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(54) **Method and apparatus for the liquefaction of natural gas**

(57) A method for the liquefaction of natural gas, comprising:

- taking unpurified natural gas from a gas well (101);
- pre-treating the gas for removing impurities;
- performing a first compression stage (201);
- performing a first heat exchange stage (202);
- performing a second compression stage (203);
- performing a second heat exchange stage (204);
- performing a third compression stage (205);
- performing a third heat exchange stage (206);
- performing an additional regeneration heat exchange

stage (207);

- performing a first main independent heat exchange cycle (208);
- performing a second main heat exchange cycle (209);
- passing the gas through a Joule-Thomson valve;
- sending the liquefied gas (215) to storage;
- injecting the portion of the gas remaining in the gaseous state (210) into the second main heat exchange stage (209) and subsequently re-injecting the remaining gas in the gaseous state into the inlet pipe (122) being mixed with the gas incoming from the treatment plant.

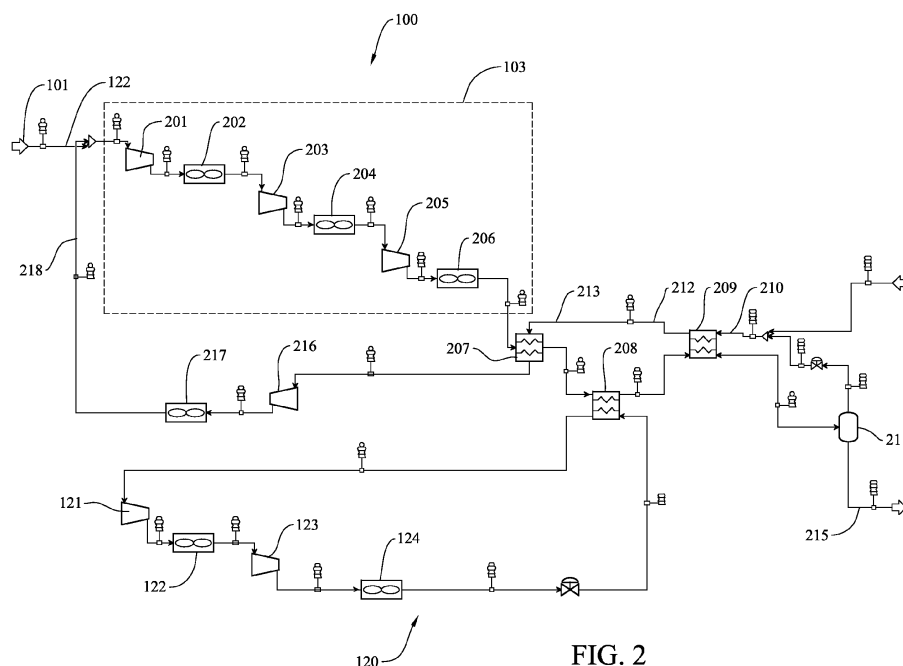


FIG. 2

Description

FIELD OF THE INVENTION

[0001] The present invention relates generally to the compression and liquefaction of gases, and more particularly to the partial liquefaction of a gas, such as natural gas, on a small scale by utilizing a combined refrigerant and expansion process.

DESCRIPTION OF THE PRIOR ART

[0002] Natural gas (NG) is a mixture of gases that was formed from fossil remains of plants and animals that are buried deep below the Earth's surface. Natural gas is composed primarily of methane, although it also contains ethane, propane, and traces of other gases. Depending on where it is extracted, it varies between 87%/96% methane with about 1.5% to 5% ethane, and 0.1 % to 1.5% propane.

[0003] Natural gas is a known alternative to combustion fuels such as gasoline and diesel. Much effort has gone into the development of natural gas as an alternative combustion fuel in order to combat various drawbacks of gasoline and diesel including production costs and the subsequent emissions created by the use thereof. As is known in the art, natural gas is a cleaner burning fuel than other combustion fuels.

[0004] Nowadays, natural gas is among the most important sources of energy in the world. Today approximately 25% of the world's energy demand is derived from natural gas. The majority of natural gas is delivered by pipeline in gaseous form. However, in the past two decades Liquefied Natural Gas (LNG) has gained importance in the world's energy market. LNG is expected to play a growing role in the world's energy supply.

[0005] LNG is natural gas in its liquid form. In order to liquefy natural gas, it must be cooled. As a liquid, natural gas occupies only 1/600th of the volume of natural gas (at atmospheric pressure) in its gaseous form and thereby allows for more economical and practical transportation over great distances. Natural gas is typically transported in liquid state when vast distances, geological or political conditions do not allow for construction of pipelines.

[0006] Conventionally, two of the known basic cycles for the liquefaction of natural gases are referred to as the "cascade cycle" and the "expansion cycle".

[0007] Briefly, the cascade cycle consists of a series of heat exchangers with the feed gas; each exchange being at successively lower temperatures until the desired liquefaction is accomplished. The levels of refrigeration are obtained with different refrigerants or with the same refrigerant at different evaporating pressures. The cascade cycle is considered to be very efficient at producing LNG as operating costs are relatively low.

[0008] However, the efficiency in operation is often seen to be offset by the relatively high investment costs

associated with the expensive heat exchange and the compression equipment associated with the refrigerant system. Additionally, a liquefaction plant incorporating such a system may be impractical where physical space is limited, as the physical components used in cascading systems are relatively large.

[0009] During an expansion cycle, gas is conventionally compressed to a selected pressure, cooled, and then allowed to expand through an expansion turbine, thereby producing work as well as reducing the temperature of the feed gas. The low temperature feed gas is then heat exchanged to effect liquefaction of the feed gas. Conventionally, such a cycle has been seen as being impracticable in the liquefaction of natural gas since there is no provision for handling some of the components present in natural gas which freeze at the temperatures encountered in the heat exchangers, for example, water and carbon dioxide.

[0010] Additionally, to make the operation of conventional systems cost effective, such systems are conventionally built on a large scale to handle large volumes of natural gas. As a result, fewer facilities are built making it more difficult to provide the liquefaction plant or facility with the raw gas as well as making distribution of the liquefied product an issue. Another major problem with large scale facilities is the capital and operating expenses associated therewith. For example, a conventional large scale liquefaction plant, i.e., producing on the order of 70,000 gallons of LNG per day, may cost around \$15 million, or more, in capital expenses. Also, such a plant may require thousands of horsepower to drive the compressors associated with the refrigerant cycles, making the operation of the plants expensive.

[0011] An additional problem with large facilities is the cost associated with storing large amounts of fuel in anticipation of future use and/or transportation. Not only is there a cost associated with building large storage facilities, but there is also an efficiency issue related therewith as stored LNG will tend to warm and vaporize over time creating a loss of the LNG fuel product.

[0012] Furthermore, safety may become an issue when larger amounts of LNG fuel product are stored. In confronting the foregoing issues, various systems have been devised which attempt to produce LNG or compressed natural gas (CNG) from feed gas on a smaller scale, in an effort to eliminate long term storage issues and to reduce the capital and operating expenses associated with the liquefaction and/or compression of natural gas. However, such systems and techniques have all suffered from one or more drawbacks.

[0013] The above explained reasons entailed the development of small scale plants for producing approximately 1,000 gallons a day of a liquefied or compressed fuel product. Small-scale liquefaction plants are advantageous because their compact size enables the production of LNG close to the location where it will be used. This proximity decreases transportation and LNG product costs for consumers.

[0014] There are some small scale Natural Gas liquefaction plants in the prior art. For example, General Electric Oil & Gas has developed a Micro LNG Integrated Plant called Micro LNG. Micro LNG is a natural gas liquefaction plant producing in the range of 50-150 k/tons per year of LNG. The biggest difference between traditional large plants, which produce in excess of 1 million tons per year, and Micro LNG is the end user the product is destined for. For the large LNG plant, the product is produced for international export, where the plant economy of scale is among the most important factors. In Micro LNG, the distributed production is primarily aimed at local markets, where it is re-gasified and fed as pipeline natural gas or used for local power generation. It includes centrifugal and integrally gear compressors and expanders, turbo expander compressors, reciprocating compressors and controllers, which makes this solution very expensive and its adaptability very rigid.

[0015] Based on the above explained challenges and unsuitable solutions, it would be additionally advantageous to provide a plant for the liquefaction of natural gas which is relatively inexpensive to build and operate.

[0016] It would be additionally advantageous to provide such a plant with an easy access of LNG fuel for consumers that is easily transportable and that may be located and operated at existing sources of natural gas, which are within or near populated communities.

[0017] Therefore, the present invention is directed to a method and apparatus for the liquefaction of natural gas that overcomes the difficulties and drawbacks of the devices of the prior art.

SUMMARY OF THE INVENTION

[0018] The present invention overcomes the deficiencies of the known art and the problems that remain unsolved by providing an easy-to-install and practical method and apparatus for the liquefaction of natural gas with which it is possible to provide a low scale production of LNG at reasonable costs.

[0019] In a first exemplary embodiment, a method is provided for liquefying natural gas comprising:

a pre-treating step for removing impurities such as carbon dioxide, nitrogen, etc., from the natural gas flow taken from a source of unpurified natural gas;

a first compression stage for compressing the natural gas from around 10/11 bar to around 30/35 bar, and in which the temperatures rise from 30/35 °C to 140/150 °C;

a first heat exchange stage for cooling down the temperature of the gas from 140/150 °C to 40/45 °C;

a second compression stage for compressing the natural gas from around 30/35 bar to around 90/95 bar, and in which the temperatures rise from 40/45

°C to 140/150 °C;

a second heat exchange stage for cooling down the temperature of the gas from 140/150 °C to 40/45 °C;

a third compression stage for compressing the natural gas from around 90/95 bar to around 245/250 bar, and in which the temperatures rise from 40/45 °C to 140/145 °C;

a third heat exchange stage for cooling down the temperature of the gas from 140/145 °C to 40/45 °C;

at 250 bar, a new heat exchange stage that is part of a regeneration cycle cools down the temperature of the gas from 40/45 °C to 7/10 °C;

a first main independent heat exchange cycle cools down the temperature of the gas from 7/10 °C to -40/-45 °C while pressure is kept at 250 bar;

a second main heat exchange cycle cools down the temperature of the gas from -40/-45 °C to -75/-80 °C while pressure is kept at 250 bar;

at 250 bar and -75/-80 °C, the gas passes through a Joule-Thomson valve allowing the stream to expand thereby reducing its temperature to -150/-155 °C and reducing its pressure to 2 bar;

at -150/-155 °C and 2 bar, a portion of the mass of gas is liquefied and sent to storage and the portion of the mass of gas remains in the gaseous state and is injected into the second main heat exchange stage to help in the cooling process described above, increasing its temperature from -150/-155 °C to -60/-65 °C;

the remaining gas in the gaseous state at -60/-65 °C is injected into the first main heat exchange stage to help in the cooling process described above.

[0020] In accordance with another aspect of the invention, a system is provided for cooling a mass of natural gas by expanding the gas through a Joule-Thomson valve. Cooling the mass of natural gas may also include flowing the gas through a heat exchanger.

[0021] In accordance with another aspect of the invention, a system is provided for cooling a mass of natural gas including the step of collecting the mass of gas already in liquid state and returning the already cooled gas to the circuit so as to use it during the heat exchange steps described above.

[0022] In accordance with another aspect of the invention, a system is provided for cooling a mass of natural gas to feed the fuel system of a boat, particularly a ferry.

[0023] In accordance with another aspect of the invention, a method of producing liquid natural gas is provided.

The method includes providing a source of unpurified natural gas.

[0024] In accordance with another aspect of the invention, the present invention is the only Nano LNG station available in the market including a single module combining all the elements needed to produce the transformation of natural gas into LNG.

[0025] The advantages of the present invention may be summarized as:

- Extremely simple to install.
- Fully automatic operation.
- Remote operation via a customized control platform.
- Intrinsically Safe.
- Minimal environmental impact, no noise or vibration.
- Can be installed in height.
- Minimum operating costs.
- Low power consumption.
- Flexible to changes in demand.
- Modular may grow according to the variation of demand.
- Redundant.

[0026] These and other aspects, features, and advantages of the present invention will become more readily apparent from the attached drawings and the detailed description of the preferred embodiments, which follow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The preferred embodiments of the invention will hereinafter be described in conjunction with the appended drawings provided to illustrate and not to limit the invention, where like designations denote like elements, and in which:

FIG. 1 presents an schematic view of the cycle for refrigerating natural gas in accordance with the present invention;

FIG. 2 is another schematic view showing in detail the present cycle including one compression cycle and the values of pressure and temperature in the different stages of the cycle.

FIG. 3 is a general perspective view of one embodiment of a modular and transportable plant for the liquefaction of natural gas in accordance with the

present invention.

FIG. 4 is a right end elevational view of part of the equipment shown in FIG. 3.

FIG. 5 is a front elevational view of the unit shown in FIG. 4, and:

FIG. 6 is a top plan view.

[0028] Like reference numerals refer to like parts throughout the several views of the drawings.

DETAILED DESCRIPTION OF REPRESENTATIVE EMBODIMENTS

[0029] The following detailed description is merely exemplary in nature and is not intended to limit the described embodiments or the application and uses of the described embodiments. As used herein, the word "exemplary" or "illustrative" means "serving as an example, instance, or illustration." Any implementation described herein as "exemplary" or "illustrative" is not necessarily to be construed as preferred or advantageous over other implementations. All of the implementations described below are exemplary implementations provided to enable persons skilled in the art to make or use the embodiments of the disclosure and are not intended to limit the scope of the disclosure, which is defined by the claims. For purposes of description herein, the terms "upper", "lower", "left", "rear", "right", "front", "vertical", "horizontal", and derivatives thereof shall relate to the invention as oriented in FIG. 3. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description. It is also to be understood that the specific devices illustrated in the attached drawings, and described in the following specification, are simply exemplary embodiments of the inventive concepts defined in the appended claim. Hence, specific dimensions and other physical characteristics relating to the embodiments disclosed herein are not to be considered as limiting, unless the claims expressly state otherwise.

[0030] The present invention is referred to a method and apparatus for the liquefaction of natural gas that includes an exclusive high pressure LNG liquefaction cycle for small scale production. This cycle allows the production at very economical costs of up to 20000 Nm³/day of LNG with a very low operating cost and a significantly lower level investment in comparison with any other known facility available in the market.

[0031] Making first reference to FIG. 1, the cycle 100 starts at the inlet 101 of unpurified natural gas. This inlet may come from a gas well, an oil well, a natural gas production pipe, or the like. That gas is pretreated at the treatment device 102 to suit it to liquefaction conditions. This natural gas contains, at this stage, impurities that

need to be removed. Some of these impurities may be carbon dioxide, nitrogen, and other gases. These impurities must be removed to make the gas fit for this cycle.

[0032] Once the gas is purified at 102, it enters into a first high-pressure multi-stage compressor 103. After the stage 103, the gas enters into a heat exchanger 104 after which the mixture of liquid and gaseous natural gas enters a cold box 105 from which the liquefied gas is transferred to a flash liquid/gas separator 106 for its storage 107 and/or transportation 108. Between the cold box and the separator an expansion valve is included to reduce the pressure creating a Joule Thompson effect.

[0033] An independent propane refrigeration cycle 120 including an additional high-pressure multi-stage 109 and a heat exchange stage 110 helps the general cycle 100 to perform the last liquefaction process in the cold box 105.

[0034] The natural gas that still remains in the gaseous state in the cold box 105 is then transferred to a booster compressor 111 and a heat exchanger 112 before it is re-injected into the inlet pipe 122 being mixed with the gas incoming from the treatment plant.

[0035] FIG. 2 shows in more detail the present method 100 for the liquefaction of natural gas. The high-pressure multi-stage compressor 103 is shown in this figure as a three-stage process including a first compression stage 201 for compressing the natural gas coming from the inlet pipe 122 at around 10/11 bar to around 30/35 bar. During this compression stage, the temperatures rise from around 36 °C to 148 °C; therefore, it is necessary to reduce this temperature drastically for which the gas enters into a first heat exchange stage 202 to cool down the temperature of the gas from 148 °C to 40 °C.

[0036] Immediately afterwards, a second compression stage 203 starts for compressing the natural gas from around 33 bar at the end of the first stage to around 95 bar, and during which the temperatures rise from 40 °C to 149 °C. Therefore, a second heat exchange stage 204 for cooling down the temperature of the gas from 149 °C to 40 °C is performed.

[0037] At the outlet of the second stage, a third compression process 205 is performed for compressing the natural gas from around 95 bar to around 250 bar, and in which the temperatures rise from 40 °C to 136 °C. Therefore, in a heat exchanger 206, a third heat exchange stage cools down the temperature of the gas from 136 °C to 40 °C.

[0038] At the end of this process the natural gas is at 250 bar and 40 °C. It is then injected into a regeneration cycle 207 that cools down the temperature of the gas from 40 °C to 7 °C keeping the pressure at 250 bar.

[0039] A first main independent heat exchange cycle 208 cools down the temperature of the gas from 7 °C to -47 °C while pressure is kept at 250 bar. This independent cycle is fed by a propane cycle 120 that includes a compressor 121, a heat exchanger 122, a second compressor 123 and a second heat exchanger 124 that basically liquefies, expands and vaporizes said propane gas.

[0040] At the exit of this first main independent heat exchange cycle 208, a second main heat exchange cycle 209 cools down the temperature of the gas from -47 °C to -77 °C while pressure is kept at 250 bar. This second main heat exchange cycle 209 uses the energy of the returning gas through line 210 as will be explained in detail below. At this stage, part of the mass of the natural gas is already in a liquid state. The mix of liquid and gaseous natural gas at -77 °C and 250 bar is expanded in an separator device 211 including an internal thermal expansion valve that reduces the gas pressure from 250 bar to 2 bar. This significant drop in the gas pressure also produces a significant drop in the gas temperature because of the Joule-Thomson effect. The Joule-Thomson expansion describes the temperature change of a gas when it is forced through a valve while kept insulated so that no heat is exchanged with the environment. This procedure is called a throttling process or Joule-Thomson process.

[0041] Thus, at the exit of this evaporator 211, around half of the mass of natural gas has been liquefied as it is at -151 °C and 2 bar. It is then collected for further processing (storage or transportation) through a pipe 215. The gaseous portion of the gas at -151 °C and 2 bar is injected through the pipe 210 into the second main heat exchange cycle 209. Because of the temperature difference between the gas returning from pipe 210 (-151 °C) and the gas entering the second main heat exchange cycle 209 at -47 °C, this returning gas helps the heat exchange process. At the exit of said second main heat exchange cycle 209, through pipe 212, said returning gas is at -60 °C and 2 bar. It is finally injected into the first main heat exchange cycle 207 through pipe 213 to help in the heat exchange process of this cycle. As in the previous case, the temperature difference between the returning gas (-60 °C) and the entering gas (40 °C) makes this returning gas an important helping role in the heat exchange cycle.

[0042] Before this returning gas can be incorporated in the aspiration pipe 122, it must be compressed, as the entrance gas is already at 11 bar and this returning gas is at 2 bar. Thus, this returning gas at 37 °C and 1.9 bar enters a compressor 216 that raises the gas pressure from 2 bar to 11 bar and the temperature rises from 37 °C to 224 °C. Therefore, before injecting it into the inlet pipe 122 is injected into a heat exchanger 217 that cools it down from 224 °C to 40 °C. Through a pipe 218, this returning gas is finally reincorporated in the circuit and the process may start again.

[0043] FIG. 3 shows one example of a transportable and compact plant used to perform the liquefaction method of the present invention. In the module 300 illustrated in FIG. 3 all the necessary elements are included. Therefore once the inlet gas pipe and the LNG outlet liquid gas are connected the plant is fully operational. Instead of having all the typical complex and expensive means used in the LNG plants of the prior art, this solution provides a flexible, affordable solution for low volumes application.

[0044] In the general perspective view of FIG. 3 some of the parts can be distinguished, including a compressor 301, three heat exchangers 302, a GNL module 303, the GNL outlet 304, refrigerating fans 305, two vent chimneys 306 and a display control 307.

[0045] FIGS. 4-6 show an internal unit of the module of FIG. 3. The unit includes accumulators 321, a GNL outlet 322, and a propane inlet 323. The heat exchangers 325 of the unit 320 are protected by an external isolating cover 324. The unit also includes a propane outlet 326 and a natural gas outlet 327.

[0046] While the preferred embodiments of the invention have been described above, it will be recognized and understood that various modifications can be made in the invention and the appended claims are intended to cover all such modifications which may fall within the spirit and scope of the invention.

Claims

1. A method for the liquefaction of natural gas, comprising:

taking unpurified natural gas from a gas well;
pre-treating the gas for removing impurities;
performing a first compression stage;
performing a first heat exchange stage;
performing a second compression stage;
performing a second heat exchange stage;
performing a third compression stage;
performing a third heat exchange stage;
performing an additional regeneration heat exchange stage;
performing a first main independent heat exchange cycle;
performing a second main heat exchange cycle;
passing the gas through a Joule-Thomson valve;
sending the liquefied gas to storage;
injecting the portion of the gas in the gaseous state into the second main heat exchange stage;
and the remaining gas in the gaseous state is injected into the first main heat exchange stage.

2. The method for the liquefaction of natural gas in accordance with claim 1, wherein during the pretreatment stage, carbon dioxide and/or nitrogen is removed from the natural gas.
3. The method for the liquefaction of natural gas in accordance with claim 1, wherein during the first compression stage the natural gas is compressed from 10/11 bar to around 30/35 bar.
4. The method for the liquefaction of natural gas in accordance with claim 1, wherein during the first heat exchange stage the temperature of the gas is re-

duced from 140/150 °C to 40/45 °C.

5. The method for the liquefaction of natural gas in accordance with claim 1, wherein during the second compression stage the natural gas is compressed from around 30/35 bar to around 90/95 bar.
6. The method for the liquefaction of natural gas in accordance with claim 1, wherein during the second heat exchange stage the temperature of the gas is reduced from 140/150 °C to 40/45 °C.
7. The method for the liquefaction of natural gas in accordance with claim 1, wherein during the third compression stage the natural gas is compressed from around 90/95 bar to around 245/250 bar.
8. The method for the liquefaction of natural gas in accordance with claim 1, wherein during the third heat exchange stage the temperature of the gas is reduced from 140/145 °C to 40/45 °C.
9. The method for the liquefaction of natural gas in accordance with claim 1, wherein during the additional regeneration heat exchange stage the temperature of the gas is reduced from 40/45 °C to 7/10 °C.
10. The method for the liquefaction of natural gas in accordance with claim 1, wherein the first main independent heat exchange cycle is an isobaric cycle to reduce the temperature of the gas from 7/10 °C to -40/-45 °C.
11. The method for the liquefaction of natural gas in accordance with claim 1, wherein during the second main heat exchange isobaric cycle the temperature of the gas is reduced from -40/-45 °C to -75/-80 °C.
12. The method for the liquefaction of natural gas in accordance with claim 1, wherein the gas is passed through a Joule-Thomson valve reducing its temperature to -150/-155 °C and reducing its pressure to 2 bar.
13. A method for the liquefaction of natural gas, comprising:

taking unpurified natural gas from a gas well;
pre-treating the gas for removing impurities;
performing a first compression stage for compressing the natural gas from around 10/11 bar to around 30/35 bar (and in which the temperatures rise from 30/35 °C to 140/150 °C);
performing a first heat exchange stage for cooling down the temperature of the gas from 140/150 °C to 40/45 °C;
performing a second compression stage for compressing the natural gas from around 30/35

bar to around 90/95 bar (and during which the temperatures rise from 40/45 °C to 140/150 °C); performing a second heat exchange stage for cooling down the temperature of the gas from 140/150 °C to 40/45 °C; 5
 performing a third compression stage for compressing the natural gas from around 90/95 bar to around 245/250 bar (and during which the temperatures rise from 40/45 °C to 140/145 °C); 10
 performing a third heat exchange stage for cooling down the temperature of the gas from 140/145 °C to 40/45 °C;
 performing an additional regeneration heat exchange stage to cool down the temperature of the gas from 40/45 °C to 7/10 °C; 15
 performing a first main independent heat exchange cycle to cool down the temperature of the gas from 7/10 °C to -40/-45 °C while pressure is kept at 250 bar;
 performing a second main heat exchange cycle to cool down the temperature of the gas from -40/-45 °C to -75/-80 °C while pressure is kept at 250 bar; 20
 passing the gas at 250 bar and -75/-80 °C through a Joule-Thomson valve allowing the stream to expand thereby reducing its temperature to -150/-155 °C and reducing its pressure to 2 bar; 25
 sending the portion of the gas already liquefied to storage; 30
 injecting the portion of the gas in the gaseous state into the second main heat exchange stage (to help in the cooling process described above, increasing its temperature from -150/-155 °C to -60/-65 °C); and the remaining gas in the gaseous state at -60/-65 °C is injected into the first main heat exchange stage to help in the cooling process described above. 35

14. A method for the liquefaction of natural gas, comprising: 40

a pre-treating step for removing impurities such as carbon dioxide, nitrogen, etc., from the natural gas flow taken from a source of unpurified natural gas; 45
 a first compression stage for compressing the natural gas from around 11 bar to around 33 bar, and in which the temperatures rise from 36 °C to 148 °C; 50
 a first heat exchange stage for cooling down the temperature of the gas from 148 °C to 40 °C;
 a second compression stage for compressing the natural gas from around 33 bar to around 95 bar, and in which the temperatures rise from 40 °C to 148 °C; 55
 a second heat exchange stage for cooling down the temperature of the gas from 149 °C to 40 °C;

a third compression stage for compressing the natural gas from around 95 bar to around 250 bar, and in which the temperatures rise from 40 °C to 136 °C;
 a third heat exchange stage for cooling down the temperature of the gas from 136 °C to 40 °C; at 250 bar, a new heat exchange stage that is part of a regeneration cycle cools down the temperature of the gas from 40 °C to 7 °C;
 a first main independent heat exchange cycle cools down the temperature of the gas from 7 °C to -47 °C while pressure is kept at 250 bar; a second main heat exchange cycle cools down the temperature of the gas from -47 °C to -77 °C while pressure is kept at 250 bar;
 at 250 bar and -77 °C, the gas passes through a Joule-Thomson valve allowing the stream to expand thereby reducing its temperature to -151 °C and reducing its pressure to 2 bar;
 at -151 °C and 2 bar, a portion of the mass of gas is liquefied and sent to storage and the portion of the mass of gas remains in the gaseous state and is injected into the second main heat exchange stage to help in the cooling process described above, increasing its temperature from -151 °C to -60 °C; and the remaining gas in the gaseous state at -60 °C is injected into the first main heat exchange stage to help in the cooling process described above.

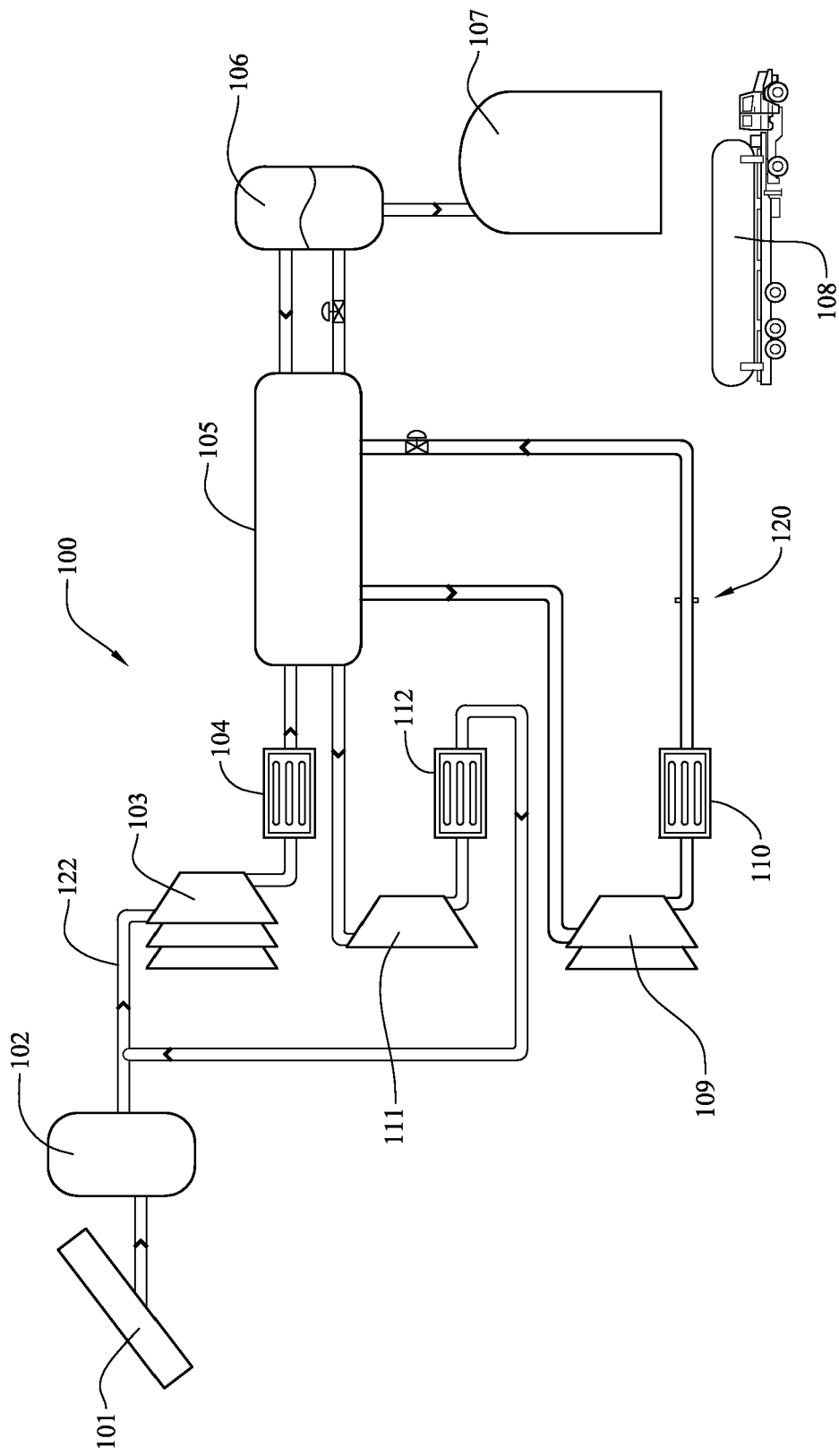


FIG. 1

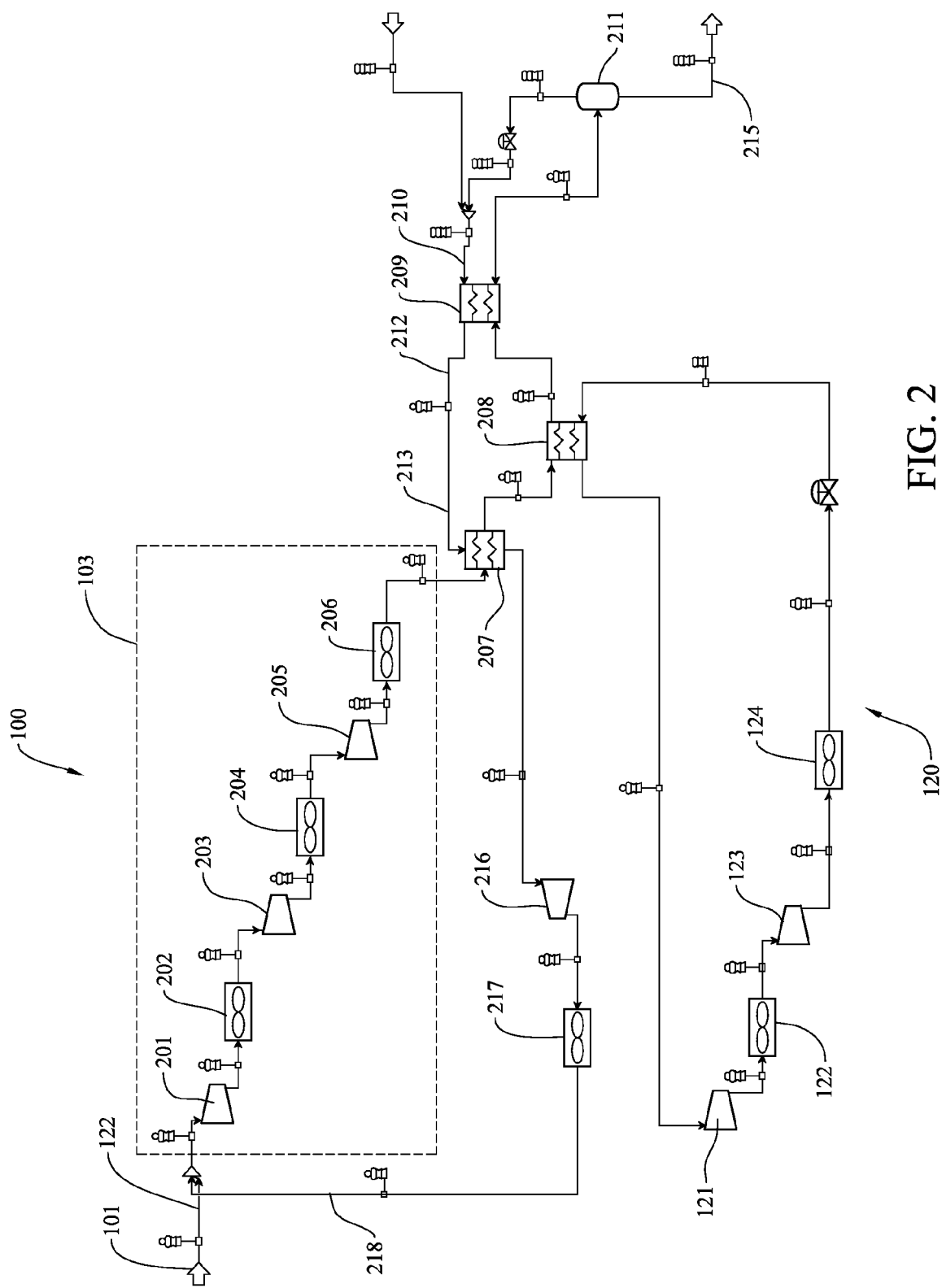


FIG. 2

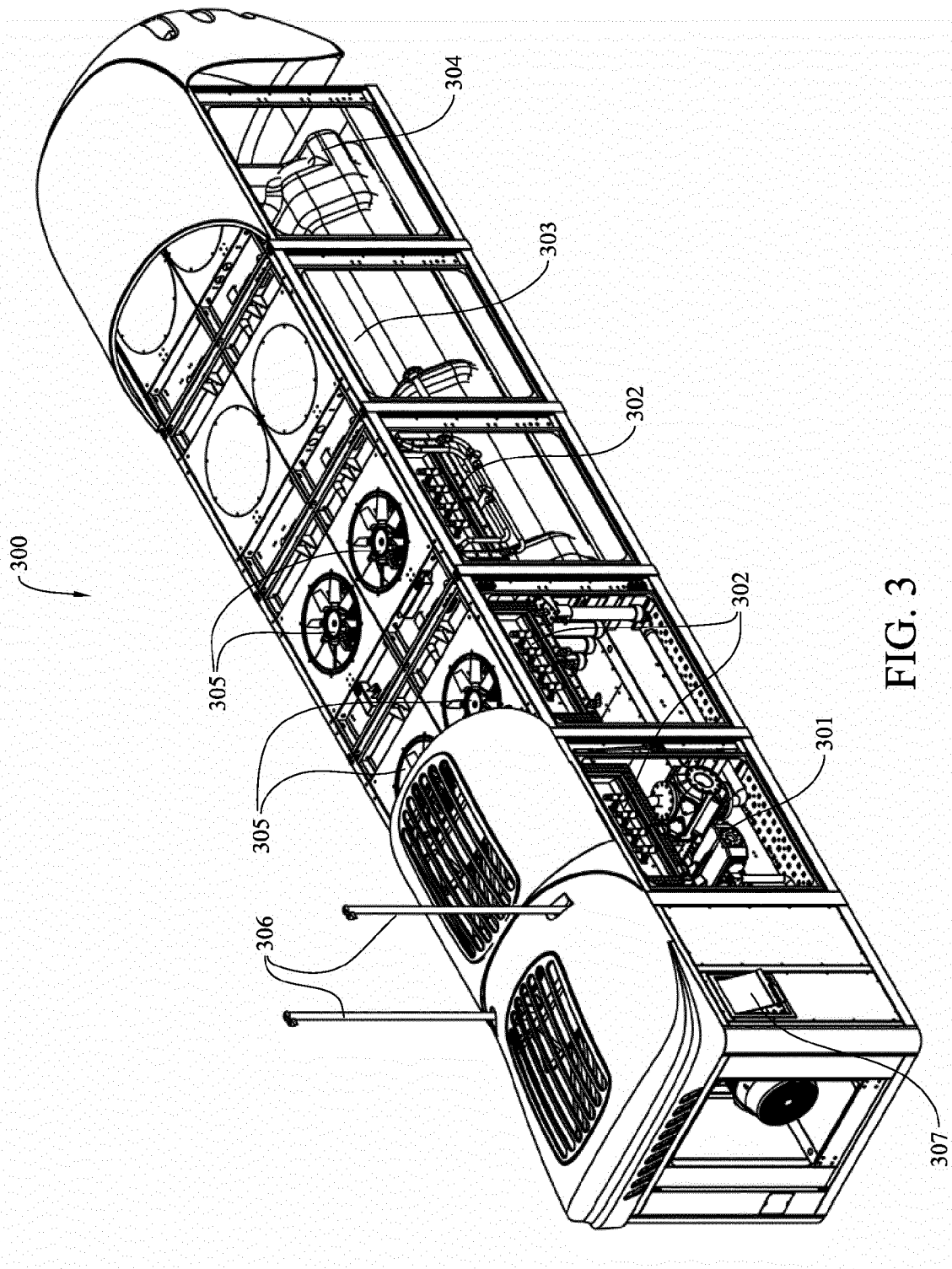


FIG. 3

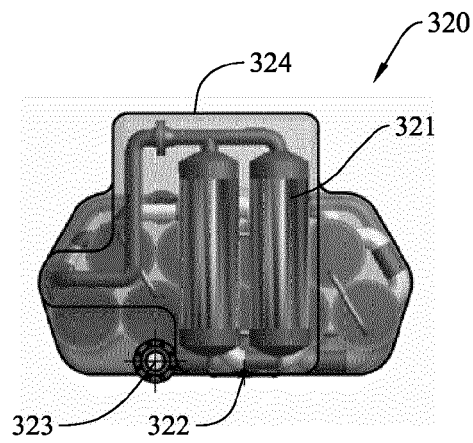


FIG. 4

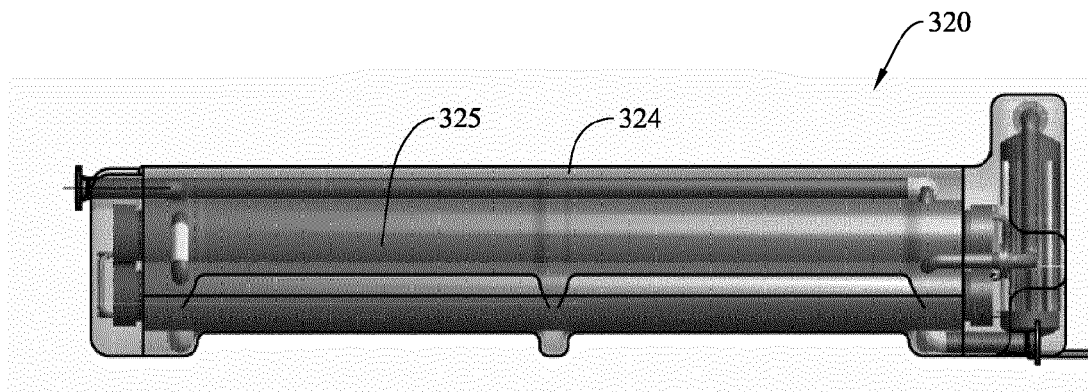


FIG. 5

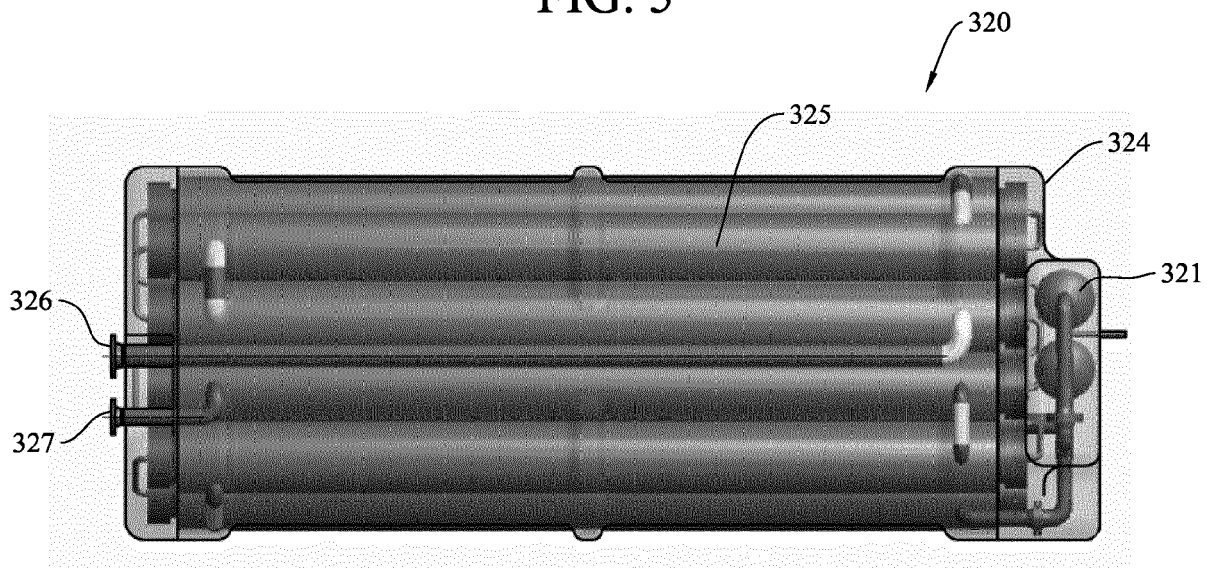


FIG. 6