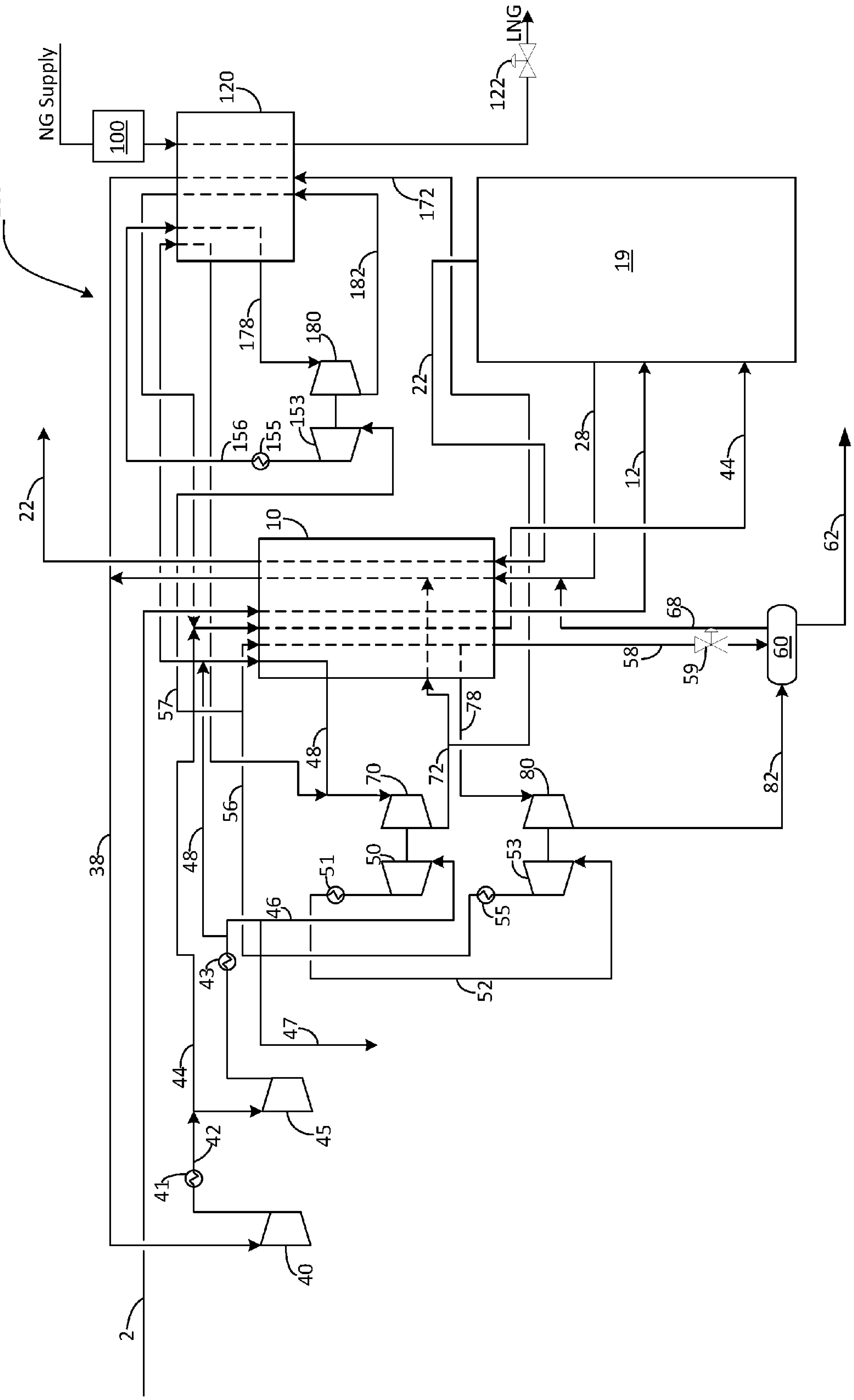
(57) **ABSTRACT**

A method for the production of liquefied natural gas ("LNG") and nitrogen is provided. The method may include the steps of: a) providing a nitrogen production facility, wherein nitrogen production facility comprises: a main heat exchanger, an air separation unit, a nitrogen recycle compressor, a first nitrogen refrigeration supply configured to provide refrigeration to the main heat exchanger for cooling a main air feed, b) providing a secondary refrigeration supply; c) liquefying a natural gas stream using refrigeration from the secondary refrigeration supply to form an LNG product stream; wherein the secondary refrigeration supply is configured to compress and expand a refrigerant to produce refrigeration, wherein the refrigerant of the secondary refrigeration supply is shared with refrigerant of the first nitrogen refrigeration supply




NG Supply
LNG
100
120
122
200
19
10
60
172
182
178
180
153
155
156
22
28
12
44
62
68
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78
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70
80
82
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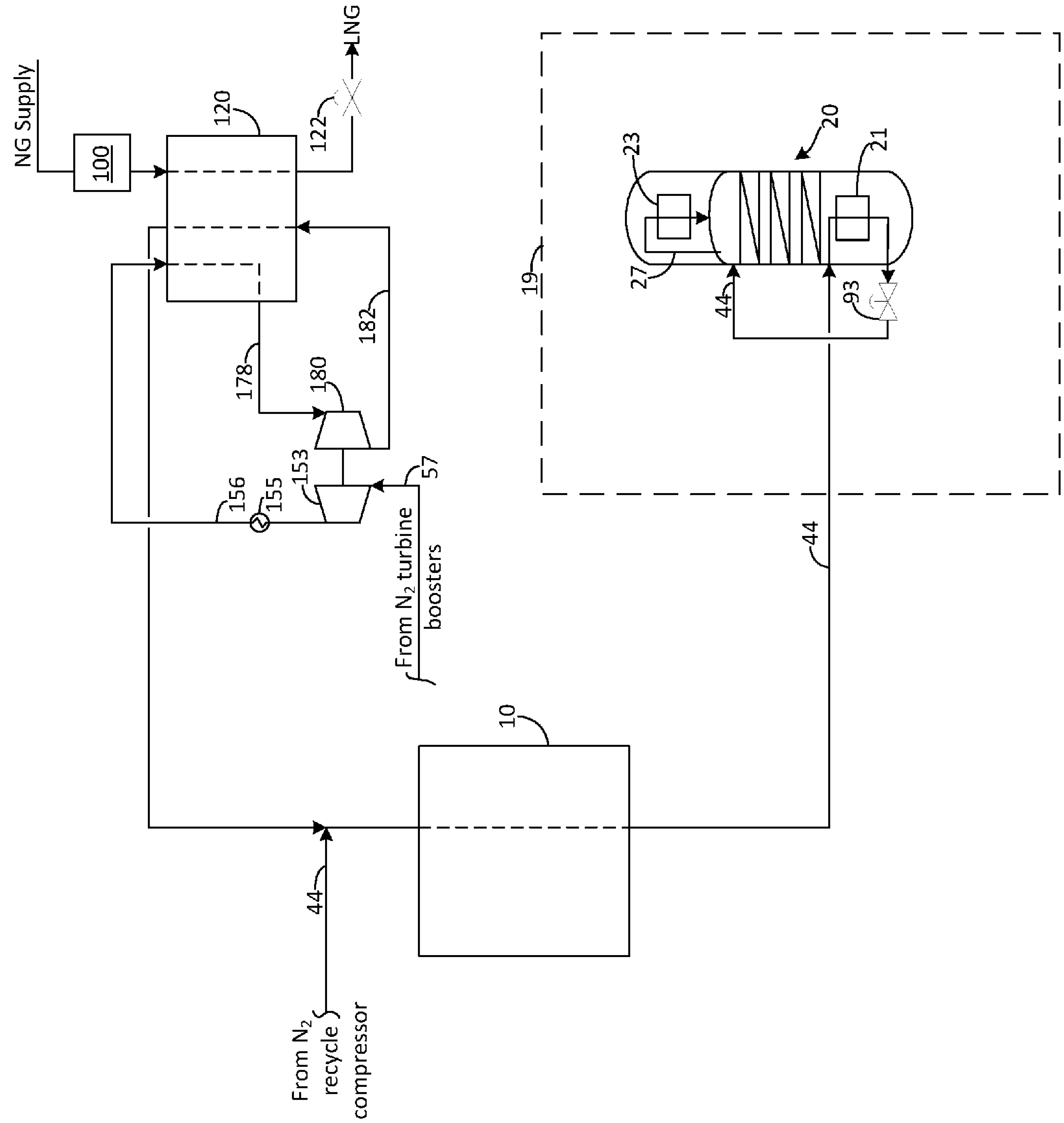
2

FIG. 1

FIG. 2


NG Supply
100
120
122
LNG
178
180
182
156
155
153
57
From N_2 turbine boosters
10
44
From N_2 recycle compressor
44
19
20
21
23
27
44
93

METHOD FOR THE PRODUCTION OF LIQUEFIED NATURAL GAS AND NITROGEN

RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application Ser. No. 62/201,947 filed on Aug. 6, 2015, U.S. Provisional Application Ser. No. 62/305,381 filed on Mar. 8, 2016, and U.S. Provisional Application Ser. No. 62/370,953 filed on Aug. 4, 2016, all of which are hereby incorporated by reference in their entireties.

TECHNICAL FIELD OF THE INVENTION

[0002] The present invention generally relates to a method and apparatus for efficiently producing liquefied natural gas ("LNG").

BACKGROUND OF THE INVENTION

[0003] Small scale nitrogen generators (e.g., typically 100 mtd to 400 mtd) are commonly needed at remote locations where the cost of an air separation unit producing O_2 and N_2 is not required or justified. The nitrogen can be (1) low purity gaseous for utility purposes (e.g., ethane cracker), (2) liquid form for fracking purposes, or (3) higher purity merchant product, particularly in locations such as North Dakota or Alberta. These sites can also have a demand for small quantities of liquefied natural gas, which is often trucked in at a high price. Alternatively, small scale LNG plants could be installed but also result in a high cost of product, thereby making these options uneconomical.

[0004] Therefore, it would be advantageous to provide a method and apparatus that could produce gaseous nitrogen, and/or LIN, while also producing LNG in a more efficient manner.

SUMMARY OF THE INVENTION

[0005] The present invention is directed to a method and apparatus that satisfies at least one of these needs. In certain embodiments, the invention can provide a lower cost, more efficient and flexible method to produce LNG. For example, in certain embodiments, the invention can include integration of a nitrogen production facility with an LNG production facility.

[0006] In one embodiment, refrigeration energy from the nitrogen production unit can be partially diverted to be used to liquefy natural gas. In one embodiment, the incoming air and natural gas are cooled in the same heat exchanger. In another embodiment, the liquefaction of the natural gas occurs in a separate heat exchanger. In embodiments in which the liquefaction of natural gas occurs in a second heat exchanger, the invention can also include an additional set of turbine boosters configured to provide additional refrigeration for the LNG heat exchanger. In one embodiment, the discharge pressure of the turbine for the LNG heat exchanger is approximate the column reboiler condensing pressure.

[0007] In one embodiment, a method for the production of liquefied natural gas ("LNG") and nitrogen is provided. In this embodiment, the method can include the steps of: a) providing a nitrogen production facility, wherein nitrogen production facility comprises: a main heat exchanger, an air separation unit, a nitrogen recycle compressor, a first nitrogen refrigeration supply configured to provide refrigeration to the main heat exchanger for cooling a main air feed; b) providing a secondary refrigeration supply; c) liquefying a natural gas stream using refrigeration from the secondary refrigeration supply to form an LNG product stream; wherein the secondary refrigeration supply is configured to compress and expand a refrigerant to produce refrigeration, wherein the refrigerant of the secondary refrigeration supply is shared with refrigerant of the first nitrogen refrigeration supply.

[0008] In optional embodiments of the method for the production of LNG and nitrogen:

[0009] the secondary refrigeration supply comprises a third turbine-booster, wherein the third turbine-booster has a third booster and a third turbine;

[0010] the natural gas stream is liquefied in a secondary heat exchanger;

[0011] the main heat exchanger is configured to receive a main air feed comprising purified and compressed air at a pressure of at least 3 bar, wherein the air separation unit is in fluid communication with a cool side of the main heat exchanger, the air separation unit being configured to receive cooled air from the main heat exchanger and produce gaseous nitrogen and waste oxygen, wherein the air separation unit comprises a single column having a bottom reboiler and a top condenser, wherein the nitrogen recycle compressor is in fluid communication with a warm side of the main heat exchanger such that the nitrogen recycle compressor is configured to receive a nitrogen recycle from the main heat exchanger, wherein at least a portion of the nitrogen recycle is made up of gaseous nitrogen from the air separation unit, wherein the first nitrogen refrigeration supply comprises a first turbine-booster which has a first booster and a first turbine, the first booster in fluid communication with the recycle compressor such that the first booster is configured to receive a compressed nitrogen recycle from the recycle compressor, and wherein the second nitrogen refrigeration supply comprises a second turbine-booster which has a second booster and a second turbine, the second booster in fluid communication with the first booster such that the second booster is configured to receive a boosted nitrogen from the first booster, wherein an outlet of the second booster is in fluid communication with the heat exchanger such that the boosted nitrogen from the second booster is cooled within the heat exchanger, wherein the second turbine is in fluid communication with the heat exchanger such that the second turbine is configured to receive a cooled fluid under pressure from the heat exchanger and then expand the cooled fluid to provide refrigeration for the apparatus;

[0012] the third booster is in fluid communication with the outlet of the second booster such that the third booster is configured to receive a portion of the boosted nitrogen from the outlet of the second booster;

[0013] the method further includes the step of compressing the portion of the boosted nitrogen in the third booster, cooling the portion of the boosted nitrogen in the secondary heat exchanger, expanding the portion of the boosted nitrogen to an expanded pressure P_E to form a cold refrigerant, and warming the cold refrigerant in the secondary heat exchanger against the natural gas stream to form a warm refrigerant stream;

[0014] the expanded pressure P_E is selected based on a first condition within the air separation unit;

[0015] the first condition includes a pressure of a reboiling fluid configured to provide reboiling duty for the bottom reboiler of the single column;

[0016] the first condition includes the vaporization temperature of bottom liquids surrounding the bottom reboiler of the single column;

[0017] the method further includes the step of cooling the warm refrigerant stream in the main heat exchanger to form a cooled refrigerant stream;

[0018] the cooled refrigerant stream, or a portion derived therefrom, is used to provide reboiling duty to the bottom reboiler of the single column;

[0019] the method further includes the steps of withdrawing a fraction of partially compressed nitrogen recycle from an internal stage of the nitrogen recycle compressor; introducing the partially compressed nitrogen recycle to the main heat exchanger for cooling before using the partially compressed nitrogen recycle as the heating fluid for the bottom reboiler; and then flashing the partially compressed nitrogen recycle into a top portion of the single column;

[0020] the warm refrigerant stream is combined with the partially compressed nitrogen recycle from the internal stage of the nitrogen recycle compressor prior to cooling in the main heat exchanger;

[0021] the third booster is in fluid communication with the outlet of the first booster such that the third booster is configured to receive a portion of the boosted nitrogen from the outlet of the first booster;

[0022] the third booster is in fluid communication with the outlet of the nitrogen recycle compressor such that the third booster is configured to receive a portion of the boosted nitrogen from the outlet of the nitrogen recycle compressor;

[0023] both the first and the second boosters are in fluid communication with the outlet of the nitrogen recycle compressor such that both the first and second boosters are configured to receive a portion of the boosted nitrogen from the outlet of the nitrogen recycle compressor;

[0024] the second turbine and third turbine are the same turbine;

[0025] the turbine outlet pressure is thermally linked with the reboiler of the single column;

[0026] the method further includes the step of providing a third refrigeration supply, wherein the third refrigeration supply comprises a natural gas expansion turbine; and/or

[0027] the method further includes the step of expanding a high pressure natural gas stream within the natural gas expansion turbine to produce an expanded natural gas stream, and warming the expanded natural gas stream in a secondary heat exchanger.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, claims, and accompanying drawings. It is to be noted, however, that the drawings illustrate only several embodiments of the invention and are therefore not to be considered limiting of the invention's scope as it can admit to other equally effective embodiments.

[0029] FIG. **1** provides an embodiment of the present invention.

[0030] FIG. **2** provides an embodiment of the present invention.

DETAILED DESCRIPTION

[0031] While the invention will be described in connection with several embodiments, it will be understood that it is not intended to limit the invention to those embodiments. On the contrary, it is intended to cover all the alternatives, modifications and equivalence as may be included within the spirit and scope of the invention defined by the appended claims.

[0032] In one embodiment, the apparatus can include a Main Air Compressor (MAC), an air purification system, heat exchange means, a distillation column, and a nitrogen refrigeration cycle having a nitrogen recycle compressor and warm and cold turbine boosters. In one embodiment, the nitrogen refrigeration cycle provides compression energy for pressurized gaseous nitrogen product as well as refrigeration for both cooling down the incoming air and liquefy nitrogen, as well as providing refrigeration to liquefy the natural gas to LNG. In one embodiment, the warm turbine booster flow can be split to provide refrigeration to both the warm section of the nitrogen portion and the warm section of the LNG portion. In one embodiment, this warm turbine load can serve to supply two refrigeration loads, since both the nitrogen and LNG portion heat exchange cooling curves have similar pressures and temperatures in this warm section.

[0033] In one embodiment, the temperature at the cold end of the nitrogen portion of the heat exchanger can be about −178° C., and the cold end of the LNG portion is about −164° C. In one embodiment, different expanded nitrogen streams at different pressures and coming from different turbines are used to liquefy the LNG as compared to cool the incoming air and liquefy nitrogen. This is preferably done since the temperature differences and cooling curve differences make it less efficient to use the same turbine for both nitrogen and LNG exchangers. Also, if the separate cold turbine for the LNG portion is simply warmed up and uses the same pressure profile (for integration in to suction of the same Recycle compressor) then the process is not optimized.

[0034] In one embodiment, warming the cold end of the LNG exchanger is achieved by reducing the turbine pressure ratio. In one embodiment, the turbine discharge pressure can be increased to ~10 bar to match the pressure for condensing in the column reboiler and the intermediate stage of the recycle compressor. This significantly reduces the flow rate at the first stage of the recycle compressor, and also improves the efficiency of the natural gas liquefaction, therefore both reducing power and cost.

[0035] In one embodiment, the method can include integrating a natural gas letdown system with a closed loop nitrogen refrigeration cycle. In this embodiment, the natural gas letdown essentially provides "free" refrigeration energy since the natural gas would have been alternatively letdown across a valve (i.e., the resulting drop in temperature of the natural gas would have been absorbed by the surroundings and would not have been recovered in any meaningful way). With the addition of a natural gas turbine booster and dryer (i.e., purification unit), LNG can be co-produced with a significant power savings, while also reducing the size of the nitrogen refrigeration cycle.

[0036] Referring to FIG. **1**, a process flow diagram of an embodiment of the current invention is shown. In FIG. **1**, main air feed **2**, which has already been purified and compressed to a pressure of about 5 to about 6 bar, is introduced to heat exchanger **10** and cooled down to a temperature near its dew point or lower to form fully cooled air feed **12**. Fully cooled air feed **12** is then introduced to air separation unit **19**, in order to separate the various components of air. Waste gaseous oxygen **22** is recovered from air separation unit **19** and is passed through the cold side of heat exchanger **10** in order to provide cooling to heat exchanger **10**. After exiting heat exchanger **10**, waste gaseous oxygen **22** can be vented to the atmosphere, used to regenerate the air adsorbers (not shown) or sent to a system of columns (not shown) if recovery of the oxygen is desired.

[0037] Gaseous nitrogen **28** is also withdrawn from air separation unit **19** and passed through the cold side of heat exchanger **10** to provide additional cooling. However, instead of venting to the atmosphere, gaseous nitrogen **28** can be recycled in the process. Nitrogen recycle **38** exits main heat exchanger **10** and is introduced to recycle compressor **40** and compressed to form compressed nitrogen recycle **46**. In one embodiment, if gaseous nitrogen is desired, a portion of compressed nitrogen recycle **46** can be removed and collected as gaseous nitrogen product **47**. Compressed nitrogen recycle **46** is then cooled in second aftercooler **43** before being boosted in first booster **50** and cooled in third aftercooler **51** to form boosted nitrogen **52**. Boosted nitrogen **52** is then introduced to second booster **53** in order to further compress boosted nitrogen **52** before being cooled in fourth aftercooler **55** to form fully boosted nitrogen **56**. In one embodiment fully boosted nitrogen **56** can be at ambient temperature and a pressure of about 45 to about 65 bar prior to entering heat exchanger **10**.

[0038] Fully boosted nitrogen **56** is then introduced to heat exchanger **10** for cooling. In one embodiment, one portion of fully boosted nitrogen **56** is fully cooled in heat exchanger **10** to form liquefied nitrogen **58**, which is subsequently introduced to liquid/gas separator **60** by flashing via valve **59**. In another embodiment, another portion of fully boosted nitrogen **56** is only partially cooled in heat exchanger **10** to form partially cooled boosted nitrogen **78**. In one embodiment, partially cooled boosted nitrogen **78** is at or above its super critical pressure. Partially cooled boosted nitrogen **78** is then introduced into second turbine **80** in order to expand partially cooled boosted nitrogen **78** to form second expanded nitrogen **82**. In one embodiment, second expanded nitrogen **82** can have a temperature that is near or below its dew point and a pressure of about 5 to about 6 bar. In one embodiment, second expanded nitrogen **82** is a two phase fluid consisting of gas and liquid phases. In a preferred embodiment, second expanded nitrogen **82** is introduced to liquid/gas separator **60** in order to separate any gaseous nitrogen from liquid nitrogen. Recovered liquid nitrogen **62** is withdrawn from liquid/gas separator **60** and collected as product. In one embodiment, gaseous nitrogen **68** is withdrawn from a top portion of liquid/gas separator **60** and combined with gaseous nitrogen **28** before introduction to the cold side of heat exchanger **10** and subsequently recycled.

[0039] In one embodiment, fraction of compressed nitrogen recycle **48** is withdrawn from compressed nitrogen recycle **46** and fed to the warm end of heat exchanger **10**, where fraction of compressed nitrogen recycle **48** is partially cooled before being expanded in first turbine **70** to form first expanded nitrogen **72**. In one embodiment, first expanded nitrogen **72** is reintroduced to heat exchanger **10**, preferably at an intermediate point, and combined with gaseous nitrogen **28** and subsequently recycled. In one embodiment, first turbine **70** is connected by a common shaft with first booster **50** and helps to provide the energy needed for first booster **50** to compress compressed nitrogen recycle **46**. Likewise, second turbine **80** is connected by a common shaft with second booster **53** and helps to provide the energy needed for second booster **53** to compress boosted nitrogen **52**. In one embodiment, first turbine **70** and second turbine **80** provide substantially all of the refrigeration needs for the process.

[0040] First turbine **70** and second turbine **80** produce refrigeration by work expansion. Their respective boosters, first booster **50** and second booster **53**, utilize the produced work to further compress their respective nitrogen streams.

[0041] Fraction of partially compressed nitrogen recycle **44** can be withdrawn from partially compressed nitrogen recycle **42** and, along with third expanded nitrogen **182** is fed to the warm end of heat exchanger **10**. After exiting the cold end of heat exchanger **10**, fraction of partially compressed nitrogen recycle **44** is used to provide heat to bottom boiler **21** before being introduced via valve **93** near a top portion of single column **20** (see FIG. **2**). Those of ordinary skill in the art will recognize that even though recycle compressor **40** and second recycle compressor **45** are pictured as two different compressors, it is possible to use one compressor and remove fraction of partially compressed nitrogen recycle **44** from an inner stage of that single compressor. In another embodiment, the two sections of the nitrogen recycle compressor can be combined on a common shaft with the main air compressor (not shown).

[0042] In the embodiment shown, portion of fully boosted nitrogen **57** is compressed in third booster **153**, cooled in fifth aftercooler **155** to produce supplemental compressed nitrogen **156**, which is then partially cooled in LNG heat exchanger **120** to form partially cooled nitrogen **178**. Partially cooled nitrogen **178** is then expanded in third turbine **180** to form third expanded nitrogen **182**, which is then warmed in LNG heat exchanger **120** against natural gas in order to form LNG. Production of LNG can be controlled by LNG control valve **122**. After warming, third expanded nitrogen **182** is then combined with fraction of partially compressed nitrogen recycle **44**, which is then used as a reboiling fluid within the distillation column (see FIG. **2**). Additional refrigeration for LNG heat exchanger **120** can be provided by removing a fraction of first expanded nitrogen **72** and then warming fraction of first expanded nitrogen **172** within LNG heat exchanger **120**. After warming, fraction of first expanded nitrogen **172** is then combined with gaseous nitrogen **28** to form nitrogen recycle **38** and then recycled back to recycle compressor **40**.

[0043] In one embodiment, stream **57** can also be derived from boosted nitrogen **52** or from stream **46**, depending on the splits of power from turbines **70**, **80** and **180**, since these turbines set the pressure ratios of the boosted nitrogen streams. In one embodiment, it is preferred to have the pressures of streams **56** and **156** be elevated, while at the limit of the design pressure of secondary exchanger.

[0044] Regarding FIG. **2**, a simplified process flow diagram showing the interconnectivity of the LNG refrigeration cycle with the reboiler of the distillation column is provided.

It is important to note here that FIG. **2** is a simplified version of the process flow diagram, in which many of the process streams have been removed for easier viewing. For a more detailed look at all of the components of the nitrogen production unit, attention should be drawn to U.S. Pub. 2015/0168057 and U.S. Pat. Pub. 2015/0168058, both of which are herein incorporated by reference in their entireties.

[0045] In FIG. **2**, gaseous nitrogen near the top of single column **20** travels up tube **27**, with a portion being withdrawn as gaseous nitrogen **28** and the rest condensing within top condenser **23** before being reintroduced to single column **20**. Oxygen-rich condensing fluid introduced near top condenser **23** provides the needed cooling to condense the nitrogen. Waste gaseous oxygen **22** is withdrawn and used to provide refrigeration to heat exchanger **10**

[0046] The vapor from the top of condenser **23** is the waste stream of the air distillation process and can be withdrawn through the plant equipment and sent to atmospheric vent. The pressure at the condenser **23** can be 1.3-1.5 bara. This pressure and the composition of this waste stream yields a vaporizing temperature of about −179° C. in condenser **23** which is thermally linked to the condensing N_2 of stream **27**, resulting in a pressure in column **20** (which is approximately 5 bara). Reboiler **21** thermally links the vaporization of the oxygen rich liquid with a condensing nitrogen stream. This vaporizer operates by condensing nitrogen at approximately −170° C., thereby setting the pressure of the condensing nitrogen at approximately 9.3 bara.

[0047] Matching the discharge pressure of the third turbine **180** to the pressure of the reboiler can help allow the LNG section and N_2 section to operate more efficiently (i.e., that is with a specific power equal to that of separate independent liquefiers, as well as a significant capex savings (shared recycle compressor and warm turbine booster)). As mentioned before, if the third expanded nitrogen pressure is at a higher level than the suction pressure of the nitrogen recycle compressor, the heat exchange efficiency of the natural gas liquefaction process can be improved. Operating at the ~9 bara (or ~8 to 11 bar range) allows the LNG liquefier to operate at its optimum point. But this third expanded nitrogen pressure is limited by the possible condensation of nitrogen at the turbine discharge, facilitated at higher pressure

[0048] The term "ambient temperature" if used herein refers to the temperature of the air surrounding an object. Typically the outdoor ambient temperature is generally between about 0 to 110° F. (−18 to 43° C.).

[0049] The term "cryogenic gas" if used herein refers to a substance which is normally a gas at ambient temperature that can be converted to a liquid by pressure and/or cooling. A cryogenic gas typically has a boiling point of equal to or less than about −130° F. (−90° C.) at atmospheric pressure.

[0050] The terms "liquefied natural gas" or "LNG" as used herein refers to natural gas that is reduced to a liquefied state at or near atmospheric pressure.

[0051] The term "natural gas" as used herein refers to raw natural gas or treated natural gas. Raw natural gas is primarily comprised of light hydrocarbons such as methane, ethane, propane, butanes, pentanes, hexanes and impurities like benzene, but may also contain small amounts of non-hydrocarbon impurities, such as nitrogen, hydrogen sulfide, carbon dioxide, and traces of helium, carbonyl sulfide, various mercaptans or water. Treated natural gas is primarily comprised of methane and ethane, but may also contain small percentages of heavier hydrocarbons, such as propane, butanes and pentanes, as well as small percentages of nitrogen and carbon dioxide.

[0052] While the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications, and variations will be apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended to embrace all such alternatives, modifications, and variations as fall within the spirit and broad scope of the appended claims. The present invention may suitably comprise, consist or consist essentially of the elements disclosed and may be practiced in the absence of an element not disclosed. Furthermore, if there is language referring to order, such as first and second, it should be understood in an exemplary sense and not in a limiting sense. For example, it can be recognized by those skilled in the art that certain steps can be combined into a single step.

[0053] The singular forms "a", "an" and "the" include plural referents, unless the context clearly dictates otherwise.

[0054] "Comprising" in a claim is an open transitional term which means the subsequently identified claim elements are a nonexclusive listing (i.e., anything else may be additionally included and remain within the scope of "comprising"). "Comprising" as used herein may be replaced by the more limited transitional terms "consisting essentially of" and "consisting of" unless otherwise indicated herein.

[0055] "Providing" in a claim is defined to mean furnishing, supplying, making available, or preparing something. The step may be performed by any actor in the absence of express language in the claim to the contrary.

[0056] Optional or optionally means that the subsequently described event or circumstances may or may not occur. The description includes instances where the event or circumstance occurs and instances where it does not occur.

[0057] Ranges may be expressed herein as from about one particular value, and/or to about another particular value. When such a range is expressed, it is to be understood that another embodiment is from the one particular value and/or to the other particular value, along with all combinations within said range.

[0058] All references identified herein are each hereby incorporated by reference into this application in their entireties, as well as for the specific information for which each is cited.

We claim:

1. A method for the production of liquefied natural gas ("LNG") and nitrogen, the method comprising the steps of:

a) providing a nitrogen production facility, wherein nitrogen production facility comprises: a main heat exchanger, an air separation unit, a nitrogen recycle compressor, a first nitrogen refrigeration supply configured to provide refrigeration to the main heat exchanger for cooling a main air feed;

b) providing a secondary refrigeration supply;

c) liquefying a natural gas stream using refrigeration from the secondary refrigeration supply to form an LNG product stream;

wherein the secondary refrigeration supply is configured to compress and expand a refrigerant to produce refrigeration, wherein the refrigerant of the secondary refrigeration supply is shared with refrigerant of the first nitrogen refrigeration supply.

2. The method as claimed in claim **1**, wherein the secondary refrigeration supply comprises a third turbine-booster, wherein the third turbine-booster has a third booster and a third turbine.

3. The method as claimed in claim **2**, wherein the natural gas stream is liquefied in a secondary heat exchanger.

4. The method as claimed in claim **3**, wherein the main heat exchanger is configured to receive a main air feed comprising purified and compressed air at a pressure of at least 3 bar,

wherein the air separation unit is in fluid communication with a cool side of the main heat exchanger, the air separation unit being configured to receive cooled air from the main heat exchanger and produce gaseous nitrogen and waste oxygen, wherein the air separation unit comprises a single column having a bottom reboiler and a top condenser,

wherein the nitrogen recycle compressor is in fluid communication with a warm side of the main heat exchanger such that the nitrogen recycle compressor is configured to receive a nitrogen recycle from the main heat exchanger, wherein at least a portion of the nitrogen recycle is made up of gaseous nitrogen from the air separation unit,

wherein the first nitrogen refrigeration supply comprises a first turbine-booster which has a first booster and a first turbine, the first booster in fluid communication with the recycle compressor such that the first booster is configured to receive a compressed nitrogen recycle from the recycle compressor, and

wherein the second nitrogen refrigeration supply comprises a second turbine-booster which has a second booster and a second turbine, the second booster in fluid communication with the first booster such that the second booster is configured to receive a boosted nitrogen from the first booster, wherein an outlet of the second booster is in fluid communication with the heat exchanger such that the boosted nitrogen from the second booster is cooled within the heat exchanger, wherein the second turbine is in fluid communication with the heat exchanger such that the second turbine is configured to receive a cooled fluid under pressure from the heat exchanger and then expand the cooled fluid to provide refrigeration for the apparatus.

5. The method as claimed in claim **4**, wherein the third booster is in fluid communication with the outlet of the second booster such that the third booster is configured to receive a portion of the boosted nitrogen from the outlet of the second booster.

6. The method as claimed in claim **4**, further comprising the step of compressing the portion of the boosted nitrogen in the third booster, cooling the portion of the boosted nitrogen in the secondary heat exchanger, expanding the portion of the boosted nitrogen to an expanded pressure P_E to form a cold refrigerant, and warming the cold refrigerant in the secondary heat exchanger against the natural gas stream to form a warm refrigerant stream.

7. The method as claimed in claim **6**, wherein the expanded pressure P_E is selected based on a first condition within the air separation unit.

8. The method as claimed in claim **7**, wherein the first condition includes a pressure of a reboiling fluid configured to provide reboiling duty for the bottom reboiler of the single column.

9. The method as claimed in claim **7**, wherein the first condition includes the vaporization temperature of bottom liquids surrounding the bottom reboiler of the single column.

10. The method as claimed in claim **6**, further comprising the step of cooling the warm refrigerant stream in the main heat exchanger to form a cooled refrigerant stream.

11. The method as claimed in claim **10**, wherein the cooled refrigerant stream, or a portion derived therefrom, is used to provide reboiling duty to the bottom reboiler of the single column.

12. The method as claimed in claim **11**, further comprising the steps of withdrawing a fraction of partially compressed nitrogen recycle from an internal stage of the nitrogen recycle compressor; introducing the partially compressed nitrogen recycle to the main heat exchanger for cooling before using the partially compressed nitrogen recycle as the heating fluid for the bottom reboiler; and then flashing the partially compressed nitrogen recycle into a top portion of the single column.

13. The method as claimed in claim **12**, wherein the warm refrigerant stream is combined with the partially compressed nitrogen recycle from the internal stage of the nitrogen recycle compressor prior to cooling in the main heat exchanger.

14. The method as claimed in claim **4**, wherein the third booster is in fluid communication with the outlet of the first booster such that the third booster is configured to receive a portion of the boosted nitrogen from the outlet of the first booster.

15. The method as claimed in claim **4**, wherein the third booster is in fluid communication with the outlet of the nitrogen recycle compressor such that the third booster is configured to receive a portion of the boosted nitrogen from the outlet of the nitrogen recycle compressor.

16. The method as claimed in claim **4**, wherein both the first and the second boosters are in fluid communication with the outlet of the nitrogen recycle compressor such that both the first and second boosters are configured to receive a portion of the boosted nitrogen from the outlet of the nitrogen recycle compressor.

17. The method as claimed in claim **4**, wherein the second turbine and third turbine are the same turbine.

18. The method as claimed in claim **17**, wherein the turbine outlet pressure is thermally linked with the reboiler of the single column.

19. The method as claimed in claim **1**, further comprising the step of providing a third refrigeration supply, wherein the third refrigeration supply comprises a natural gas expansion turbine.

20. The method as claimed in claim **19**, further comprising the step of expanding a high pressure natural gas stream within the natural gas expansion turbine to produce an expanded natural gas stream, and warming the expanded natural gas stream in a secondary heat exchanger.

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