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(54) **NATURAL GAS LIQUEFACTION SYSTEM FOR PRODUCING LNG AND MERCHANT GAS PRODUCTS**

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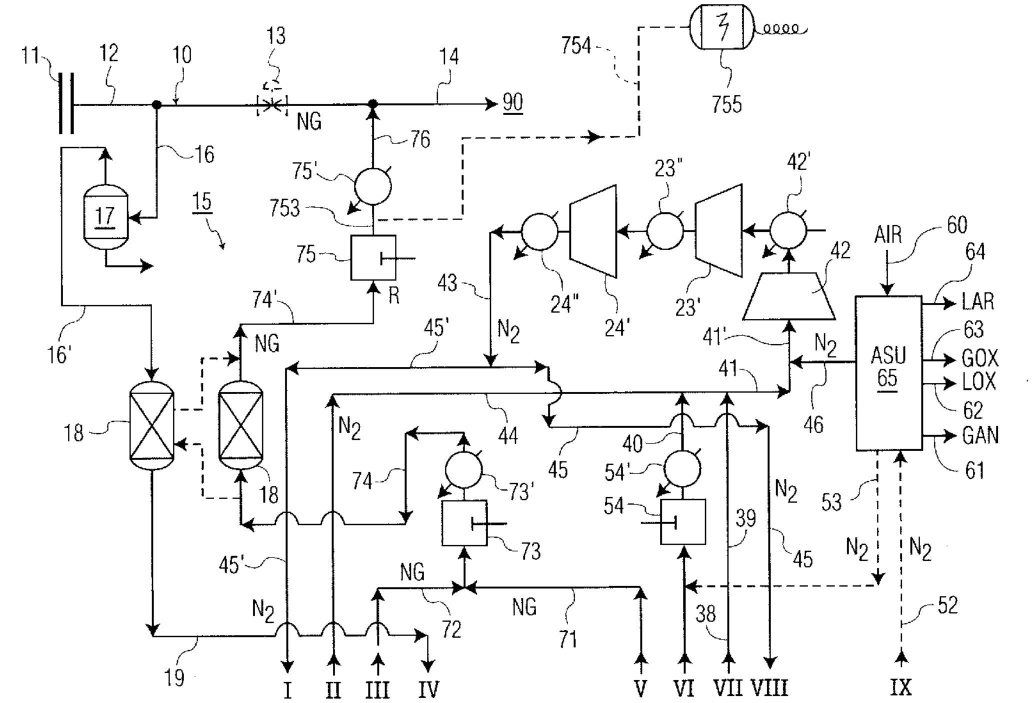
USPC **62/611**

(57) **ABSTRACT**

Pipeline natural gas is dried to remove water and carbon dioxide and liquefied. This gas and nitrogen are fed into a first heat exchanger for cooling against colder flash and expanded gases. High pressure nitrogen gas is expanded producing refrigeration to liquefy the natural gas passing through further heat exchangers and throttled via a control valve where the resulting liquid natural gas (LNG) exits into a separator. A portion of the LNG is fed to a nitrogen liquefaction unit with a major portion of LNG stored as product. The LNG portion is vaporized and heated to ambient against a pressurized liquefied nitrogen stream, a portion of which is stored as product. The remaining portion of the liquid nitrogen is optionally sent to an air separation unit (ASU) as "liquid assist" producing liquid and gaseous oxygen, liquid argon and gaseous nitrogen merchant gases. A portion of the natural gas stream selectively regenerates one of two dryers. If a letdown station is employed, a smaller booster compressor may be used. Medium and low pressure nitrogen is recovered and recycled through compression. The ASU separates and produces merchant gases to be liquefied wherein the liquid is generally produced by expanding nitrogen gas to generate refrigeration producing the liquid products while consuming nitrogen molecules. Natural gas feed streams richer in ethane, propane and heavier hydrocarbons enables the production of natural gas liquids as additional products in a further embodiment. Other embodiments are also disclosed.



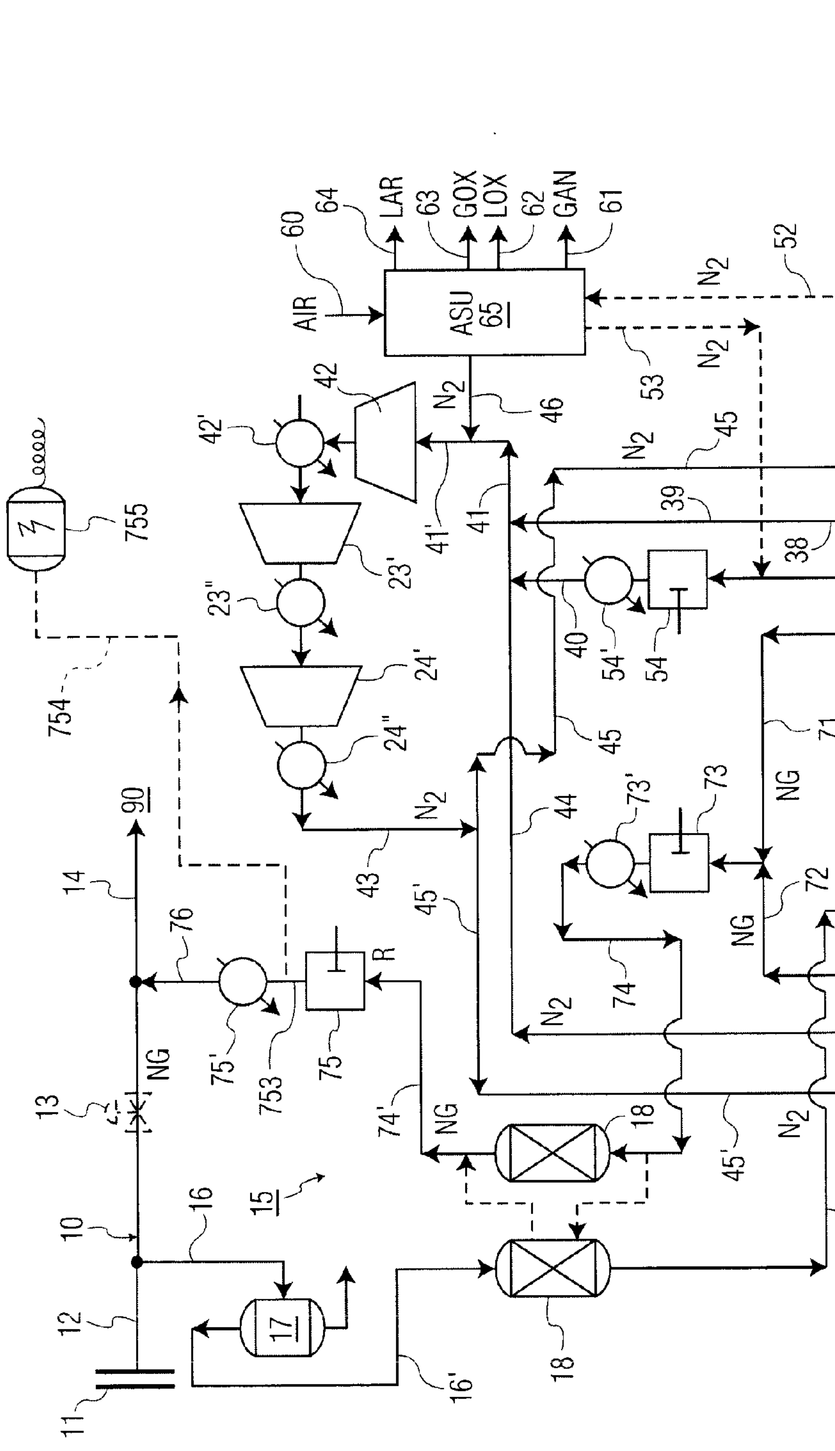
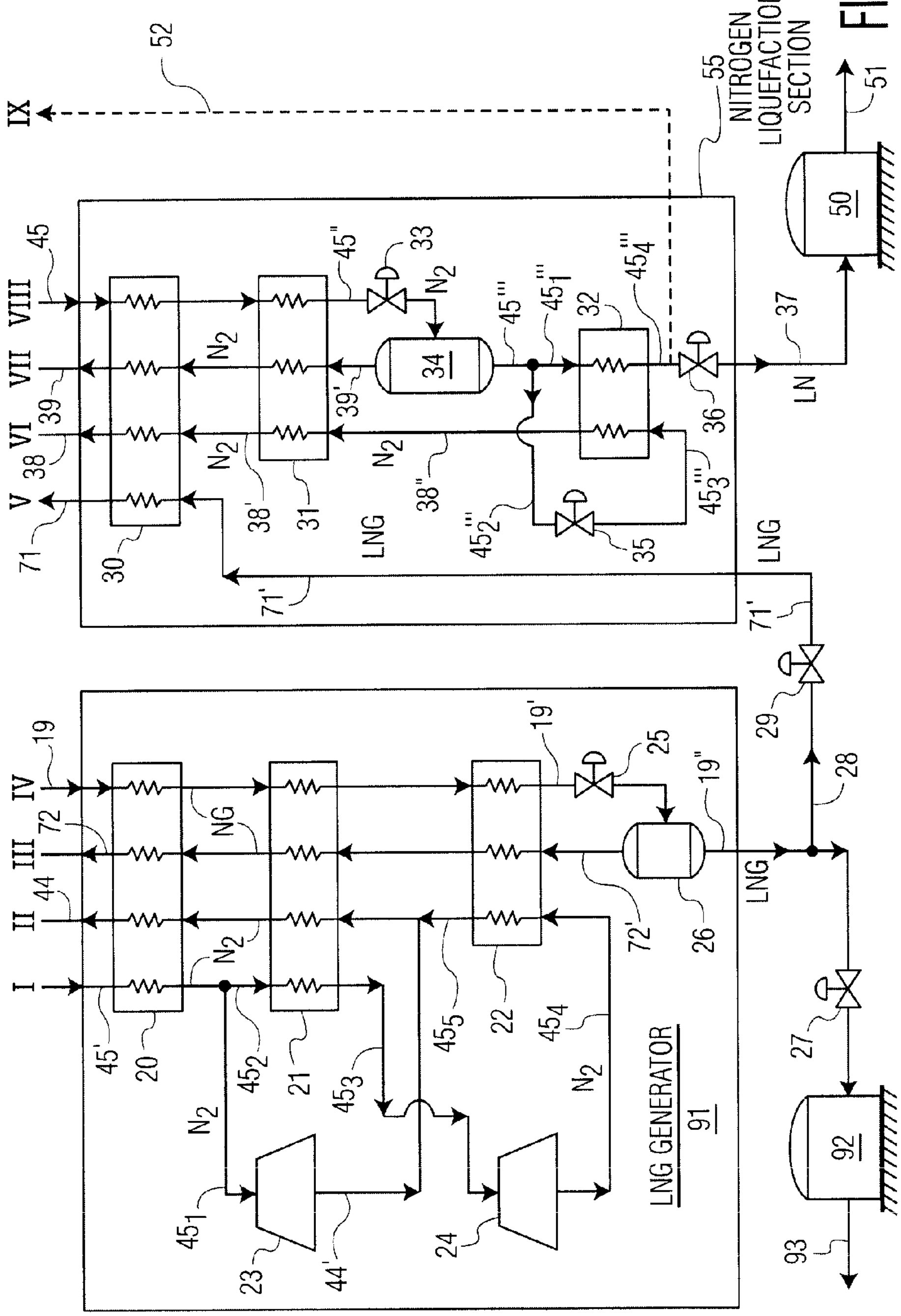
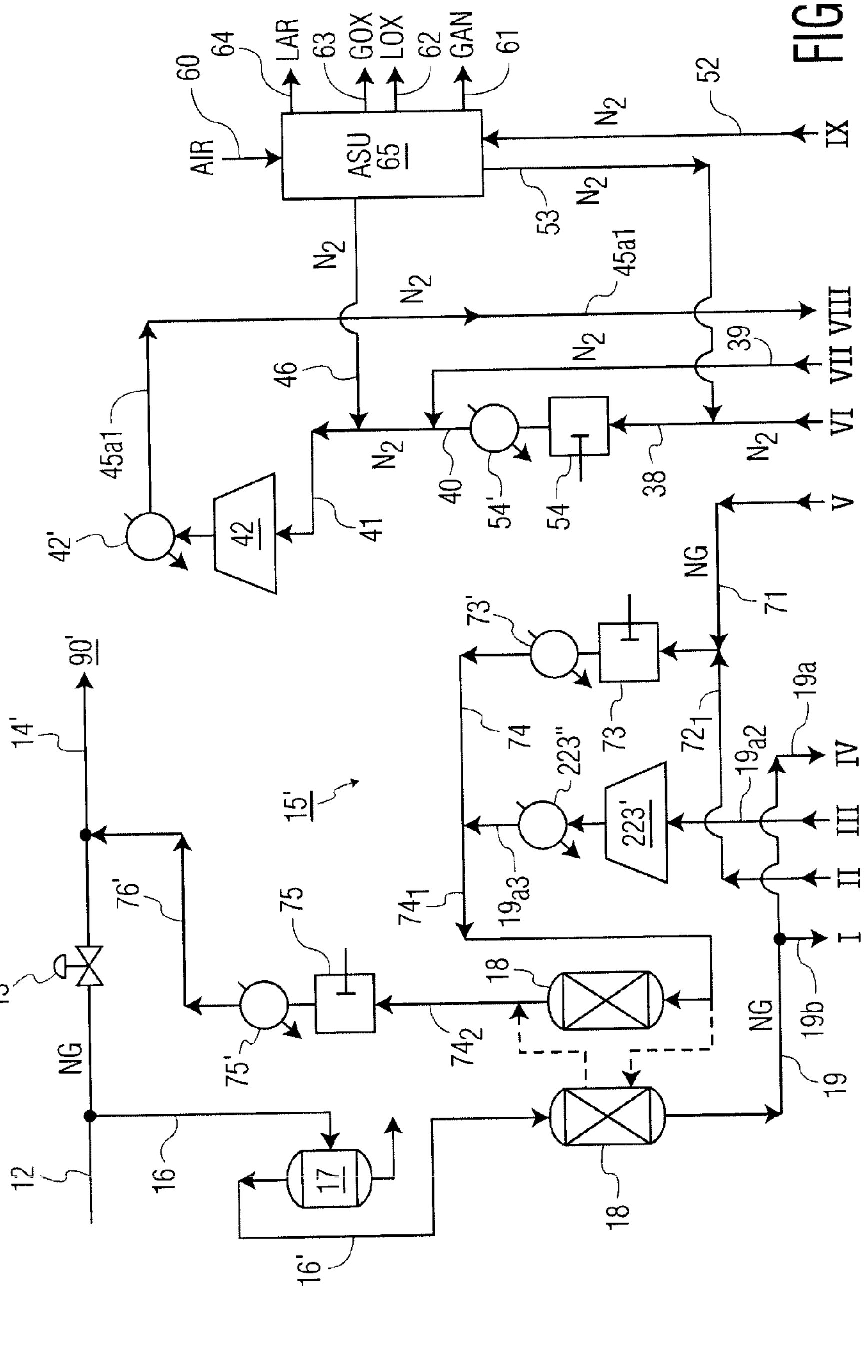


FIG. 1a



NITROGEN LIQUEFACTION SECTION
LNG GENERATOR
91
LNG
LN
NG
N_2
I
II
III
IV
V
VI
VII
VIII
IX

FIG. 1b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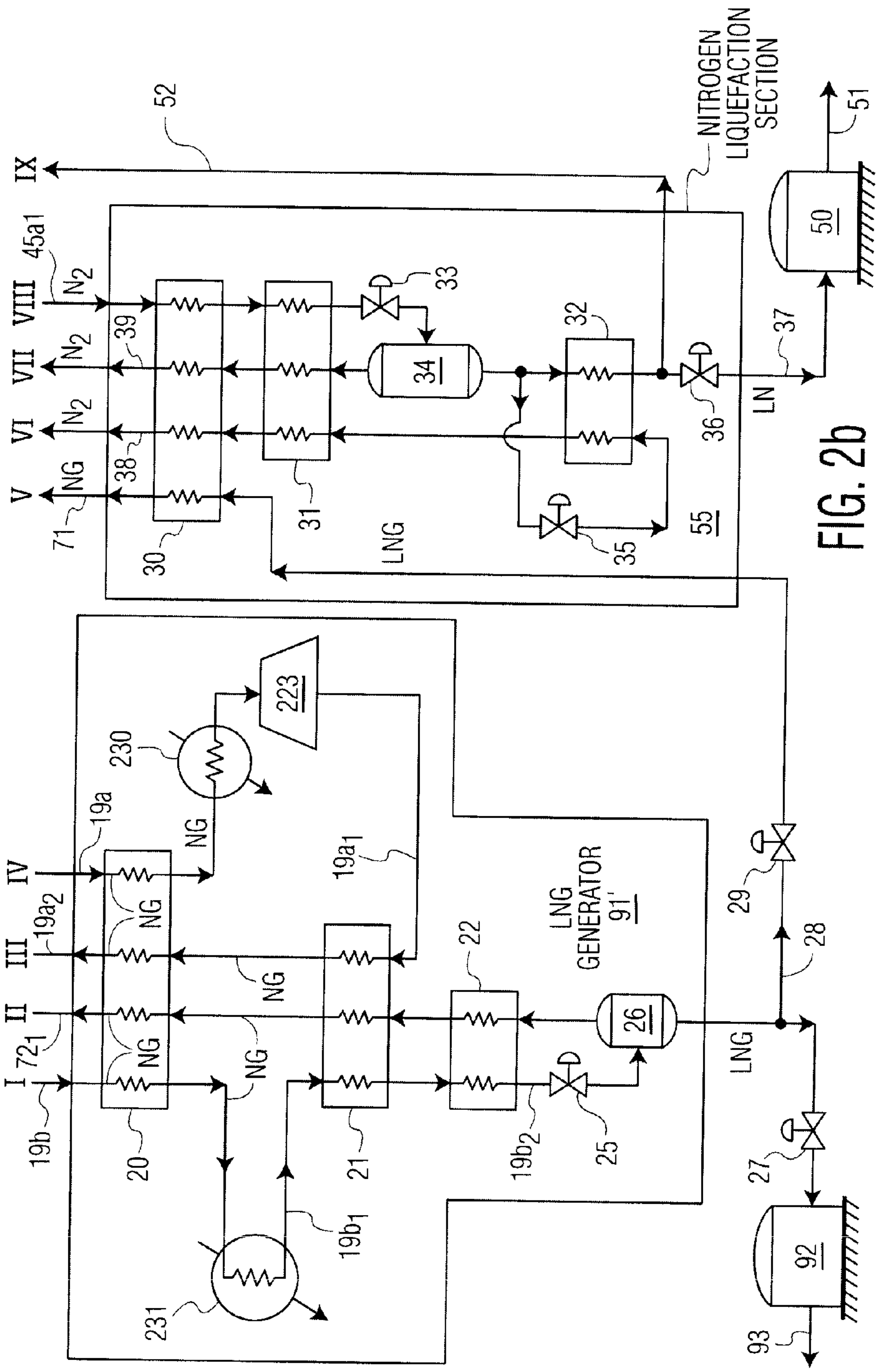
ASU
65
LAR
GOX
LOX
GAN
60
64
63
62
61
52
53
N_2
45a1
46
39
38
40
41
42
42'
54
54'
VI
VII
VIII
IX
V
NG
71
72
73
73'
74
223'
223''
19a
19a2
19a3
IV
III
II
I
19b
19
18
75
75'
76'
13
14'
90'
15'
12
16
16'
17

FIG. 2a


NITROGEN LIQUEFACTION SECTION
LNG GENERATOR 91'
I
II
III
IV
V
VI
VII
VIII
IX
NG
N2
LNG
LN
19a
19a1
19a2
19b
19b1
19b2
20
21
22
223
230
231
25
26
27
28
29
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45a1
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55
71
721
92
93

FIG. 2b

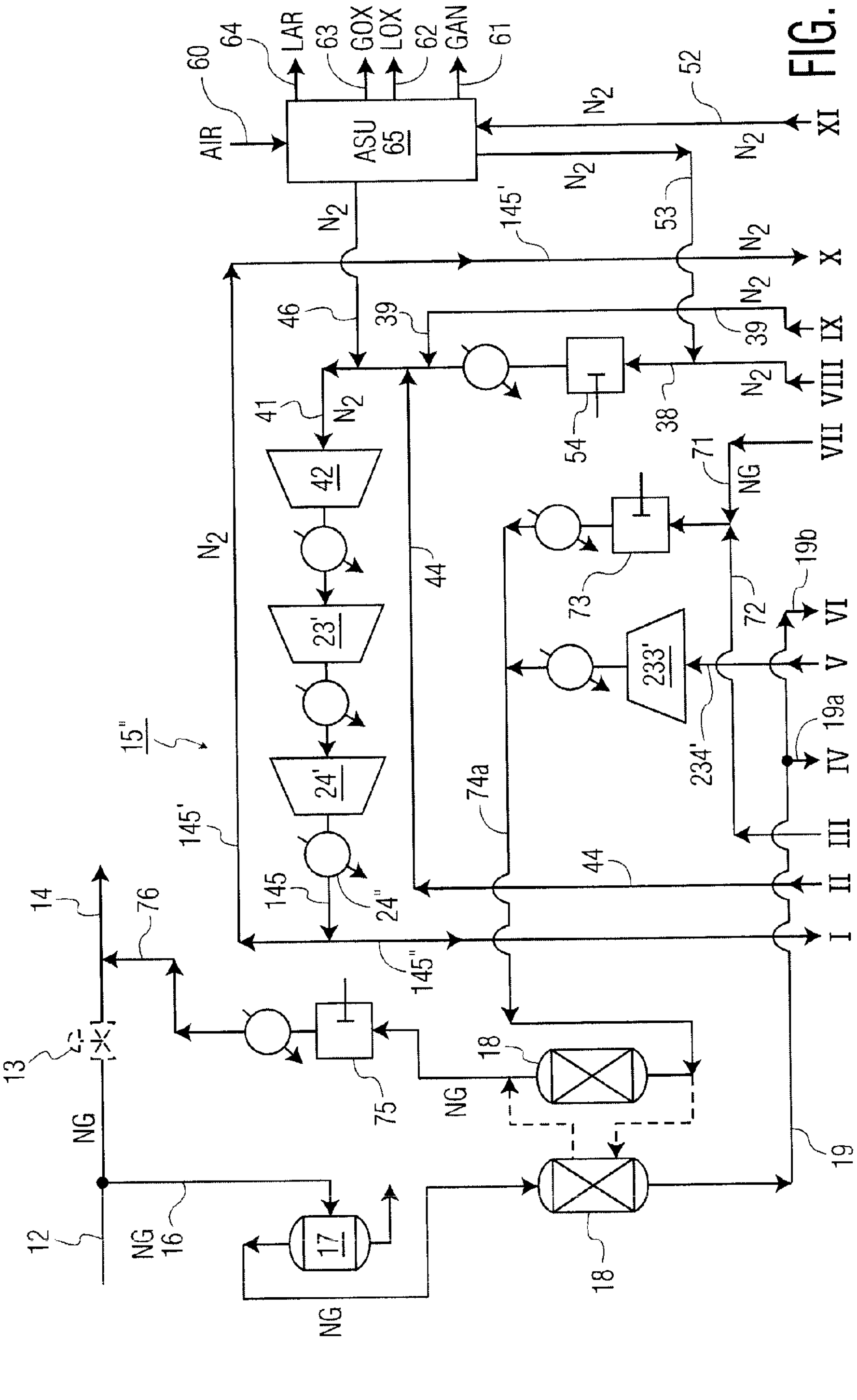
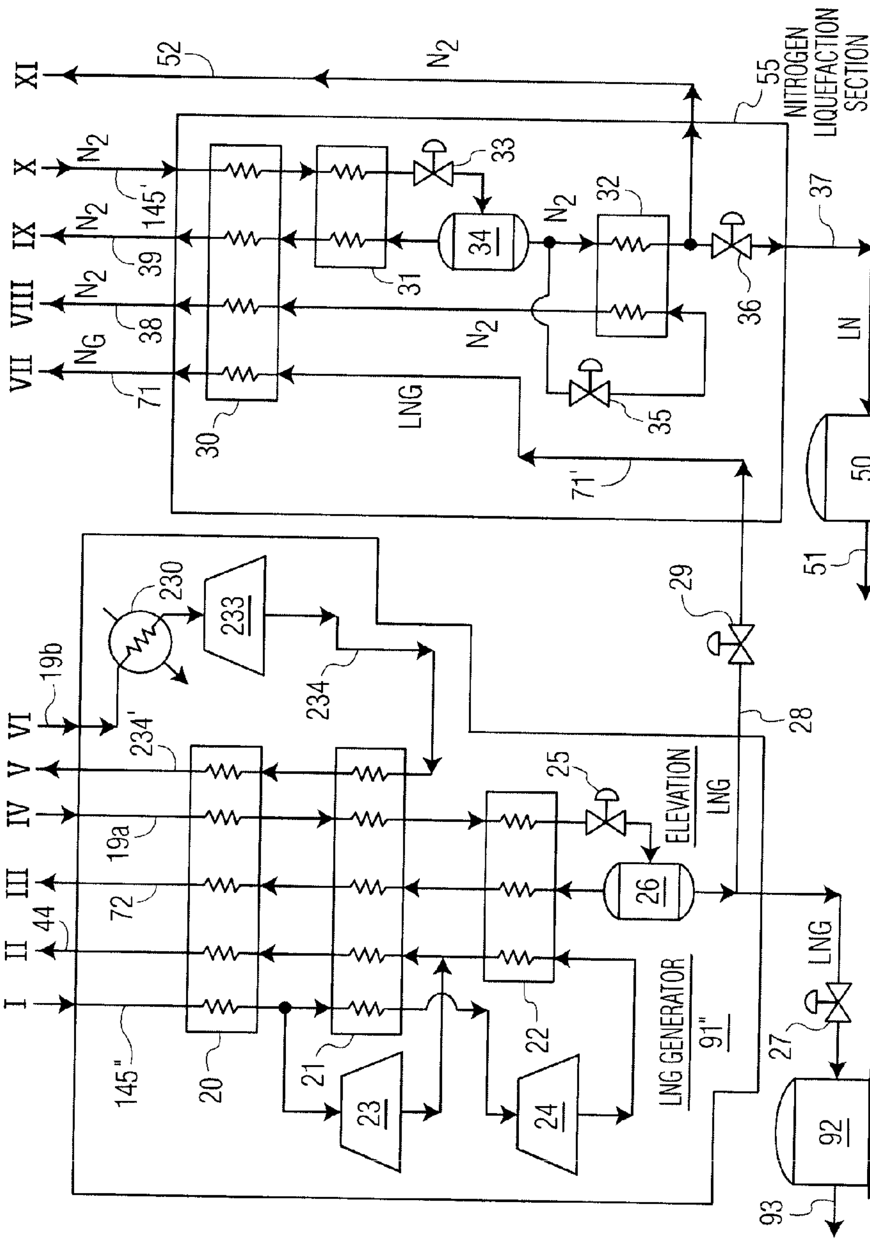


FIG. 3a


NITROGEN LIQUEFACTION SECTION
55
LNG GENERATOR
91"
ELEVATION LNG
LNG
LN
N_2
N_G
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
19a
19b
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
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44
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51
52
71
71'
72
92
93
145'
145"
230
233
234
234'

FIG. 3b

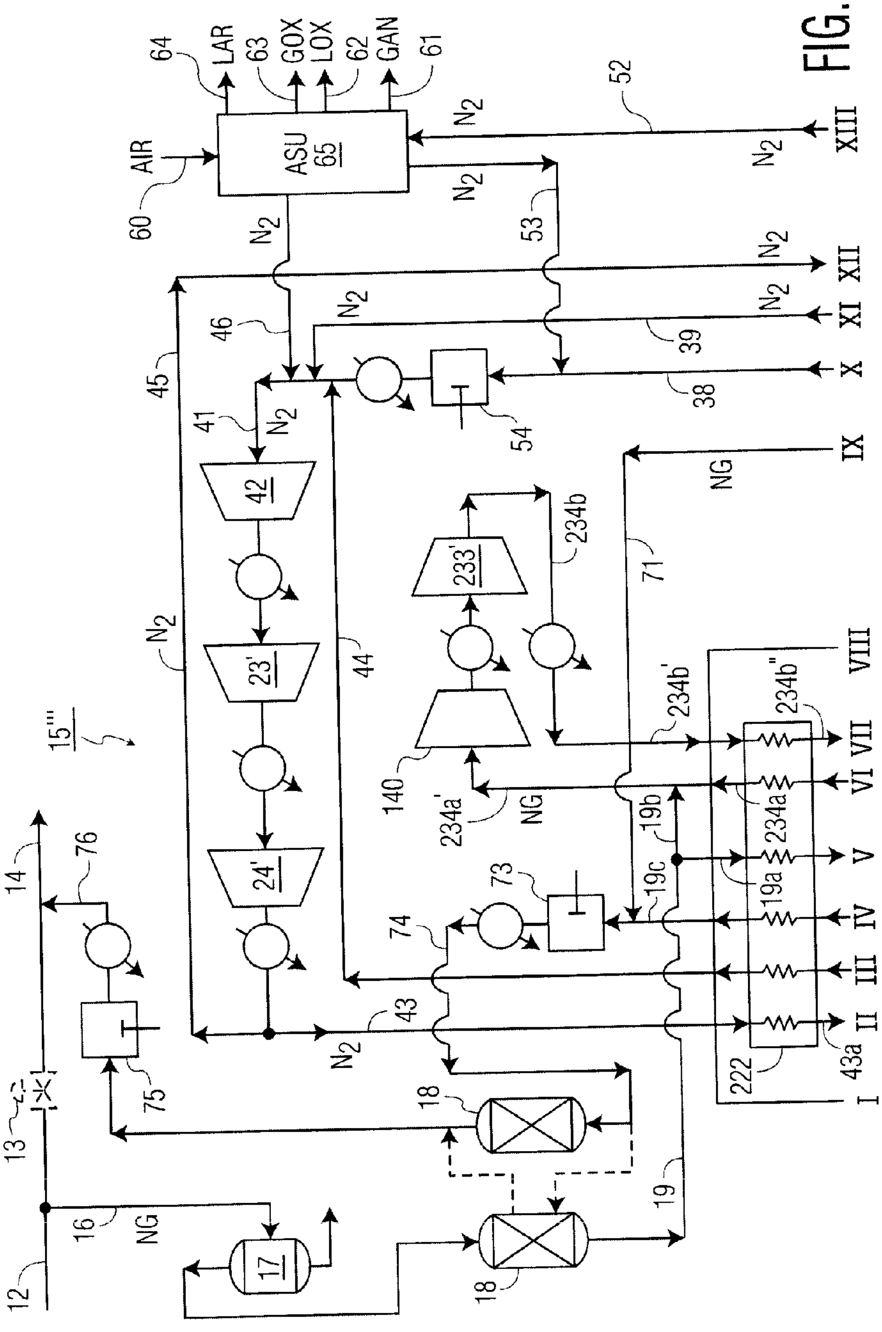
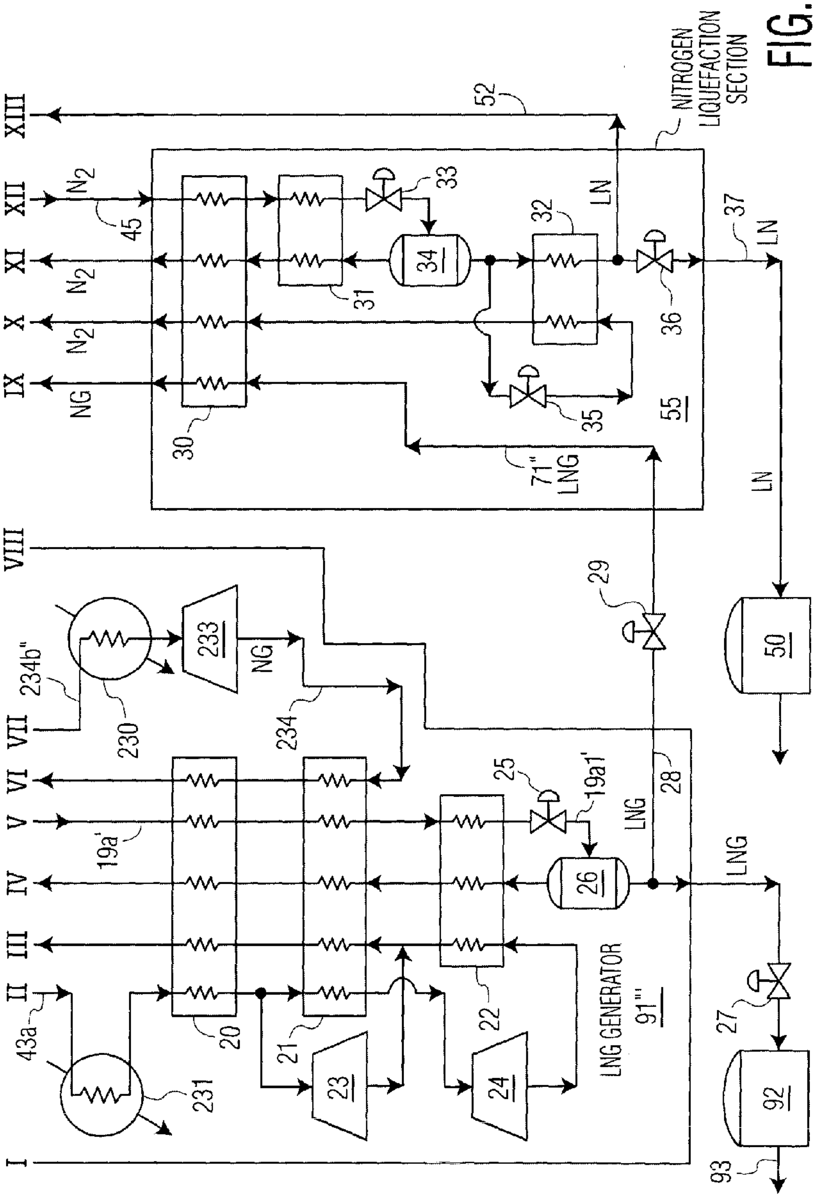


FIG. 4a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II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
43a
231
20
21
22
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24
25
26
27
28
29
30
31
32
33
34
35
36
37
45
50
52
55
92
93
19a'
19a1'
230
233
234
234b"
71"
NG
N2
LN
LNG
LNG GENERATOR
91'''
NITROGEN LIQUEFACTION SECTION

FIG. 4b

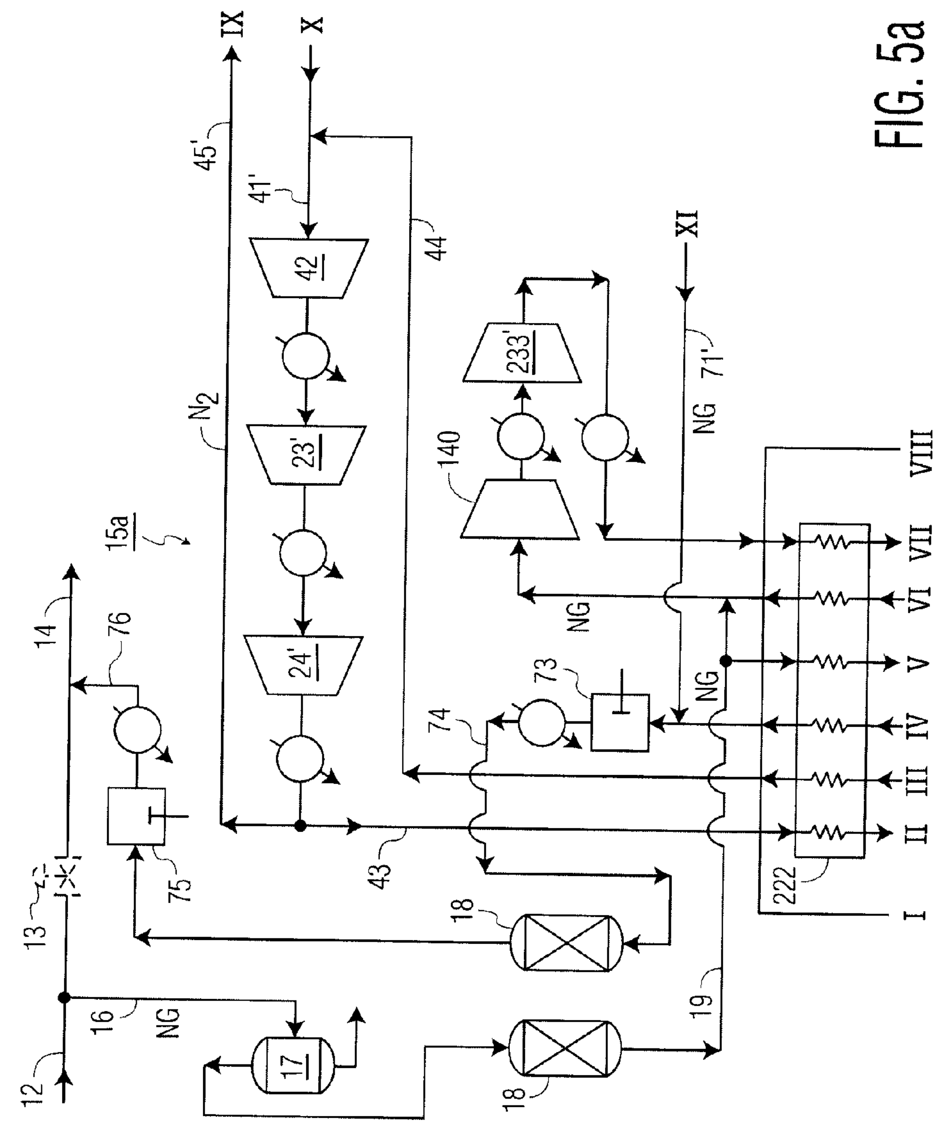

12
13
14
15a
16
NG
17
18
18
19
43
44
45'
N2
IX
X
41'
42
23'
24'
73
74
75
76
NG
NG
140
233'
71'
NG
XI
222
I
II
III
IV
V
VI
VII
VIII

FIG. 5a

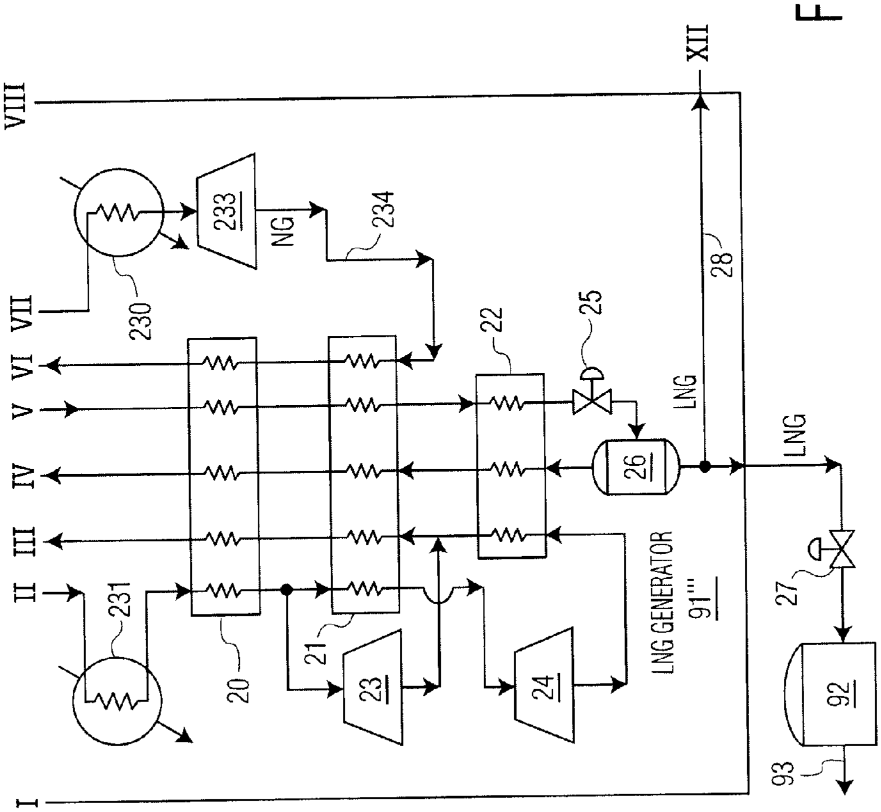
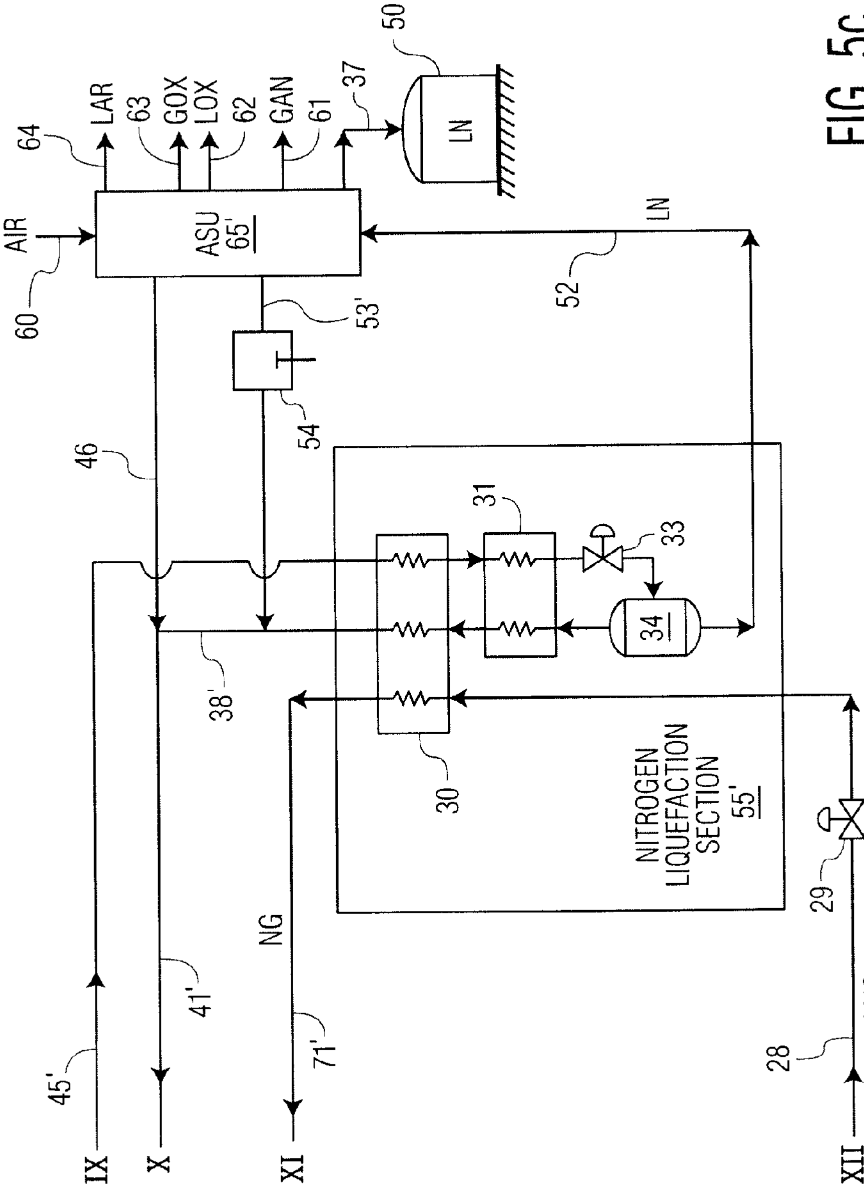

I
II
III
IV
V
VI
VII
VIII
XII
20
21
22
23
24
25
26
27
28
92
93
230
231
233
234
NG
LNG
LNG
LNG
LNG GENERATOR
91'''

FIG. 5b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ASU
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LAR
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GOX
LOX
62
GAN
61
37
50
LN
LN
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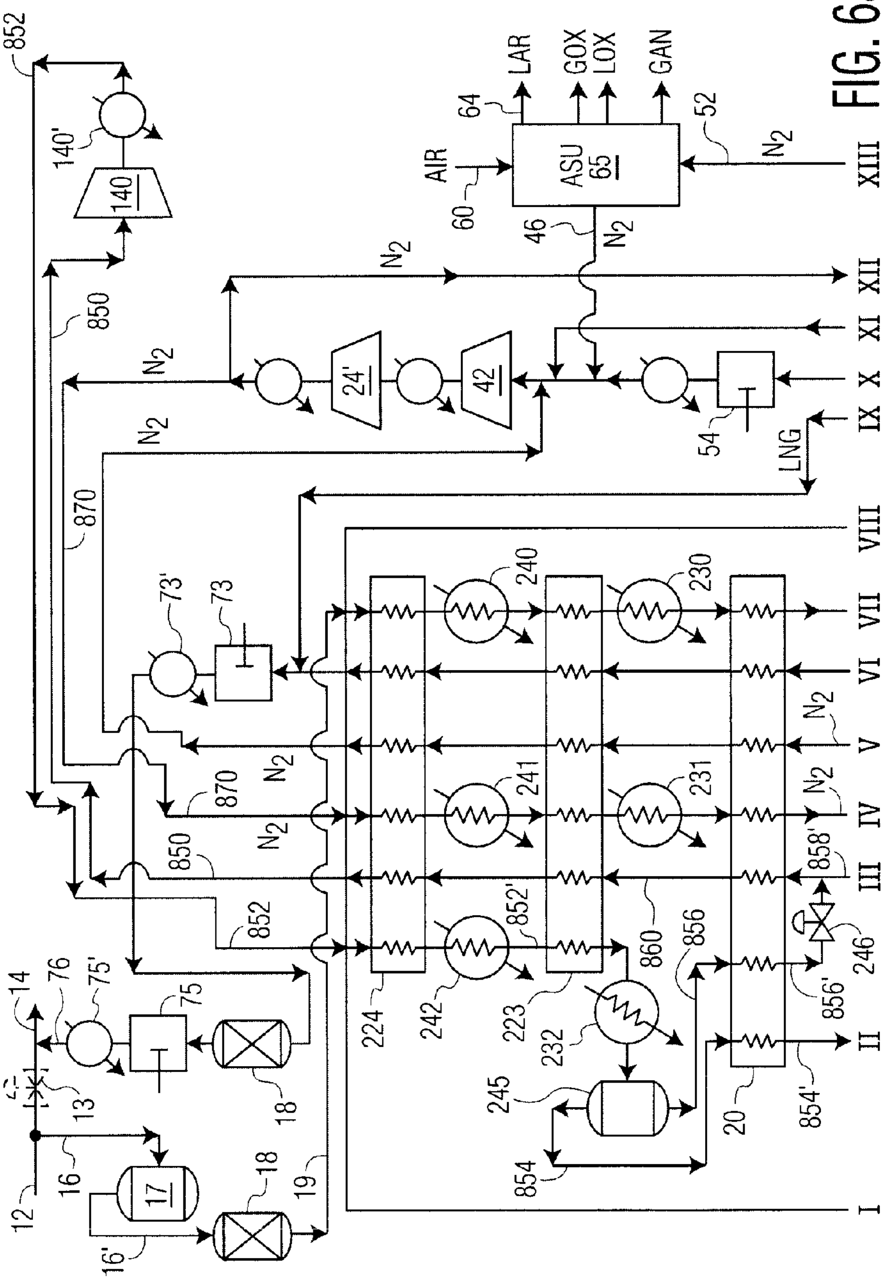
53'
54
46
31
33
34
38'
30
NITROGEN
LIQUEFACTION
SECTION
55'
29
NG
LNG
28
45'
41'
71'
IX
X
XI
XII

FIG. 5c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140'
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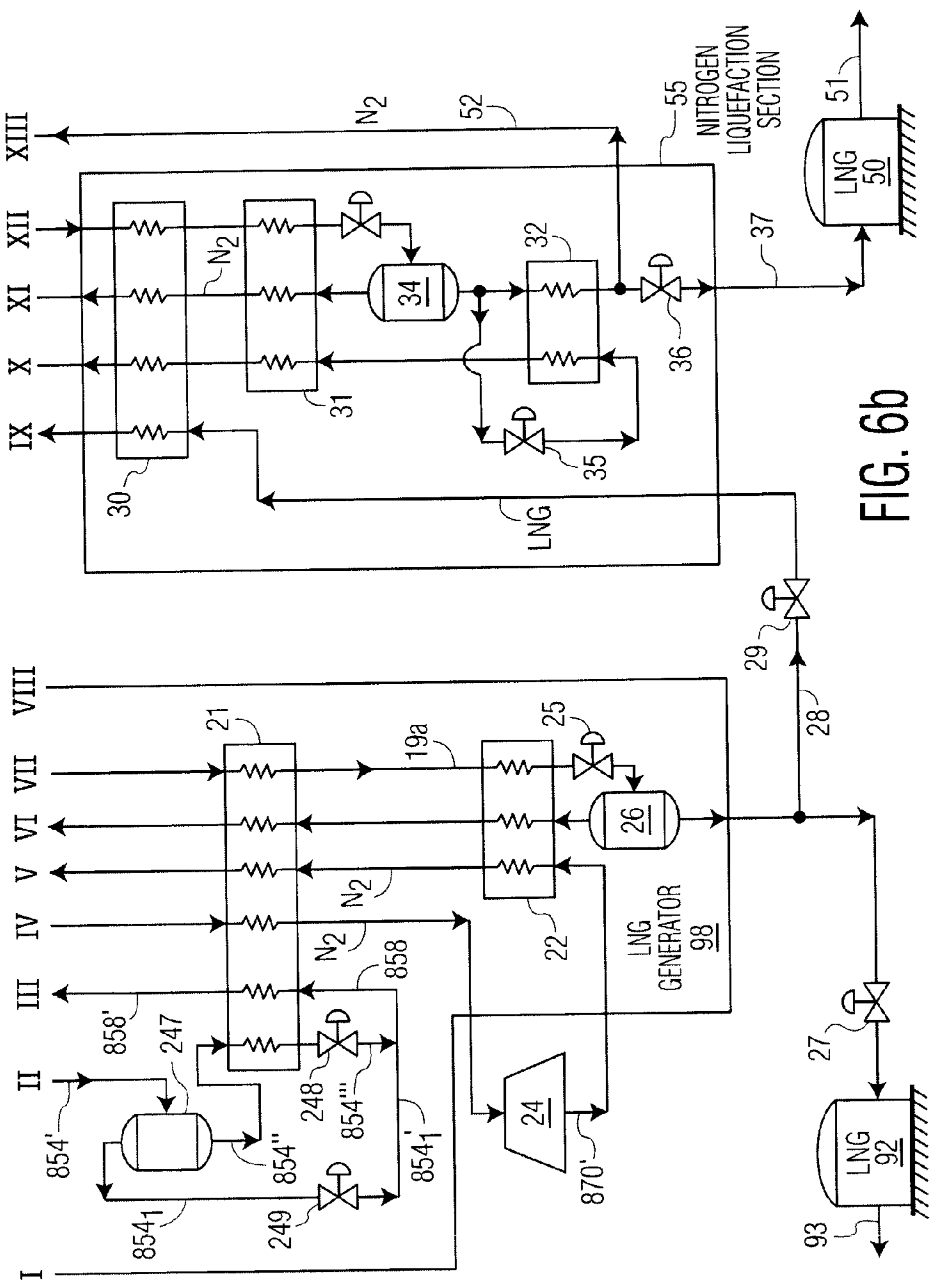
850
N_2
870
24'
42
N_2
46
ASU
65
AIR
60
64
LAR
GOX
LOX
GAN
52
N_2
54
LNG
73'
73
75'
75
76
14
13
12
16
17
16'
18
19
224
223
20
242
240
241
230
231
232
245
246
852'
856
856'
858'
854
854'
860
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII

FIG. 6a


I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
N2
LNG
LNG GENERATOR 98
NITROGEN LIQUEFACTION SECTION
LNG 50
LNG 92
21
22
24
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27
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31
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34
35
36
37
51
52
55
93
19a
247
248
249
858
858'
854'
854''
854'''
854₁
854₁'
870'

FIG. 6b

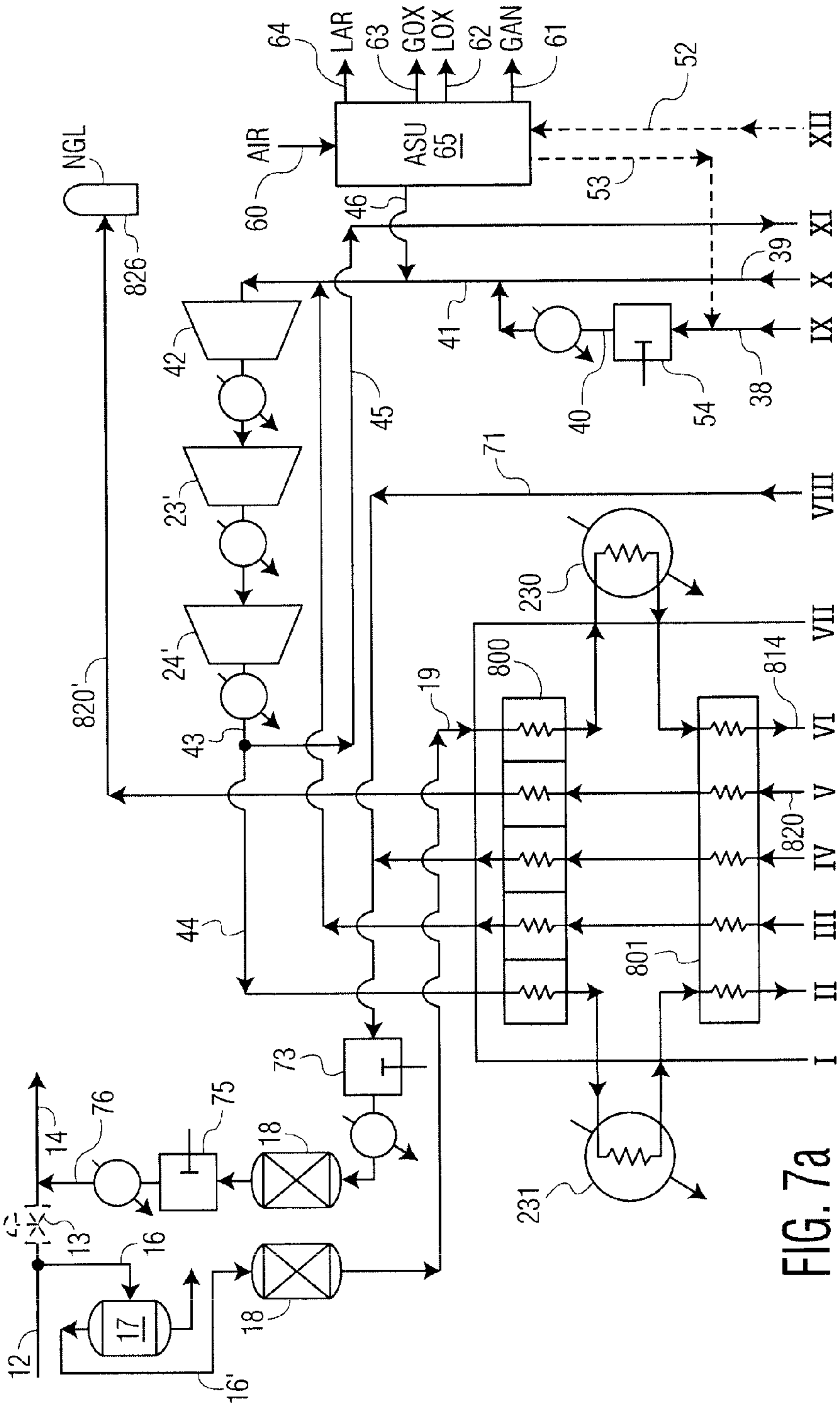
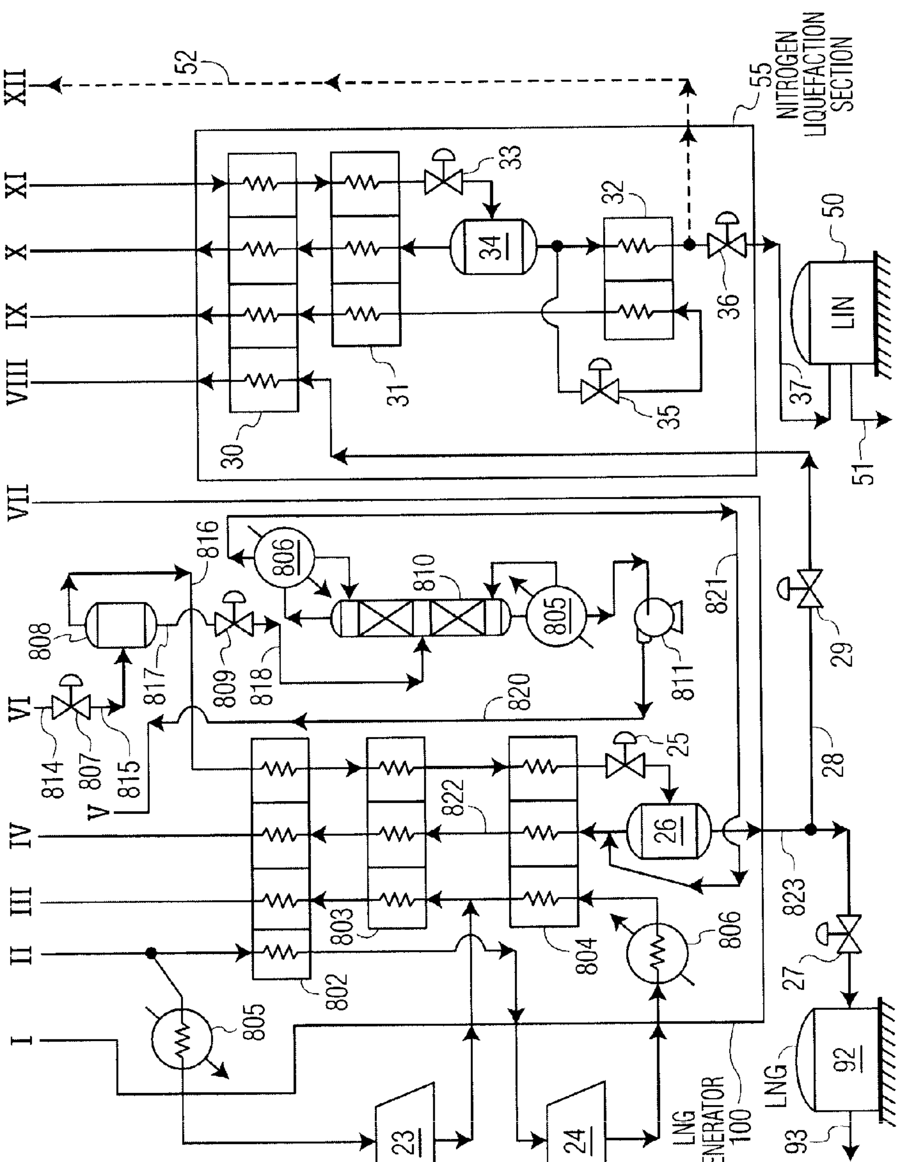

LAR
GOX
LOX
GAN
64
63
62
61
52
AIR
ASU
65
60
53
NGL
826
46
XII
XI
X
39
42
41
IX
40
54
38
45
71
VIII
23'
230
VII
24'
800
814
820'
19
VI
43
V
820
IV
44
III
801
II
73
I
14
76
75
18
231
13
16
17
18
12
16'

FIG. 7a

FIG. 7b


I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
52
55
NITROGEN LIQUEFACTION SECTION
LIN
LNG
LNG GENERATOR 100
23
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51
92
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802
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823

NATURAL GAS LIQUEFACTION SYSTEM FOR PRODUCING LNG AND MERCHANT GAS PRODUCTS

[0001] This invention claims priority on U.S. provisional application No. 61/827,973 filed May 28, 2013 in the name of Robert Wissolik incorporated by reference in its entirety herein.

FIELD OF INVENTION

[0002] The present invention relates to the manufacture of liquid natural gas (LNG), liquid propane, butane and heavier hydrocarbon gases commonly referred to as natural gas liquids (NGL) and merchant liquid gases such as liquid nitrogen (LN), gaseous nitrogen (GAN), liquid oxygen (LOX), gaseous oxygen (GOX), and liquid argon (LAR) utilizing an air separation unit (ASU) and a combination of liquefaction units that liquefy both natural gas and nitrogen, the LNG, NGL and LN gases being derived from a conventional natural gas (NG) pipeline.

CROSS REFERENCE TO RELATED PATENTS

[0003] Of interest is commonly owned U.S. Pat. No. 6,131,407 entitled Natural Gas Letdown Liquefaction System filed Mar. 4, 1999 in the name of Robert Wissolik and U.S. Pat. No. 6,669,774 entitled Gas Liquefaction Method Using Natural Gas and Mixed Gas Refrigeration in the name of Rashad et al. assigned to Praxair Technology, Inc., both of which patents are incorporated by reference herein in their entirety.

BACKGROUND OF INVENTION

[0004] U.S. Pat. No. 6,131,407 discloses a natural gas letdown liquefaction system. A let down station employs a control valve or the like to reduce relatively high pipeline gas pressures, e.g., 715 psia, to lower user pressure levels, e.g., 200 psia or lower. This system uses the high gas pressure of the pipeline to assist in the generation of refrigeration. In this system, a liquid natural gas (LNG) generator generates LNG which is supplied to a nitrogen liquefaction section as an internal process intermediate gas to generate industrial merchant gas final output products such as liquid argon, liquid or gaseous oxygen or gaseous nitrogen using an air separation unit (ASU). The ASU may be a conventional nitrogen or oxygen plant.

[0005] In one embodiment, the liquid nitrogen (LN) is also stored as a product. However, the nitrogen is refrigerated by the LNG, each gas being processed in a closed cycle independent of each other. That is, the natural gas (NG) is recycled in a closed loop through a LNG generator comprising a cascaded bank of first heat exchangers using only NG. The N_2 is recycled in a closed loop in a separate independent nitrogen liquefaction section using a cascaded bank of second heat exchangers, which feed liquid N_2 to the ASU. The LNG is fed to and processed in the N_2 liquefaction section heat exchangers to liquefy the N_2 as an intermediate gas.

[0006] In another embodiment, one bank of cascaded heat exchangers are employed to generate both liquid natural gas and liquid nitrogen. This cycle, however, is only used when less natural gas is available to make the desired amounts of merchant gas products. In this embodiment, and the in other disclosed embodiments, no liquid LNG or N_2 products are provided outside that generated by the ASU outputting the desired non-LNG industrial merchant gas products.

[0007] U.S. Pat. No. 6,694,774 to Rashad discloses a gas liquefaction method also using a natural gas letdown system with natural gas and mixed gas refrigeration to generate LNG product. This reference discloses an output at line 36, FIGS. 1 and 2 and at line 79, FIG. 3. Line 36 comprises LNG product, and line 79 comprises industrial gas as liquefied nitrogen. The liquid nitrogen and the LNG are produced in different processes employing separate and independent systems in separate different corresponding manufacturing plants which is costly. Such different plants are not recognized by the prior art as being capable of being combined into a single manufacturing plant as recognized by the present inventor with the resulting considerable cost savings in the construction of such plants.

[0008] Air and oxygen are not liquefied directly with natural gas due to safety concerns. Traditionally, liquid natural gas (LNG) plants are constructed using a variety of refrigeration methods. Some use a nitrogen gas expansion cycle to create the refrigeration required to liquefy the natural gas. High pressure nitrogen gas is expanded, which results in relatively low temperatures that can then be used as refrigeration to liquefy the natural gas.

[0009] Airco Industrial Gases designed and installed a number of such plants in the early 1970s. One such plant was constructed for the Southern Connecticut Gas Company. Other companies use a mixed refrigerant cycle as done by British Oxygen Company in Avonmouth, England. A mixture of carefully chosen hydrocarbons is liquefied selectively, and the liquid is throttled to lower pressure providing the refrigeration necessary to liquefy both the mixed refrigerant and the natural gas feed stream. Air Products has built many plants using what they call the propane precooled multicomponent (mixed refrigerant) refrigeration cycle, or some variation of this process cycle. Air Products has published articles about their cycles as has Linde, a major corporate player in the LNG plant building business.

[0010] Linde also uses a mixed refrigeration cycle. Another method for generating refrigeration uses expanded natural gas available from natural gas pipeline letdown stations as done by Airco for the UIG Corporation in Reading, Pa. U.S. Pat. No. 6,694,774 to Rashad teaches this method of producing LNG using letdown stations in combination with a number of mixed refrigerant cycles.

[0011] The refrigeration cycle of choice for the industrial gas business is the nitrogen gas expansion cycle. It is the dominate cycle used in the United States and in most other parts of the world. The only exceptions may be found on newer merchant gas manufacturing plants. These plants take advantage of LNG to reduce the power consumption in manufacturing merchant gas liquid products. British Oxygen Company built one such plant in Dandenong, Australia. LNG at low pressure is vaporized and warmed by heat transfer using higher pressure nitrogen, and the nitrogen gas is liquefied by the warming natural gas. The refrigeration inherent in the LNG is saved, resulting in reduced power consumption for manufacturing industrial gas liquids. U.S. Pat. No. 6,130,407, discloses using a letdown station to produce LNG, which in turn is used in an internal process as an intermediate gas to liquefy the nitrogen, which in turn is used for the production of industrial merchant liquid and gaseous gas products as well as the LNG intermediate gas.

[0012] U.S. Pat. No. 6,449,984 to Paradowski discloses the liquefaction of natural gas and extraction of nitrogen from the natural gas under pressure to obtain liquid natural gas (LNG)

24 free of nitrogen product and waste gaseous nitrogen 29 essentially free of hydrocarbons that is vented to the atmosphere. There is no disclosure or suggestion of producing liquid nitrogen as a product nor the production of merchant gas products such as liquid oxygen, gaseous oxygen or gaseous argon. While the disclosed products produced in this reference include liquid natural gas and gaseous waste nitrogen, industrial merchant gas products such as liquid oxygen, gaseous oxygen or gaseous argon are not manufactured.

[0013] Qualls US Patent Application Nos. 2007/0012072 and Qualls et al. Patent Application No. 2012/0042690 disclose an LNG facility with integrated natural gas liquids (NGL). These applications are silent as to the generation of nitrogen and merchant liquid and gaseous gases.

[0014] US Patent Application No. 2008/0264099 to Mock et al. discloses LNG product and domestic natural gas product. The LNG process uses a mixed refrigerant process. The domestic gas product is defined as any gaseous predominantly methane stream originating within an LNG facility and routed to an external location prior to sale or use. Nitrogen or merchant gas, liquid or gaseous, product is not disclosed.

[0015] US Patent Application No. 2008/0271480 to Mak and US Patent Application No. 2013/0061633 to Mak et al. disclose integrated natural gas liquids (NGL) recovery and LNG liquefaction. The production of nitrogen or other industrial merchant gases, liquid or gaseous, is not disclosed.

[0016] US Patent Application No. 2010/0126186 to Marriott et al. discloses a method and apparatus for generating a gaseous hydrocarbon stream from a liquefied hydrocarbon stream useful for the starting up of a liquefaction plant. Nitrogen generation or other industrial merchant gases, liquid or gaseous, production is not disclosed.

[0017] PCT International Patent Application No. WO2013/052325 to Sethna et al. discloses a system for integration of a liquefied natural gas liquefier with the production of liquefied natural gas from a methane containing gas stream. The methane gas stream is fed through a heat exchanger to liquefy the natural gas while capturing gaseous nitrogen. The liquefied natural gas is captured and the Nitrogen gas recovered, fed through the heat exchanger to recover cold and purified. Only LNG is stored as product. Neither nitrogen nor other industrial merchant gases are produced as a product.

[0018] The present inventor recognizes that none of the aforementioned patents and applications disclose or suggest individually, or in combination, the production of LNG product, LN product, NGL product and industrial merchant liquid and gaseous product in the same plant. Typically, present manufacturers in this field either produce LNG product or merchant gas products in separate plants as represented by the aforementioned patents. The aforementioned U.S. Pat. No. 6,131,407 avoids this problem by using LNG to make the merchant gas products in an internal process and thus is less costly than the prior art plants. However, a separate plant is suggested as being needed to manufacture LNG as a product such as illustrated by the Rashad patent among others. Several of such plants may need external supplies of liquid nitrogen (LN) to make the desired merchant gas end products. The aforementioned Rashad patent discloses that separate and independent plants are needed to produce either LNG product, or the nitrogen merchant liquid product.

[0019] The present inventor recognizes that using separate plants to manufacture LNG and merchant gases such as O, N_2, and Ar is costly duplication of facilities. There are no plants presently in existence that produce both LNG product and industrial gas merchant liquid or gaseous O, Ar, and liquid and gaseous N_2 product together. This is true even though a number of companies build both LNG plants and industrial gas merchant plants as independent separate gas manufacturing plants. Air Products, Airco, Air Liquide, and Linde are examples of companies that have built both types of gas manufacturing plants as separate facilities over the past forty years. The number of plants built by just these four companies is in the hundreds.

[0020] The development of vast new quantities of natural gas made available using advanced technologies has created a large economic incentive to replace diesel fuel with compressed natural gas and LNG. The LNG industry has many facets of the business that are common to the industrial merchant gas business even though these industries have developed along separate paths. An example is the economic distances of product distribution. The economics tend to dictate that product can only be distributed in most cases for a distance of two hundred to three hundred miles before distribution costs become prohibitive. Distribution costs dictate that numerous smaller plants are required to satisfy demand in their local area. This situation is exactly the same for the industrial gas merchant liquid gases nitrogen and oxygen.

[0021] As recognized by the present inventor, in contrast to present commercial gas production plants, according to an embodiment of the present invention, is the advantage of combining the product production in one plant, such as LNG and merchant gases O_2, N_2, and Ar.

[0022] Such an advantage is most easily seen by the implementation of the nitrogen gas expansion cycle shown in FIG. 1 of U.S. Pat. No. 6,131,407. The two nitrogen gas expanders required in the LNG plant and the two nitrogen gas expanders required in a merchant gas manufacturing plant can be combined into two larger nitrogen gas expanders according to an embodiment of the present invention. Sharing this process service is recognized by the present inventor as improving the overall economics of the combined plant.

[0023] A further economic enhancement that is recognized by the present inventor is realized due to economies of scale for the larger expansion equipment. The same is especially true of a nitrogen recycle compressor, and is also true for many other pieces of process equipment.

[0024] Among the objects and advantages according to an embodiment of the present invention as recognized by the present inventor is to produce LNG and liquid nitrogen, and merchant gaseous nitrogen, liquid and gaseous oxygen, and liquid argon together in the same plant rather than in separate plants as presently done. The economic benefit of producing both products together is realized when almost all of the compression equipment, expansion equipment, cold boxes, heat exchangers, process piping systems, instrumentation, controls, electrical equipment, buildings, computers, cooling water system, utility systems, loading facilities, and like systems can be shared according to an embodiment of the present invention.

[0025] The benefit is readily apparent as recognized by the present inventor when cost estimates for the capital of the combined plant are generated. The combined plant is estimated to save from 20% to 30% or more of the capital that would be required to build a separate LNG plant and a separate merchant liquid plant as presently done in the prior art.

[0026] The savings can be realized using a number of refrigeration cycles or by using other less conventional natural gas feed sources as recognized by the present inventor. The savings also can be realized with or without the use of natural gas pipeline letdown stations. The use of letdown stations is believed to improve the power consumption of a combined plant, but the combined plant without a letdown station does not share any power advantage over two separate plants. The amount of savings will depend on the situation encountered at a particular site.

[0027] Another object and advantage of the inventive system as recognized by the present inventor is when merchant liquid tanker trucks can use LNG fuel at spigot (rack) pricing without distribution costs, and possibly also without taxes, since LNG would be produced by the same plant as a product for such use. That is, as LNG is gradually coming into use as a fuel for vehicles, the trucks that are used to transport the LNG can also be fueled by the same facility supplying the LNG at considerable cost savings. Furthermore, most of the distribution for both industries is accomplished using tanker trucks that haul product from the plant to the customer and then return to the plant for refill. Long haul trucks returning to the same location are ideally suited for using LNG fuel at the present time. This extends the range of economically viable product sales.

[0028] Another object and advantage of the inventive system as further recognized by the present inventor is realized when the LNG portion of the plant utilizes utility nitrogen liquid at spigot pricing without distribution costs, and can use common liquid nitrogen storage.

[0029] Another object and advantage of the present invention is the use of NG flash gas as a fuel gas for gas engine drivers on selected compressors and electrical generator sets. This is especially valuable if the pipeline company will not take back the NT regenerated gas. It is also valuable when using non-conventional natural gas feed sources such as purified landfill gas.

[0030] A further object and advantage realized by the present invention is product diversity. This diversity is similar to the practice of stock diversification recommended by financial advisers. LNG product is currently the more profitable product in a newer market. But this could change as more LNG becomes available in the market resulting in stiffer competition. The industrial gases, however, are in a mature market with relatively lower pricing due to stiff competition. The pricing with these products is expected to rise slowly, but will rise.

[0031] A further object is the fact that according to an embodiment of the present invention wherein both LNG and LN products can be made in a common plant facility results in both products are less costly to make and therefore are more competitive.

[0032] In another embodiment, the present inventor also recognizes that the same plant can be used to manufacture propane and butane as an additional product, referred to as natural gas liquids or NGL, as distinguished from LNG (liquid natural gas comprising substantially methane and ethane) in addition to LN (liquid nitrogen) and LNG. This results in a further saving of capital costs in building separate plants using present technology in liquefied gas plant constructions.

SUMMARY OF THE INVENTION

[0033] A system for producing liquid natural gas (LNG), and liquid nitrogen utilizing a methane rich natural gas source and an air separation unit (ASU) to produce merchant gases according to an embodiment of the present invention comprise an LNG generator including at least one heat exchanger responsive to applied processed pipeline natural gas for producing liquid natural gas; a nitrogen liquefaction section for liquefying nitrogen received from the ASU; a liquid nitrogen storage unit and an LNG storage unit;

[0034] a first control valve for applying a predetermined amount of LNG in a selected first portion of the produced LNG to the LNG storage unit as product; and a second control valve for applying a second portion of the produced LNG by the LNG liquefaction generator to the nitrogen liquefaction section for assisting in the liquefaction of nitrogen as determined by the selected first portion amount; the liquefaction section for assisting in the production of the merchant gases as products by the ASU; and

[0035] a third control valve for applying liquid nitrogen from the liquefaction section to the liquid nitrogen storage unit for storing the liquefied nitrogen as product.

[0036] the LNG generator is arranged to be responsive to applied pressurized nitrogen and includes a nitrogen gas expansion arrangement for causing the pressurized nitrogen to produce refrigeration to assist in liquefying the natural gas into LNG in the LNG generator.

[0037] In a further embodiment, a nitrogen feed compressor is responsive to nitrogen gas fed from the ASU to provide compressed nitrogen to the LNG generator.

[0038] In a further embodiment, a compander is provided for supplying compressed and then expanded natural gas (NG) to the LNG generator.

[0039] In a further embodiment, the LNG generator includes a control valve and separator for producing vaporized low pressure and flashed natural gas and including a bank of heat exchangers for heating to ambient temperature the flashed natural gas passed through the heat exchangers and at least one compressor for compressing the passed natural gas to pipeline pressure.

[0040] In a further embodiment, an arrangement is included for recovering medium and low pressure nitrogen from the liquefaction section and recycling the recovered nitrogen through compression into the LNG generator.

[0041] In a further embodiment, the LNG generator includes a bank of heat exchangers, the arrangement for recovering nitrogen includes a series of compressors for sequentially compressing the nitrogen and for then selectively applying the compressed nitrogen to the LNG generator to selected ones of the heat exchangers.

[0042] In a further embodiment, a series of expanders are included each for expanding the compressed nitrogen applied to a different one of the selected ones of the heat exchangers.

[0043] In a further embodiment, the LNG generator produces liquid natural gas LNG wherein the liquid is produced by a series of nitrogen expanders and a series of nitrogen compressors for generating nitrogen refrigeration to assist in the production of the LNG.

[0044] In a further embodiment, the nitrogen liquefaction section comprises a bank of heat exchangers, a compressor arrangement and a gas flash arrangement for recycling nitrogen gas supplied by the ASU through the heat exchangers for the liquefying of the nitrogen in cooperation with the liquefied natural gas and for selectively feeding the liquefied nitrogen to a selected one or both of the ASU and nitrogen storage unit.

[0045] In a further embodiment, the nitrogen liquefaction section cooperates with the ASU for generating liquid nitrogen.

[0046] In a further embodiment, the nitrogen liquefaction section comprises a series of heat exchanger, a separator, and at least one nitrogen gas flash valve which cooperates with the ASU to produce liquid nitrogen.

[0047] In a further embodiment, a letdown station is in the pipeline to assist in reducing power required and for providing refrigeration to the LNG liquefaction generator.

[0048] In a further embodiment, a cooling heat exchanger is included comprising an ammonia refrigerant and an expander for expanding and cooling the natural gas output of the cooling heat exchanger coupled to the LNG generator.

[0049] In a further embodiment, the LNG generator comprises a series of nitrogen expanders for cooling nitrogen gas applied to a cascaded series of heat exchangers in the LNG generator.

[0050] In a further embodiment, the ASU supplies nitrogen to a series bank of compressors whose output of compressed nitrogen is applied to a series bank of heat exchangers in the LNG generator.

[0051] In a further embodiment, the LNG generator comprises a series of nitrogen expanders for cooling nitrogen gas applied to a cascaded series of heat exchangers in the LNG generator, the expanders comprising corresponding companders forming the compressors.

[0052] In a further embodiment, the LNG generator includes at least one expander and at least one cooling heat exchanger comprising an ammonia refrigerant for cooling at least one of nitrogen and natural gas.

[0053] In a further embodiment, the LNG generator includes at least one expander for expanding natural gas for cooling natural gas in the generator and at least one cooling heat exchanger comprising an ammonia refrigerant for cooling nitrogen gas used to cool the natural gas in the generator.

[0054] In a further embodiment, the LNG generator includes at least one expander for expanding and cooling natural gas applied thereto.

[0055] In a further embodiment, the system includes at least one nitrogen expander for expanding nitrogen gas applied thereto.

[0056] In a further embodiment, the system includes at least one natural gas expander for expanding recycled natural gas applied thereto.

[0057] In a further embodiment, the LNG generator further includes at least one natural gas expander and at least one nitrogen gas expander.

[0058] In a further embodiment, the LNG generator utilizes at least one ammonia gas refrigeration cooler, a nitrogen gas refrigeration cooling system and a mixed gas cooling refrigeration system.

[0059] In a further embodiment, a system is provided utilizing a source of a methane rich natural gas for producing 1) liquid natural gas (LNG), 2) natural gas liquids (NGL) predominately comprising propane and butane and heavier hydrocarbons, 3) liquid nitrogen and 4) an air separation unit (ASU) to produce merchant gases. The system including an arrangement for producing NGL product from the applied processed source of natural gas and for storing the NGL in a NGL storage unit.

[0060] In a further embodiment, the LNG generator includes a control valve and separator for producing vaporized low pressure and flashed natural gas and including a bank of heat exchangers for heating to ambient temperature the flashed natural gas passed through the heat exchangers whereby the passed natural gas can be partially or completely fed to an electrical generator set to generate electricity.

BRIEF DESCRIPTION OF THE DRAWING

[0061] FIGS. **1***a* and **1***b* illustrate a first embodiment comprising a process flow diagram of a liquefaction refrigeration system to liquefy natural gas, nitrogen and selected merchant gases without a letdown station and includes a generator for generating liquid natural gas LNG, a liquefaction section for generating liquid nitrogen (LN) and an air separation unit (ASU) for generating merchant gases such as liquid argon LAR, gaseous and liquid oxygen GOX, LOX and gaseous nitrogen GAN products.

[0062] FIGS. **2***a* and **2***b* illustrate a second embodiment of the present invention comprising a process flow diagram similar to that of FIGS. **1***a* and **1***b* with a letdown station illustrating an LNG generator, a liquid nitrogen (LN) liquefaction section for generating LN and an air separation unit (ASU) for generating merchant gas products LAR, GOX, LOX, and GAN products, utilizing two after cooling units and an expander in a LNG heat exchanger bank and one high pressure compressor and one low pressure compressor with associated cooling units using ammonia refrigerants;

[0063] FIGS. **3***a* and **3***b* illustrate a third embodiment of the present invention comprising a process flow diagram similar to that of FIGS. **1***a* and **1***b* illustrating a LNG generator, an LN liquefaction section and an ASU for generating liquid and gaseous industrial merchant gas products LAR, LAX, LOX and GAN utilizing four N_2 compressors in a N_2 feedback cycle and three expanders for the LNG generator;

[0064] FIGS. **4***a* and **4***b* illustrate a fourth embodiment of the present invention comprising a process flow diagram similar to that of FIGS. **1***a* and **1***b* illustrating a LNG generator, an LN liquefaction section and an ASU for generating liquid and gaseous industrial merchant gas products utilizing a similar feedback cycle as in FIGS. **3***a*, **3***b* and three expanders and two compressors for the LNG recycling for use with the LNG generator, all of the aforementioned embodiments using a similar nitrogen liquefaction section for generating LN;

[0065] FIGS. **5***a*, **5***b* and **5***c* illustrate a fifth embodiment of the present invention comprising a process flow diagram illustrating the LNG generator of FIGS. **4***a* and **4***b*, including an ASU for generating LN and liquid and gaseous industrial merchant gas products, using a nitrogen liquefaction section having a different feedback cycle using the ASU for nitrogen refrigeration;

[0066] FIGS. **6***a* and **6***b* illustrate a sixth embodiment, comprising an LNG generator having a cascaded set of five heat exchangers, three separator units, six ammonia refrigerant after coolers and an expander for generating LNG, a nitrogen liquefaction section for generating LN, and an ASU for generating liquid nitrogen LN and for generating liquid and gaseous industrial merchant gas products, using three refrigerants, ammonia, nitrogen and a mixed refrigerant in respective three closed refrigeration systems; and

[0067] FIGS. **7***a* and **7***b* illustrate a seventh embodiment, including an LNG generator comprising a cascaded set of five heat exchangers, six ammonia refrigerant after coolers, two separator units, a distillation unit, a pump and two expanders, a separate nitrogen liquefaction section for generating LN, an arrangement for generating natural gas liquid (NGL) products, and an ASU for generating liquid nitrogen LN and liquid and gaseous industrial merchant gas products.

DETAILED DESCRIPTION

[0068] In the various figures, the source of natural gas is shown as a pipeline. However, this is by way of illustration and not limitation. It should be understood that natural gas source may be in any form such as a landfill or any other source of non-pipeline source of methane rich natural gas. In FIGS. **1***a* and **1***b*, system **15** is of relatively lower cost than the other embodiments disclosed herein. There are no natural gas NG expanders and no ammonia refrigeration units to provide added cooling as in these other embodiments. System **15** provides only nitrogen refrigeration. A letdown station could optionally be used in this embodiment. If a letdown station is used, it reduces the output pipeline pressure. Thus, there may be no need to compress the gas being returned to the relatively high pipeline pressure as without a letdown station. This saves power.

[0069] System **15** utilizes two nitrogen (N_2) expanders in the LNG generator and three N_2 feed compressors according to an embodiment of the present invention. FIGS. **1***a* and **1***b* are related and illustrate a single system wherein the same Roman numerals of the two figures identify common interconnected gas transmission lines. A similar notation of common lines in a single system depicted by multiple figures is used in the remaining figures. Parts in the different figures with the same reference numerals comprise identical components. However, it should be understood that while the components may be identical in structure, the refrigerants and gases being processed by such components may differ.

[0070] In FIGS. **1***a* and **1***b*, an incoming stream **12** of natural gas (NG) is diverted from pipeline **11** to pipeline **10**. This stream is conventional and may comprise any combination of gases including methane, butane, propane, CO_2 and heavier hydrocarbons as known in this art. The pipeline NG stream may typically comprise 80% to 95% methane, and lesser, but different amounts of the other gaseous products. The stream **12** is under high pressure, typically 350 to 1000 psia, but in this case by way of example, may be at a pressure of about 715 psia and at ambient temperature, assumed to be generally at about 70° F. All temperatures given hereinafter will be in ° F. All temperatures and pressures given herein are approximate and could vary as would be understood by one of ordinary skill. The input pressure could be lower, especially if the natural gas is being fed from a sub-main, but is assumed to be 715 psia for illustrative purposes only. An optional letdown station **13**, shown in phantom, is not present in this embodiment. However, a letdown station could be used in this embodiment if available. If the pipeline pressure is 100 psia, for example, then a feed compressor will be needed to raise the pressure. The pipe **10** downstream from the stream in pipeline **11** may have a slightly reduced pressure stream **14** of about 714 psia or lower. With respect to the various heat exchangers in the different figures, some are shown with a different number of flow channels. However, the exchangers with the same reference numerals are the same in construction with the different channels shown representing only the flow channels in use in that particular embodiment. This is only a matter of simplicity of illustration. If a different smaller heat exchanger is desired needing fewer gas flow channels, then one of ordinary skill could provide the same in the interest of cost savings.

[0071] Natural gas NG, which may comprise methane and other gases and/or fluids of different components as discussed above, for a specific customer or group of customers is withdrawn from the pipeline **11** at stream **12**. The gas continues along the pipe **10** to outlet **90**. The natural gas flows from stream **12** into NG liquefaction system **15** via stream **16**. The natural gas diversion starts with stream **12**. Stream **16** feeds into a first conventional process separator **17** which removes any undesirable liquids in the natural gas stream **16**. Vapor from the first process separator **17** passes to a conventional moisture adsorption system comprising dryers **18**. The dryers **18** remove moisture and CO_2 from the incoming natural gas stream **16'**. The two dryers **18** represent one dryer with two drying beds, which beds can be switched so that the stream from separator **17** can be applied to either dryer bed depending upon which of the dryers **18** is regenerated and which dryer has its bed being loaded with moisture and CO_2 from the incoming stream **16'**. This switching action is represented by the dashed lines showing that either of dryers **18** may be used in the incoming stream and the other in the return regeneration NG stream **74'** in the regeneration mode.

[0072] Stream **74** at the output of compressor **73** and its associated after cooler **73'** (all such after coolers may use cooling water as a refrigerant as known in this art) is returned to the selected dryer **18** from the NG refrigeration system generator **91** (FIG. **1***b*) and, therefore, is dry natural gas free of CO_2. The dryer **18** having output stream **74'** is being regenerated, while the other dryer **18** having output stream **19**, is drying the incoming gas stream **16'** from separator **17**. One of the dryers **18** is regenerated at a time by the gas, stream **74**, returning from compressor **73** and its associated cooler **73'**. Stream **71** from the liquefaction section **55** and stream **72** from the generator **91** are combined and inputted into compressor **73**. If stream **74** has insufficient flow to properly regenerate dryer **18**, then a small natural gas slip stream (not shown) is taken from dryer **18** discharge, flashed, and combined with stream **74** to make sufficient flow for proper dryer regeneration.

[0073] While removing the $C0_2$ at ambient temperature by dryers **18** requires relatively large adsorbers and more energy, it does not waste refrigeration, which tends to be in short supply in most applications of this technology.

[0074] The dryers **18** selectively remove moisture and CO_2 from the natural gas depending upon which one is in the incoming stream **16'** to prevent hydrate formation and frozen CO_2 when the natural gas is cooled later in the cycle. Mercaptans used to impart an odor to the natural gas are also selectively removed in the incoming stream **16'** and corresponding dryer **18** as are aromatic hydrocarbons.

[0075] After drying by the selected dryer **18**, the natural gas stream **19** is fed directly into a first heat exchanger **20** in liquid natural gas (LNG) generator **91**, FIG. **1***b*. Generator **91** comprises a series bank of heat exchangers **20**, **21** and **22**, expanders **23** and **24** having respective corresponding compressors **23'** and **24'** (FIG. **1***a*), control valve **25** and separator **26**. The heat exchanger **20**, as are all of the heat exchangers disclosed herein, are compartmentalized with isolated fluid channels represented by the udulating lines depicted in each heat exchanger block. These lines represent separate gas flow channels for fluid isolating the different gases flowing through the heat exchangers from each other so that the only coupling of the gases in a heat exchanger is by thermal heat transfer from gas to gas.

[0076] Natural gas stream **19**, FIG. **1***b*, at about 700 psia and ambient temperature, is fed into the respective bank of heat exchangers **20**, **21** and **22** for liquefaction to about −205° F., stream **19'** The substantially liquefied gas is fed to separator **26** through control valve **25** where the gas is flashed to about 20 psia. The liquefied NG stream **28** at about −251° F. is outputted from the separator **26** and fed through control valves **27** and **29**. A predetermined calculated portion of the LNG is passed through the valve **27** to storage tank **92**.

[0077] After stream **19** is chilled in the first heat exchanger **20** and further chilled in the second and third heat exchangers **21** and **22**, the temperature of the resulting stream **19'** is approximately minus 205° F. and, when throttled by control valve **25** results in a stream **19"** having about 80% liquefied natural gas (LNG) which could differ according to a given implementation. This mixed phase stream **19"** is inputted to the separator **26**. The cold gas and liquid (LNG) are separated by separator **26**. Pressure level of the stream **19"** may be varied, but in this example the pressure is kept at about 20 psia, and at a temperature of approximately minus 251° F. The LNG from the separator **26**, stream **28**, is fed into the heat exchanger **30** in nitrogen liquefaction section **55** through control valve **29** as stream **71'**. Stream **71'** is at about −254° F. and about 18 psia.

[0078] The calculated portion of the LNG gas, stream **28**, fed to valve **29** is determined by the setting of control valve **27**. Separator **26** may be elevated to provide a gravity induced pressure head forcing the LNG product into tank **92** via valve **27**, or the LNG may be pumped by a pump (not shown) into tank **92** via valve **27**. This amount is important as it is set to pass a predetermined amount of LNG through the valve **29** to the liquefaction section **55**. The amount of LNG fed to the liquefaction section **55** is that value that will result in the production of the predetermined desired amount of liquid nitrogen to be produced by the liquefaction section **55**, the amount of nitrogen produced depending upon the amount of refrigeration available from the supplied LNG. The LNG is used as a major assist in the generation of liquid nitrogen LN by section **55**. The amount of LNG fed to the section **55** is calculated to produce a given amount of LN by section **55** in combination with the other aspects of the section **55** refrigeration elements used together with the LNG to generate the LN.

[0079] The remaining portion of the LNG not passed to section **55** is fed to the tank **92** for storage via valve **27**. The LNG in tank **92** is then removed as product at output **93** for transportation, typically by tanker trucks (not shown). Such trucks if fueled by LNG could also be fueled at output **93** also for efficient use of the LNG available. Stream **72'** is outputted by separator **26** in the generator **91** as flash natural gas from the valve **25**, which is then fed through the bank of respective heat exchangers **22**, **21** and **20** for cooling of incoming NG stream **19** forming warm output stream **72** at about 70° F. and at about 15 psia. Thus stream **72'** from the separatort **26** assists in the cooling of stream **19** in combination with other streams applied to the heat exchangers of generator **91** as discussed below.

[0080] In FIG. **1***a*, NG stream **72** is combined with NG stream **71**, also at 70° F. and 15 psia, from heat exchanger **30**, FIG. **1***b*, in the liquefaction section **55**, whose input is LNG stream **71'**. The stream **72** outputted by heat exchanger **20** of LNG generator **91**, FIG. **1***b*, is combined with warm NG stream **71**, FIG. **1***a*, and applied to compressor **73** and its associated cooler **73'** forming stream **74**. Stream **74** is applied to a selected dryer **18** for regeneration of that dryer forming stream **74'**, which is returned to the input stream **14** through booster compressor **75** and its associated cooler **75'** as output stream **76**. Compressor **75** matches the pressure of the output stream **74'** of the selected dryer **18** to that of pipeline stream **14** and may or may not be necessary depending upon whether a letdown station **13** is employed. The natural gas stream exiting compressor **75** (if required) can be partially or completely diverted to an electrical generator **755** through line **754**.

[0081] In FIG. **1***b*, the liquefaction section **55** is substantially the same in FIGS. **2***b*, **3***b* and **4***b* and thus the description of section **55** in FIG. **1***b* is representative. The liquefaction section **55** comprises a series coupled bank of heat exchangers **30**, **31** and **32**, separator **34**, a throttling control valve **35** between LN stream **45'"**, at about 84 psia and about −287° F., outputted from separator **34** and stream $\mathbf{45_3}$**'"**, at about 19 psia and about −316° F., applied as an input to heat exchanger **32** and a second control valve **36** having an input stream $\mathbf{45_4}$**'"** at about −314° F. that outputs liquid nitrogen LN at stream **37** at about −318° F. The separator **34** separates the vapor-liquid stream, forming nitrogen stream **45"** and vapor stream **39'**.

[0082] In FIG. **1***a*, stream **45**, the stream formed from compressed stream **43** merged with stream **45'**, is applied to heat exchanger **30** of the liquefaction section **55**, FIG. **1***b*, at about 410 psia. In FIG. **1***b*, Nitrogen stream **45**, to be cooled from about 85° F., is applied as an input to the cascaded series of respective heat exchangers **30** and **31** and outputted from exchanger **31** as stream **45"**. Stream **45"** is applied to separator **34** via flash control valve **33**. Separator **34** outputs the cooled nitrogen stream **45'"**, which is divided into streams $\mathbf{45_1}$**'"** and $\mathbf{45_2}$**'"**. These streams are applied respectively to heat exchanger **32** and flash control valve **35**. The valve **35** output stream $\mathbf{45_3}$**'"** and is inputted to heat exchanger **32** for further cooling of stream $\mathbf{45_1}$**'"**. The heat exchanger **32** output stream $\mathbf{45_4}$**'"**, which comprises the cooled input stream $\mathbf{45_1}$, is passed through flash control valve **36** and applied to storage tank **50** as liquid nitrogen LN product, stream **37**. The LN product is withdrawn from the tank **50** via outlet **51**.

[0083] The separator **34** of liquefaction section **55**, FIG. **1***b*, receives the flash vapor from valve **33** outputting it as stream **39'** applied to the respective series cascaded respective heat exchangers **31** and **30**. whose output is warmed nitrogen gas stream **39** merged with stream **41**, FIG. **1***a*.

[0084] In FIG. **1***b*, the heat exchanger **31** nitrogen input stream **38"**, i.e., the output of exchanger **32**, is applied as an input stream to heat exchanger **31**. Stream **38"** applied to the respective series of exchangers **31** and **30** is outputted from heat exchanger **30** as warmed nitrogen stream **38**. The stream **38"** output of exchanger **32** is inputted to exchanger **32** as nitrogen stream $\mathbf{45_3}$**'"** via valve **35** as cold flash gas at about −316° F. with some liquid and vapor at about 19 psia.

[0085] Air separation unit **65**, FIG. **1***a*, outputs nitrogen stream **46** (from a nitrogen plant or oxygen plant) which combines with nitrogen stream **41** as a nitrogen input to feed compressor **42**, at 70° F. 79 psia, forming stream **41'**. Stream **41'** applied to serial bank of respective compressors **42**, **23'**, **24'** and corresponding coolers **42'**, **23"** and 24", which output high pressure warm nitrogen stream **43** at 410 psia and 85° F. The compressors **23'** and **24'** are associated with expanders **23**, **24** and may be companders (compressor/expanders, typically one unit). Stream **43** is divided into two nitrogen streams **45'** and **45**.

[0086] Stream **45'**, FIG. **1***b*, is inputted into heat exchanger **20** of the LNG generator **91**. The heat exchanger **20** output stream is split into two streams $\mathbf{45_1}$ and $\mathbf{45_2}$ each at about 396 psia and about −50° F. Stream $\mathbf{45_1}$ is applied to expander **23** and stream $\mathbf{45_2}$ is applied to heat exchanger **21** for further cooling. The output nitrogen stream of expander **23** is at about

83 psia and about −182° F. The nitrogen stream **45**$_3$ output of heat exchanger **21** at about 395 psia and about −120° F. is applied to expander **24** whose output is stream **45**$_4$ is about 84 psia and about −230° F. Stream **45**$_4$ is inputted into the series bank of respective heat exchangers **22**, **21** and **20** for cooling the NG input stream **19**, and outputted as warm nitrogen at about 70° F., stream **44**. In FIG. **1***a*, stream **44** is combined with nitrogen streams **39** and **40** to form stream **41**, which is at about 70° F. and at about 79 psia.

[0087] In the liquefaction section **55**, FIG. **1***b*, high pressure warm nitrogen stream **45**, at about 85° F. and about 410 psia, is applied to the series of cascaded respective bank of heat exchangers **30**, **31** for cooling. The cooled stream **45** exits exchanger **31** as output stream **45"** at about −255° F. Stream **45"** is applied to separator **34** through control valve **33** as flash gas at about 84 psia and further cooled by valve **33** to about −287° F. The output stream **45'"** of separator **34** is split into two streams **45**$_1$**'"** and 45$_2$'". Stream **45**$_1$**'"** is applied as an input to heat exchanger **32** which is further cooled by stream **45**$_2$**'"** applied to heat exchanger **32** in a reverse direction as stream **45**$_1$**'"** through flash control valve **35** and at about 19 psia and about −316° F.

[0088] The cold output vapor stream **39'** of separator **34** is applied as an input to the respective cascaded heat exchangers **31**, **30** to provide cooling to the inputted nitrogen stream **45** applied to the heat exchangers in the reverse direction as stream **45**, producing stream **45"**. The stream **39'** exits these heat exchangers as stream **39**, which is combined with stream **44** as discussed above to form stream **41** applied to compressor **42**, FIG. **1***a*.

[0089] Nitrogen stream **45**$_2$**'"** derived from separator **34** output stream **45'"** is applied as an input to heat exchanger **32** through valve **35** forming stream **45**$_3$**'"** applied to the bank of heat exchangers **32**, **31** and **30** in a direction opposite to the fed direction of stream **45**. The output of exchanger **30** is stream **38**. In FIG. **1***a*, stream **38** is compressed by compressor **54** and cooled by its associated cooler forming stream **40** which is merged with streams **39** and **44** forming stream **41**.

[0090] In FIGS. **1***a* and **1***b*, nitrogen, N_2, from compressor **24'**, stream **45'**, at about 85° F. and 410 psia, is inputted to heat exchanger **20** of LNG generator **91** for cooling to about −50° F. 396 psia. The nitrogen output stream from exchanger **20** is split into two streams **45**$_1$ and **45**$_2$. Stream **45**$_1$ is applied to expander **23**, which cools the gas to about −182° and at about 83 psia, stream **44'**. The stream **44'** is fed to the cascaded bank of respective heat exchangers **21** and **20** in a direction opposite to stream **45** to be cooled'. Stream **44'** is outputted from exchanger **20** as stream **44** and is combined with stream **39**, forming stream **41** applied to compressor **42** of the bank of series compressors, FIG. **1***a*.

[0091] The output stream **45**$_3$ from exchanger **21**, formed from exchanger **21** input stream **45**$_2$, is applied to expander **24**. Expander **24** output stream **45**$_4$ is cooled by the expander **24** to about 84 psia and −230° F. This stream is then applied to the respective bank of heat exchangers **22**, **21** and **20** for cooling the NG input stream **19** applied to the heat exchangers in the opposite feed direction. The degree of cooling of streams **45**$_1$ and **45**$_3$ is a function of the pressure ratio and flow through expanders **23** and **24**.

[0092] Freezing of the stream **45**$_4$ should not interfere with throughput through the plant, since the CO_2 which might freeze and thus cause such interference has been removed by dryer **18**.

[0093] In FIG. **1***b*, the output stream **45**$_4$ of the expander **24** is inputted into heat exchanger **22** for cooling stream **19**. Exchanger **22** output stream **45**$_5$ is combined with expander **23** output stream **44'** and applied as an input into respective heat exchangers **21** and **20** for cooling respective streams **19**, **45'** and **45**$_2$.

[0094] The energy recovered from expanding the nitrogen gas in expanders **23** and **24** can be used to drive an electric generator brake (not shown). As shown, use of this energy drives a compression brake, compressors **23'** and **24'** on the expanders **23** and **24**, rather than an electric generator brake. A compression or generator brake could be substituted with a compander such as expander **24** and compressor **24'**. The compander as nitrogen compressors **23'** and **24'**, saves nitrogen compression energy. Placement of such a compander could be at stream **43'**, or stream **45** applied to nitrogen liquefaction section **55**.

[0095] In FIG. **1***a*, in this example, the pressure levels only require compression of stream **38** by compressor **54** and forming stream **40** applied to stream **44** forming stream **41**. However, with other systems, compression of both streams **38** and **39** may be required.

[0096] The air separation unit (ASU) **65**, FIG. **1***a*, can either be a conventional nitrogen plant, common in the industrial gas industry; or it can be a common known oxygen plant that produces merchant gases such as gaseous oxygen (GOX) and gaseous nitrogen (GAN), respective streams **63** and **61**, or liquid oxygen (LOX), stream **62**, or liquid argon (LAR), stream **64**. The air separation unit (ASU) **65** can be a self-supported plant from a refrigeration standpoint with one or more expanders providing the refrigeration. It could also be optionally liquid assisted from the liquefaction section **55** with liquid nitrogen as represented by the dashed lines **52** (input stream **45**$_4$**'"**). Stream **53** (dashed line) is merged in this case with stream **38** to provide the nitrogen to the LNG generator for assisting in the generation of the LNG.

[0097] For all embodiments, if the ASU **65** is a nitrogen plant, i.e., medium pressure nitrogen, stream **46** is employed to feed the nitrogen liquefaction section **55**. Gaseous nitrogen product stream **61** is also possible from a nitrogen ASU **65**. Streams **62** (liquid oxygen), **63** (gaseous oxygen) and **64** (liquid argon) would not be employed then. If the ASU is an oxygen plant, streams **61** (gaseous nitrogen), **62**, **63** and **64** are all possibly employed. The nitrogen liquefaction section **55** will be fed from low pressure nitrogen stream **53**, and may or may not also be fed from the nitrogen stream **46**.

[0098] If the air separation unit **65** is a nitrogen plant, the pressure of nitrogen stream **46** will vary between approximately 25 psia to 130 psia. If the air separation unit **65** is an oxygen plant producing nitrogen and argon as well as oxygen, the nitrogen of stream **46** will be close to 84 psia. In either case, the nitrogen stream **46** exiting the air separation unit **65** is compressed by compressors **42**, **23'** and **24'** and thereafter cooled and liquefied by the LNG generator **91** and by the nitrogen liquefaction section **55**. It should be understood that various valves in the fluid system for directing or closing off fluid streams are not shown for clarity of illustration.

[0099] Streams **62** and **64** preferably respectively represent liquid oxygen and argon exiting the air separation unit **65** after they have been optionally cooled by the nitrogen liquefaction system **55**. In the alternative, such streams may be created by internal ASU refrigeration. Any combination of streams **61**, **62**, **63** and **64** may be withdrawn from the separation unit **65**. In the example shown, an 80 ton per day air separation unit **65** is designed to produce 80 tons per day of liquid oxygen, 200 tons per day of liquid nitrogen and approximately 4 tons per day of liquid argon. All the refrigeration in this example is generated by the nitrogen liquefaction system **55** when optional stream **52** is employed.

[0100] It should be understood, that in the various figures herein, the number and positions of separators is given by way of example. There may be more or fewer such separators. Further, the particular number, configuration and position of heat exchangers is also by way of illustration. As shown in others of the figures below, a heat exchanger may be arranged to process a number of separate gases in different channels thereof. There may be more or fewer heat exchangers in the embodiment of FIGS. **1***a* and **1***b* for a given set of functions. A single heat exchanger performing multiple stages of heat exchange is contemplated, the multiple separate heat exchangers in FIGS. **1***a* and **1***b* being given by way of example. The above possible variations in the number and position and configuration of the heat exchangers is intended to be applicable both for natural gas liquefaction as well as the liquefaction processing of the merchant gas such as nitrogen and so on.

[0101] In the above process, it is important that the CO_2 be removed from the stream of natural gas. Keeping the CO_2 in the entire natural gas stream during liquefaction of the natural gas results in the freezing up of the CO_2 and clogging of separators and so on resulting in a non-workable system. The dryers **18** remove 1 to 1.5% CO_2. If the CO_2 content for the natural gas feed goes above 1 to 1.5% CO_2, then an additional CO_2 removal system would be employed (not shown).

[0102] FIGS. **2***a* and **2***b*, illustrate a letdown liquefaction system **15'** utilizing air separation unit (ASU) **65** and nitrogen liquefaction section **55**, which as noted above, is identical to section **55**, FIG. **1***b*. In this embodiment, letdown station **13** is utilized. This station reduces the pressure on line **12** to a substantial degree of more or less 200 psia by way of example. This assists in providing supplemental refrigeration over the FIG. **1***a*, **1***b* embodiments with no letdown station. As a result, more product can be produced due to the added refrigeration ability assuming a constant power utilization.

[0103] In FIG. **2***a*, stream **74** at the output of compressor **73** and its associated cooler **73'** (a heat exchanger) as shown in FIG. **1***a* is combined with stream $\mathbf{19}a_3$, the output stream of compressor **223'** and its associated cooler **223"**, to form stream $\mathbf{74}_1$. This stream is returned to the selected dryer **18** from the NG refrigeration system generator **91'** (FIG. **2***b*) and, therefore, is dry natural gas free of CO_2. As shown, one dryer **18** is being regenerated, while the other dryer **18** is drying the incoming gas from separator **17** via stream **16'**.

[0104] Oxygen gas from an oxygen plant could be substituted for nitrogen gas in these examples. While use of this gas is possible and falls within the scope of the claims appended hereto, it has not been illustrated because of its limited use due to safety concerns with processing natural gas and oxygen together in the liquefaction system **15'**. The liquefaction of air is also possible within the scope of the claims appended hereto with liquid air assist to the air separation unit, but it also has not been shown for the same reasons as oxygen.

[0105] In FIGS. **2***a* and **2***b*, the nitrogen liquefaction section **55** is identical to section **55** of FIG. **1***b*. In FIG. **2***a*, letdown station **13** reduces the pipeline pressure to about 200 psia. Dryers **18** are selectively regenerated by the gas, stream $\mathbf{74}_1$, returning from compressors **23'** and **73** and their associated coolers. Stream **71** from the liquefaction section **55** and stream $\mathbf{72}_1$ from the LNG generator **91'** are combined and inputted into compressor **73**.

[0106] After drying by the selected dryer **18**, the natural gas stream **19** is fed directly into a first heat exchanger **20** in liquid natural gas (LNG) generator **91'**, FIG. **2***b* Generator **91'** comprises the series bank of heat exchangers **20**, **21** and **22**, expander **223** having the above noted respective corresponding compressor **223'** (FIG. **1***a*), control valve **25**, separator **26** and coolers **230** and **231**.

[0107] Natural gas stream **19**, FIG. **2***b*, at about 700 psia and ambient temperature of about 75° F., is divided into two stream portions **19***a* and **19***b*, with both stream portions being fed into heat exchanger **20** for cooling. Stream portion **19***a* is fed through ammonia refrigeration cooler **230** for providing additional cooling to about −20° F. and about 695 psia and then expanded at expander **223** forming stream $\mathbf{19}a_1$. Both the cooler **230** and expander **223**, FIG. **2***b*, are not utilized in the prior embodiment, but the cooler **230** could be utilized if desired. Ammonia refrigerant gas for this cooler and cooler **231** is used in this embodiment, but other refrigerants such as R-134a could be substituted for the ammonia. This stream $\mathbf{19}a_1$ is further cooled to about 60 psia and about −185° F. and fed to heat exchangers **21** and **20** in the opposite direction of stream **19***a*. This stream exits heat exchanger **20** as stream $\mathbf{19}a_2$, which in turn is fed to compressor **223'**, FIG. **2***a*. The output stream $\mathbf{19}a_3$ of compressor **223'** and its associated cooler **223"** is at about 115 psia and ambient temperature.

[0108] Portion **19***b* of stream **19** is fed to heat exchanger **20** and, upon exiting this exchanger, is applied to exchanger **21** through cooler **231** as stream $\mathbf{19}b_1$, exiting cooler **231** at about −20° F. Upon exiting heat exchanger **21**, stream **19***b***1** is fed to exchanger **22** whose output stream $\mathbf{19}b_2$ is inputted into separator **26** through control valve **25**, where the gas is flashed. The separator **26** outputs a liquefied NG stream $\mathbf{19}b_3$ at 20 psia, and −251° F. The liquefied NG stream $\mathbf{19}b_3$ is fed to control valve **27** and fed as stream **28** through control valve **29** as discussed above in connection with FIGS. **1***a* and **1***b*.

[0109] In FIG. **2***a*, NG stream **71**, from heat exchanger **30** from the liquefaction section **55**, FIG. **2***b*, is processed similarly as stream **71**, FIG. **1***a*. The stream $\mathbf{72}_1$ outputted by heat exchanger **20** of LNG generator **91**, FIG. **1***b*, is combined with warm NG stream **71** forming stream **74** at the output of compressor **73** and its associated cooler **73'**. Compressor **75**, which may be optional, matches the pressure of the output stream $\mathbf{74}_2$ of the selected dryer **18** to the lower pressure of pipeline stream **14'**, if necessary.

[0110] The ASU **65** outputs nitrogen N_2 stream **46**. However, liquid nitrogen N_2 stream **52** at about 82 psia and −314° F. is applied to the ASU from the liquefaction section **55**, shown only as optional in the embodiment of FIGS. **1***b* and **1***a* via the phantom line in these figures. The ASU **65** also outputs nitrogen stream **53** at about 15 psia also optional in the FIG. **1***a* embodiment. The liquefaction section **55** outputs N_2 streams **38** and **39** (FIG. **2***a*) from similar structures as in FIG. **1***b* as discussed previously. Stream **45**, FIG. **1***a*, which is outputted from the LNG generator **91** is changed to stream **45***a***1**, FIG. **2***a*. This stream is applied to section **55** heat exchanger **30** similarly as stream **45**, FIG. **1***b*. Stream **38**, FIG. **2***a*, is fed to compressor **54** and its associated cooler **54'** forming stream **40** as in FIG. **1***a*. The compressor **54** output stream is at about 200-280° F. whereas the output stream of its cooler **54'** is at about 85° F. Stream **40**, the output of compressor **54** and its associated cooler **54'**, is combined with stream **46** to form stream **41'**, which is fed to compressor **42** and its associated cooler **42'** forming stream **45*a*1**. The output stream **45*a*1** is at about 410 psia. The valve **29**, FIG. **2*b***, and the surface area of heat exchanger **30** determines the amount of nitrogen that can be liquefied. The liquefied nitrogen LN is stored in tank **50**.

[0111] FIGS. **3*a*** and **3*b*** are a further embodiment, which is a variation of the embodiment of FIGS. **1*a***, **1*b*** and **2*a***, **2*b***, in that both nitrogen and natural gas are utilized for cooling the NG in LNG generator **91"**. No letdown station is used. (Letdown station **13** is shown with dashed lines as optional) In this embodiment more refrigeration is needed to increase the output volume of product as compared to the FIGS. **1*a*** and **1*b*** embodiment. The output can be several hundred tons per day of LNG and LN. The letdown station, if present, helps with reducing the power needed. Ammonia cooler **230**, FIG. **3*b***, provides the additional refrigeration desired.

[0112] Liquefaction section **55'** is substantially similar to section **55** of FIGS. **1*b*** and **2*b***, wherein heat exchanger **30** receives the LNG stream **71'** for cooling, which is at −254° F. and about 18 psia as in the FIG. **1*b*** embodiment. The output streams **71**, **38** and **39**, FIG. **3*b***, are substantially as described with the prior embodiments. Nitrogen input stream **145'** fed into section **55** heat exchanger **30** from the LNG generator **91"** (FIG. **3*b***) corresponds generally to nitrogen stream **45** of the prior embodiments, but is processed differently.

[0113] Stream **46** (N_2) from ASU **65** is applied to the series bank of three compressors **42**, **23'** and 24', FIG. **3*a***, as in FIG. **1*a***. The output stream **145** of the compressor **24'** associated cooler **24"** is split into two streams **145'** and **145"**. Stream **145"**, FIG. **3*a***, is applied to the generator **91"** heat exchanger **20** similarly as stream **45'**, FIG. **1*a***, and split also into stream **145'** applied to heat exchanger **30** of nitrogen liquefaction section **55**. Stream **145"** is processed through the series of cascaded respective heat exchangers **20** and **21** and expanders **23** and **24**, similarly as stream **45'**, of the embodiment of FIG. **1*b***. Stream **145"** exits expanders **23** and **24** and returned as inputs in the opposing direction into respective heat exchangers **22** and **21** for providing cooling. The stream from expander **24** subsequently outputted by exchanger **22** is combined with the output stream of expander **23** applied to heat exchanger **21** and then fed into exchanger **20** in a direction to provide cooling to the exchangers. This arrangement is similar to that of FIG. **1*b*** with respect to corresponding streams of these expanders.

[0114] Also, as in the embodiment of FIGS. **2*a*** and **2*b***, the ASU **65** receives LN stream **52** and outputs stream **53** applied with stream **38** as a combined input to compressor **54**. N_2 stream **46** is generated from the ASU **65**, which is required in FIG. **1*a*** and optional in FIGS. **2*a*** and **2*b***.

[0115] The natural gas input stream **19**, FIG. **3*a***, is divided into two streams **19*a*** and **19*b***. Stream **19*a*** is processed by generator **91"** similarly as stream **19**, FIG. **1*b***. Stream **19*b*** is inputted into cooler **230** comprising an ammonia refrigerant and then into expander **233**. The expander **233** output stream **234** is at about 120 psia and −157° F. The cooler **230** output is at about −20° F. Stream **234** is applied to series cascaded respective heat exchangers **21** and **20** in the opposing cooling direction as stream **19*a*** in generator **91"** to be cooled thereby and outputted by exchanger **20** as stream **234'**, FIG. **3*a***, applied to compressor **233'**. The outputs from the associated coolers of compressors **73** and **233'** are combined to form stream **74*a*** applied to dryer **18** for regeneration. Streams **72** and **71** are compressed by compressor **73** as in FIG. **1*a***. The letdown station **13** (shown in phantom) is not employed in this embodiment. The line pressure of stream **14** is high at about 714 psia. However, a letdown station could be employed in this embodiment, which results in power and cost savings. By increasing the output with added components, economy of the increased capacity makes up the difference in the increased system cost. Nitrogen is more efficient for refrigeration when used at the colder temperatures, e.g., −230° F.−−270° F. Ammonia is more efficient as a refrigerant at warmer temperatures, e.g., −20° F. Natural gas is most efficient as a refrigerant when processed at intermediate temperatures, e.g., −100° F.

[0116] FIGS. **4*a*** and **4*b*** are a variation of the FIGS. **3*a***, **3*b*** embodiment using an additional heat exchanger **222** in the LNG generator **91'"**, FIG. **4*a***. Here, NG liquefaction system **15'"** comprises generator **91'"** and nitrogen liquefaction section **55**. Stream **19** is applied to the respective cascaded series of heat exchangers **222** (FIG. **4*a***), **20**, **21**, and **22** through flash valve **25** (FIG. **4*b***) into separator **26** as partial LNG and vapors, stream **19*a***. The vapor output stream **19*b*** of separator **26** is applied to the respective heat exchangers **22**, **21**, **20** and **222** in the reverse direction as the warm gas stream **19*b*** applied thereto. This stream is outputted from heat exchanger **222** as stream **19*c*** which is compressed by compressor **73** and applied in a return stream for regeneration of dryer **18**. This stream is then returned to stream **14** through booster compressor **75** (optional and used if needed) for transmission to users.

[0117] In FIG. **4*a***, stream **19** of natural gas is divided into two streams **19*a*** and **19*b***. Stream **19*a*** is fed to heat exchanger **222**. Stream **19*b*** is combined with stream **234*a*** outputted by heat exchanger **222** to form stream **234*a*'**. Stream **234*a*'** is inputted into the respective series of two compressors **140** and **233'** (part of the compander having expander **233**, FIG. **4*b***) each having an associated cooler at its output. The output stream **234*b*** of compressor **233'** is at about 500 psia. The output stream **234*b*'** of the compressor **233'** associated cooler is inputted into heat exchanger **222** for cooling the inputted gas streams. This produces output stream **234*b*"** from heat exchanger **222** (FIGS. **4*a*** and **4*b***). This output stream is applied as an input to the cooler **230**, FIG. **4*b***. The output stream of cooler **230** is at −20° F. and 496 psia. The output stream **234** of expander **233**, FIG. **4*b***, at −152° F. and at 85 psia, is applied as an input to the series of respective heat exchangers **21**, **20** and **222** whose output is stream **234*a***. This stream is combined with stream **19*b*** forming stream **234*a*'** applied to compressor **140**, FIG. **4*a***. Stream $\mathbf{19}_a$ is applied to control valve **25** through respective heat exchangers **222**, **20**, **21** and **22** and thence through control valve **25** as valve output stream $\mathbf{19}_{a1}$**'** to separator **26**. The output vapor stream **19*b*** of separator **26** is then applied to the heat respective heat exchangers **22**, **21**, **20** and **222** for cooling the input gases. Stream **19*b*** is outputted from heat exchanger **222** as stream **19*c*** applied to compressor **73** for regenerating dryer **18** and fed back to stream **14** through optional compressor **75**. Heat exchanger **222** is not used in the prior embodiments as discussed.

[0118] Nitrogen stream portion **43**, FIG. **4*a***, output of compressor **24'** and its associate cooler is applied to heat exchanger **222** and outputted as stream **43*a***. In FIG. **4*b***, cooler **231** refrigerated with ammonia receives the cooled nitrogen stream **43*a***. The cooler **231** output at −20° F. is applied to heat exchangers **20** and **21** and expanders **23**, **24** in a manner similar to that described above for stream **45'**, FIG.

1*b*. Except for added heat exchanger **222**, the series arrangement of compressors **140** and **233'** and added cooler **231**, the remaining structures are the same as in the prior embodiment of FIGS. **3***a*, **3***b*. In FIG. **4***a*, the ASU **65** outputs one or more selected merchant gases as in the prior embodiments. A selected amount of LNG is stored in tank **92**, FIG. **4***b*, as before and this amount is set to allow a predetermined amount of LNG flow to the nitrogen liquefaction section **55** through control valve **29** as stream **71"** for liquefaction of the nitrogen and stored as previously described. Stream **52** of LN is also applied to the ASU **65** as in certain of the prior embodiments. Temperatures and pressures correspond generally to that described in the prior embodiments with respect to similarly processed streams of the gases.

[0119] The ASU **65** in the various embodiments may provide it's own refrigeration including the production of liquid product. Both nitrogen and oxygen air separation units **65** are capable of this. A letdown liquefaction system can be integrated with the air separation units **65** to take advantage of a smaller compressor **75** as in the other embodiments. Nitrogen gas under the intermediate pressure (approximately 80 psia) is withdrawn from the air separator units **65**. The nitrogen gas may come off the air separator unit **65** at sufficient pressure or some or all of it may need to be compressed by a nitrogen compressor (not shown) to obtain the proper pressure for streams **46**.

[0120] In FIGS. **5***a*, **5***b* and **5***c*, a further embodiment of the present invention, a liquefaction system **15***a* is shown. In FIGS. **5***a* and **5***b*, the components of the system shown comprises the same corresponding components of FIGS. **4***a* and **4***b*. However, the nitrogen liquefaction section **55'** is different. The heat exchanger **32** and control valve **35** of FIG. **4***b* are not used. Instead, the ASU **65'** has heat exchangers that are used to supply additional nitrogen refrigeration previously supplied by the heat exchanger of the prior embodiments of the liquefaction sections **55**. This is an alternate embodiment that is equivalent to the embodiment of FIGS. **4***a* and **4***b* with respect to the generation of LNG in LNG generator **91'''** and LN in exchanger **30**.

[0121] FIGS. **6***a* and **6***b* illustrate a further embodiment of the present invention. Refrigeration to cool and liquefy the natural gas can also be provided by a number of mixed refrigerant process cycles. One such cycle is illustrated in FIGS. **6***a* and **6***b*. A mixed refrigerant stream **850**, FIG. **6***a*, is utilized in this process not used in the prior disclosed embodiments hereinabove. Stream **850**, for example, in this embodiment, is composed of approximately 50 mole percent methane, 30 mole percent ethylene, 15 mole percent propane, and 5 mole percent nitrogen. The mixed refrigerant stream **850** is compressed from around 120 PSIA to over 500 PSIA in compressor **140**. It is then cooled in the after cooler **140'** and fed into heat exchanger **224** as a mixed gas stream **852**. Cooling of the mixed refrigerant stream **852** to 40° F. is provided by heat exchanger **224** and ammonia cooler **242**. The cooled stream **852'** is further cooled by heat exchanger **223**, and then cooled to −20 degrees F. via ammonia cooler **232**. The mixed refrigerant stream is now partially liquefied and the liquid separated in separator **245**.

[0122] Both gas **854** and liquid **856** streams from separator **245** are cooled in exchanger **20** to −90 degrees F. The liquid stream **856** is sub cooled as stream **856'** which is flashed through valve **246** where it flashes to around −109° F. providing refrigeration as it is sent back up through the respective bank of heat exchangers **20**. **223** and **224** as stream **850**. The other mixed refrigerant stream **854** cooled in exchanger **20** turns into a mixed phase stream **854'** that has its phases separated in separator **247**, FIG. **6***b*. The gas stream **854**$_1$ from separator **247** is flashed via valve **249** forming stream **854**$_1$' The liquid stream **854"** from separator **247** is sub cooled in exchanger **21** to −145° F., flashed through valve **248** to −166° F., as stream **854'''**, and combined with stream **854**$_1$' forming steam **858**. This stream is applied in the reverse direction up through the heat exchanger bank of respective exchangers **21**, **20**, **223** and **224** forming stream **858'** out of exchanger **21**. Stream **858'** combines with the output stream from valve **246**, FIG. **6***a*, forming stream **860**. Stream **860** applied to respective exchangers **223** and **224** is outputted at exchanger **224** as stream **850**.

[0123] These latter streams provide refrigeration for cooling the natural gas feed stream **19** applied to the bank of heat exchangers starting with exchange **224**, the nitrogen recycle stream **870** applied to the bank of exchangers starting with exchanger **224**, the mixed refrigerant gas stream **858**, FIG. **6***b*, from separator **247**, and themselves. The gas stream **854**$_1$ from separator **247** is flashed through valve **249** to around 130 PSIA pressure at −166° F. and combined with the mixed refrigerant stream **854'''** that was flashed through valve **248**.

[0124] The natural gas feed stream **19**, FIG. **6***a*, at approximately 90° F. and 860 PSIA is fed into heat exchanger **224** to be cooled, then enters ammonia chiller **240** at 55° F. to be cooled to 40° F., further cooled in exchanger **223** to 14° F., chilled in ammonia chiller exchanger **230** to −20° F., cooled to −90° F. in exchanger **20**, and "liquefied" in exchanger **21**, FIG. **6***b*, exiting at −145° F. This stream **19***a* is then sub cooled in exchanger **22** to −190° F. before flashing through valve **25** to 20 PSIA at −251° F. before entering separator **26**. As in previous embodiments (not shown), separator **26** may be elevated to provide a gravity induced pressure head forcing the LNG product into the tank **92** via valve **27** or the LNG is pumped by a pump (not shown) into tank **92** via the valve **27**. Some of the LNG is diverted to the nitrogen liquefaction section **55** via valve **29** as in previous embodiments.

[0125] The nitrogen recycle stream is handled as described above in previous embodiments. The high pressure nitrogen N_2 stream **870**, FIG. **6***a*, at 90° F. and approximately 400 PSIA is cooled through the heat exchanger bank of exchangers **224**, **223**, **20** and **21** and the ammonia coolers, as shown, before entering the suction of expander **24**, FIG. **6***b*, at −145° F. The nitrogen recycle stream **870'** exits the expander **24** at approximately −250° F. and 86 PSIA to provide refrigeration for all of the heat exchangers in LNG generator **98**.

[0126] FIGS. **6***a* and **6***b* show one possible mixed refrigerant process cycle. Many other mixed refrigerant process cycles are possible. One example would be to add butane to the mixed refrigerant stream which eliminates the need for the ammonia coolers. In another example, propane chillers can be substituted for the ammonia coolers. A cascade refrigerant cycle using propane or ammonia along with separate hydrocarbon compression cycles would also be possible.

[0127] In FIGS. **7***a* and **7***b*, some natural gas feeds at pipeline **12** to the LNG plant will be richer in ethane, propane, butane and heavier hydrocarbons. These heavier hydrocarbons are more economically valuable than the methane in the natural gas. Furthermore, the engine manufacturers who produce engines that will burn the LNG as fuel want the ethane content in the LNG product below 4 mole percent. This dictates that some natural gas liquids (NGL) (e.g., butane and propane) must be extracted from the natural gas feed stream in the LNG manufacturing process. Therefore, a natural gas liquids (NGL) product needs to be produced. This product needs to be added to the production of the LNG, LN and industrial merchant gas liquid products described in the above embodiments for the appropriate natural gas feeds. An example of such a process is presented in the embodiment of FIGS. **7***a* and **7***b*. This further process produces LNG, liquid nitrogen LN, liquid oxygen LOX, gaseous oxygen GOX, liquid argon LAR, GAN and natural gas liquids. The natural gas feed source at pipeline **12** is richer in the heavier hydrocarbons. The composition of this feed after drying is approximately 93.5 mole percent methane, 4.5 mole percent ethane, 1 mole percent propane, 0.7 mole percent nitrogen with the remaining heavier hydrocarbons at 0.3 mole percent combined.

[0128] The natural gas feed temperature is 90° F. and the feed pressure is 905 PSIA after drying.

[0129] The refrigeration scheme utilized is similar to the process cycle presented in FIGS. **1***a* and **1***b*. This scheme uses two nitrogen expander/companders **23**, **24**. Ammonia coolers **230**, **231**, **805**, and **806** are added. However, equipment is also added for the NGL natural gas liquids extraction. The natural gas feed stream **19**, FIG. **7***a*, is cooled in heat exchanger **800**, chilled in ammonia cooler **230** to −20° F., and further cooled in heat exchanger **801** to about −70° F., forming stream **814**. Valve **807**, FIG. **7***b*, is added to flash the feed stream **814** down to 550 PSIA forming stream **815** in which a small amount of hydrocarbon liquid is present. The gas and liquid phases of the feed stream **815** output of the valve **807**, are separated in separator **808**. The gas stream **816** exiting separator **808** is low enough in ethane concentration to make the LNG product well under 4 mole percent ethane.

[0130] The liquid stream **817** from separator **808** is flashed through valve **809** to approximately 25 PSIA as stream **818** before entering distillation column **810** where the methane in the natural gas liquids is separated out to make acceptable NGL, natural gas liquids product. The natural gas liquid product stream from the bottom of distillation column **810** passing through reboiler **805** and pumped up in pressure by pump **811** forming stream **820**. Stream **820** then is applied to respective heat exchangers **801** and **800**, FIG. **7***a*, where its refrigeration is recovered. The NGL natural gas liquid product pressure is about 500 PSIA in this example. Reboiler **805** is heated by cooling the nitrogen stream at the suction of nitrogen expander **23**, and condenser **806** is integrated by heating nitrogen exiting nitrogen expander **24**. Methane rich gas from the top of distillation column **810** stream **821** is combined with flashed gas from separator **26** forming stream **822** to help refrigerate the natural gas feed stream **814'** cascading down through heat exchangers **802**, **803** and **804**. The natural gas feed stream exiting exchanger **804** at about −230° F. is flashed through valve **25** before entering separator **26**. Separator **26** produces LNG, stream **823**. The disposition of the LNG is the same as presented in FIGS. **1***a* and **1***b* enabling the LNG and industrial gas merchant liquid products to be generated. The NGL product stream **820'** exiting the successive chain of heat exchangers **804**, **803**, **802**, **801** and **800**, respectively, is stored in storage tank **826**.

[0131] Thus, in one plant, the incoming stream of natural gas feed is formed into LNG, LN, merchant gases and NGL. Such products previously needed to be produced in separate plants, therefore reducing capital costs for the production of such gases.

[0132] It will occur to one of ordinary skill that various modifications may be made to the disclosed embodiments which are given by way of illustration and not limitation. For example, the merchant liquefied gases need not be returned to or supplied from an air separation unit. The merchant gas may be supplied from a separate gas source for liquefaction by the disclosed systems. Also, the gas returned to the air separation unit need not be liquid, but may be cold vapor. Drivers for expanders and compressors are not shown. The source of natural gas may be any methane rich natural gas feed whether from a pipeline, landfill, or biogas digester, for example. The number, configuration and location of the various elements such as heat exchangers, separators, compressors, control valves and so on may differ from the embodiments disclosed as discussed herein. It is intended that the scope of the invention is as defined in the appended claims.

What is claimed is:

1. A system for producing liquid natural gas (LNG), and liquid nitrogen utilizing a source of a methane rich stream of natural gas and an air separation unit (ASU) to produce merchant gases comprising:

an LNG generator including at least one heat exchanger responsive to applied processed pipeline natural gas for producing liquid natural gas;

a nitrogen liquefaction section for liquefying nitrogen received from the ASU;

a liquid nitrogen storage unit and an LNG storage unit;

a first control valve for applying a predetermined amount of LNG in a selected first portion of the produced LNG to the LNG storage unit as product;

a second control valve for applying a second portion of the produced LNG by the LNG generator to the nitrogen liquefaction section for assisting in the liquefaction of nitrogen as determined by the selected first portion amount; the nitrogen liquefaction section for producing nitrogen to assist in the production of the merchant gases as products by the ASU; and

a third control valve for applying liquid nitrogen from the nitrogen liquefaction section to the liquid nitrogen storage unit for storing the liquefied nitrogen as product.

2. The system of claim **1** wherein the LNG generator is arranged to be responsive to applied pressurized nitrogen and includes a nitrogen gas expansion arrangement for causing the pressurized nitrogen to produce refrigeration to assist in liquefying the natural gas into LNG in the LNG generator.

3. The system of claim **1** including a nitrogen feed compressor responsive to nitrogen gas fed from the ASU to provide compressed nitrogen to the LNG generator.

4. The system of claim **1** including a compander for supplying compressed and then expanded natural gas (NG) to the LNG generator.

5. The system of claim **1** wherein the LNG generator includes a control valve and separator for producing vaporized low pressure and flashed natural gas and including a bank of heat exchangers for heating to ambient temperature the flashed natural gas passed through the heat exchangers and at least one compressor for compressing the passed natural gas to pipeline pressure.

6. The system of claim **1** including an arrangement for recovering medium and low pressure nitrogen from the liquefaction section and recycling the recovered nitrogen through compression into the LNG generator.

7. The system of claim **6** wherein the LNG generator includes a bank of heat exchangers, the arrangement for recovering nitrogen includes a series of compressors for sequentially compressing the nitrogen and for then selectively applying the compressed nitrogen to the LNG generator to selected ones of the heat exchangers.

8. The system of claim **7** including a series of expanders each for expanding the compressed nitrogen applied to a different one of the selected ones of the heat exchangers.

9. The system of claim **1** wherein the LNG generator produces liquid natural gas LNG wherein the liquid is produced by a series of nitrogen expanders and a series of nitrogen compressors for generating nitrogen refrigeration to assist in the production of the LNG.

10. The system of claim **1** wherein the nitrogen liquefaction section comprises a bank of heat exchangers, a compressor arrangement and a gas flash arrangement for recycling nitrogen gas supplied by the ASU through the heat exchangers for the liquefying of the nitrogen in cooperation with the liquefied natural gas and for selectively feeding the liquefied nitrogen to a selected one or both of the ASU and nitrogen storage unit.

11. The system of claim **1** wherein the nitrogen liquefaction section integrates with the ASU for generating liquid nitrogen.

12. The system of claim **1** wherein the nitrogen liquefaction section comprises a series of heat exchanger, a separator, and at least one nitrogen gas flash valve which cooperates with the ASU to produce liquid nitrogen.

13. The system of claim **1** wherein the system includes a letdown station in the pipeline to assist in reducing power required and for providing refrigeration to the LNG liquefaction generator.

14. The system of claim **13** including a cooling heat exchanger comprising a refrigerant and an expander for expanding and cooling the natural gas output of the cooling heat exchanger coupled to the LNG generator.

15. The system of claim **1** wherein the LNG generator comprises a series of nitrogen expanders for cooling nitrogen gas applied to a cascaded series of heat exchangers in the LNG generator.

16. The system of claim **1** wherein the ASU supplies nitrogen to a series bank of compressors whose output of compressed nitrogen is applied to a series bank of heat exchangers in the LNG generator.

17. The system of claim **16** wherein the LNG generator comprises a series of nitrogen expanders for cooling nitrogen gas applied to a cascaded series of heat exchangers in the LNG generator, the expanders comprising corresponding companders forming the compressors.

18. The system of claim **1** wherein the LNG generator includes at least one expander and at least one cooling heat exchanger comprising an ammonia refrigerant for cooling at least one of nitrogen and natural gas.

19. The system of claim **1** wherein the LNG generator includes at least one expander for expanding natural gas for cooling natural gas in the generator and at least one cooling heat exchanger comprising an ammonia refrigerant for cooling nitrogen gas used to cool the natural gas in the generator.

20. The system of claim **1** wherein the LNG generator includes at least one expander for expanding and cooling natural gas applied thereto.

21. The system of claim **1** including at least one nitrogen expander for expanding nitrogen gas applied thereto.

22. The system of claim **20** further including at least one natural gas expander for expanding recycled natural gas applied thereto.

23. The system of claim **1** wherein the LNG generator further includes at least one natural gas expander and at least one nitrogen gas expander.

24. The system of claim **1** wherein the LNG generator includes three different closed gas systems utilizing corresponding three different refrigeration gases.

25. The System of claim **1** wherein the LNG generator utilizes at least one ammonia gas refrigeration cooler, a nitrogen gas refrigeration cooling system and a mixed gas cooling refrigeration system.

26. The system of claim **1** wherein the LNG generator includes a control valve and separator for producing vaporized low pressure and flashed natural gas and including a bank of heat exchangers for heating to ambient temperature the flashed natural gas passed through the heat exchangers whereby the passed natural gas can be partially or completely fed to an electrical generator set to generate electricity.

27. A system utilizing a source of a methane rich natural gas for producing 1) liquid natural gas (LNG), 2) natural gas liquids (NGL) predominately comprising propane, butane and heavier hydrocarbons, 3) liquid nitrogen and 4) an air separation unit (ASU) to produce merchant gases comprising:

an LNG generator including at least one heat exchanger responsive to an applied processed source of natural gas for producing liquid natural gas LNG;

a nitrogen liquefaction section for liquefying nitrogen received from the ASU;

a liquid nitrogen LN storage unit, an NGL storage unit and an LNG storage unit;

a first control valve for applying a predetermined amount of LNG in a selected first portion of the produced LNG to the LNG storage unit as product; and

a second control valve for applying a second portion of the produced LNG by the LNG generator to the nitrogen liquefaction section for assisting in the liquefaction of nitrogen as determined by the selected first portion amount; the nitrogen liquefaction section for assisting in the production of the merchant gases as products by the ASU;

a third control valve for applying liquid nitrogen from the nitrogen liquefaction section to the liquid nitrogen storage unit for storing the liquefied nitrogen as product; and

an arrangement for producing NGL product from the applied processed source of natural gas and for storing the NGL in the NGL storage unit.

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