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(71) Applicant: **Korea Gas Corporation**
Gyeonggi-do 463-754 (KR)

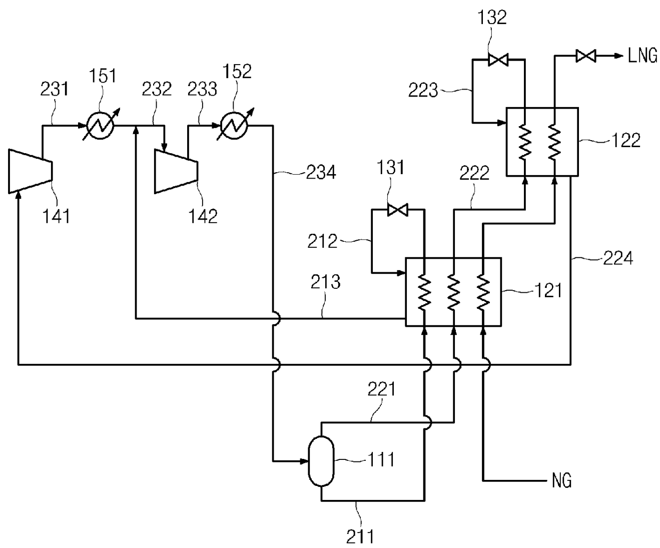
(72) Inventors:
- **LEE, Sang Gyu**
  Seoul 137-040 (KR)
- **YOON, Ihn Soo**
  Incheon 406-840 (KR)
- **CHO, Byoung Hak**
  Incheon 406-738 (KR)
- **SOHN, Young Soon**
  Incheon 406-734 (KR)
- **CHA, Kyu Sang**
  Incheon 403-828 (KR)
- **PARK, Chang Won**
  Incheon 406-761 (KR)
- **KWON, Yong Soo**
  Incheon 405-824 (KR)

(74) Representative: **Cabinet Laurent & Charras**
Le Contemporain
50 Chemin de la Bruyère
69574 Dardilly Cedex (FR)

(54) NATURAL GAS LIQUEFACTION PROCESS

(57) A natural gas liquefaction process according to the present invention uses a single closed-loop refrigeration cycle employing a mixed refrigerant, thereby having a simple structure for the liquefaction process and allowing the liquefaction process to be easily operated. Furthermore, the present invention cools natural gas after one stream is separated into two streams, thereby having an excellent efficiency of the liquefaction process.

[Fig. 1]



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Description

TECHNICAL FIELD

[0001] The present invention relates to a natural gas liquefaction process, and more particularly, to a natural gas liquefaction process which is capable of being simplified in structure and being easily operated as well as having excellent efficiency.

BACKGROUND ART

[0002] A thermodynamic process of liquefying natural gas to produce liquefied natural gas (LNG) has been developed since 1970s in order to satisfy various assignments including demands for higher efficiency and larger capacity. In order to satisfy these demands, i.e., to increase the efficiency and capacity of the liquefaction process, various attempts to liquefy natural gas by using different refrigerants or different cycles have been continuously conducted up to now. However, the number of liquefaction processes that are practically used is very small.

[0003] One of the liquefaction processes that are being operated and have been most widely used is a 'propane pre-cooled mixed refrigerant process (or a C3/MR process)'. As illustrated in FIG. 12, in the C3/MR process, natural gas (NG) is pre-cooled up to approximately 238 K through a Joule-Thomson (JT) cycle (or a propane cycle) using a propane refrigerant C3. Then, the pre-cooled natural gas is liquefied and sub-cooled up to approximately 123 K through a mixed refrigerant cycle using a mixed refrigerant (MR) or a multi-component refrigerant. As described above, since the C3/MR process uses a refrigeration cycle using a single refrigerant and a refrigeration cycle using a mixed refrigerant, the liquefaction process is complex, and also it is difficult to operate the liquefaction process.

[0004] Another one of the liquefaction processes that are being operated is a cascade process by Conoco Phillips Company. As illustrated in FIG. 13, the liquefaction process by Conoco Phillips Company consists of three Joule-Thomson cycles using methane C1, ethylene C2, and propane C3. As described above, since the cascade process uses only the refrigeration cycle using the single refrigerant, the liquefaction process is simplified in operation and improved in reliability. However, since an individual equipment (e.g., a heat exchanger) is needed for each of the three refrigeration cycles in the cascade process, there is a disadvantage that the liquefaction process needs to be increased in scale.

[0005] Another one of the liquefaction processes that are being operated is a 'single mixed refrigerant process (or SMR process)'. As illustrated in FIG. 14, in the SMR process, the natural gas is liquefied through a single closed-loop refrigeration cycle using the mixed refrigerant. The above-mentioned SMR process has an advantage that the liquefaction process is simplified in structure. However, the SMR process has a disadvantage in that the liquefaction process has low efficiency.

DISCLOSURE OF THE INVENTION

TECHNICAL PROBLEM

[0006] To solve the above-described problems, an objective of the present invention is to provide a natural gas liquefaction process which is capable of being simplified in structure and being easily operated as well as having excellent efficiency.

TECHNICAL SOLUTION

[0007] A natural gas liquefaction process according to the present invention relates to a natural gas liquefaction process in which natural gas is primarily cooled in a first heat exchange part and secondarily cooled in a second heat exchange part distinguished from the first heat exchange part by using a single closed-loop refrigeration cycle using a mixed refrigerant, wherein the closed-loop refrigeration cycle includes: a condensation step of partially condensing the mixed refrigerant; a first separation step of separating the mixed refrigerant into a first stream having a liquid phase and a second stream having a gas phase after the condensation step; a first introduction step of introducing the first stream into the first heat exchange part after the first separation step; a first expansion step of expanding the first stream discharged from the first heat exchange part after the first introduction step; a first cooling step of introducing the first stream again into the first heat exchange part to cool the natural gas in the first heat exchange part through the first stream after the first expansion step; a first recovery step of recovering the first stream from the first heat exchange part after the first cooling step; a second introduction step of introducing the second stream into the first heat exchange part after the first separation step; a third introduction step of introducing the second stream discharged from the first heat exchange part into the second heat exchange part after the second introduction step; a second expansion step of expanding the second stream discharged from the second heat exchange part after the third introduction step; a second cooling step of introducing the second stream again into the second heat exchange part to cool the natural gas in the second heat exchange part through the second stream after the second expansion step; and a second recovery step of recovering the second stream from the second heat exchange part after the second cooling step.

ADVANTAGEOUS EFFECTS

[0008] In the natural gas liquefaction process according to the present invention, since the single closed-loop refrigeration cycle using the mixed refrigerant is used, the liquefaction process may be simplified in structure and easily operated. In addition, since a single stream is separated into two streams, and then, each of the two streams cools the natural gas, the liquefaction process may have the excellent efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

FIG. 1 is a flowchart illustrating a natural gas liquefaction process according to Embodiment 1 of the present invention.
FIG. 2 is a flowchart illustrating a first modified example of the natural gas liquefaction process of FIG. 1.
FIG. 3 is a flowchart illustrating a second modified example of the natural gas liquefaction process of FIG. 1.
FIG. 4 is a flowchart illustrating a third modified example of the natural gas liquefaction process of FIG. 1.
FIG. 5 is a flowchart illustrating a fourth modified example of the natural gas liquefaction process of FIG. 1.
FIG. 6 is a flowchart illustrating a fifth modified example of the natural gas liquefaction process of FIG. 1.
FIG. 7 is a flowchart illustrating a sixth modified example of the natural gas liquefaction process of FIG. 1.
FIG. 8 is a flowchart illustrating a natural gas liquefaction process according to Embodiment 2 of the present invention.
FIG. 9 is a flowchart illustrating a modified example of the natural gas liquefaction process of FIG. 8.
FIG. 10 is a flowchart illustrating a natural gas liquefaction process according to Embodiment 3 of the present invention.
FIG. 11 is a flowchart illustrating a modified example of the natural gas liquefaction process of FIG. 10.
FIG. 12 is a conceptual flowchart of a C3/MR process according to a related art.
FIG. 13 is a conceptual flowchart of a cascade process according to the related art.
FIG. 14 is a conceptual flowchart of an SMR process according to the related art.

MODE FOR CARRYING OUT THE INVENTION

[0010] Preferred embodiments of the present invention will be described below in more detail with reference to the accompanying drawings. However, the present invention is not limited to the embodiments below.

Embodiment 1

[0011] FIG. 1 is a flowchart illustrating a natural gas liquefaction process according to Embodiment 1 of the present invention. A liquefaction process according to Embodiment 1 of the present invention, as illustrated in FIG. 1, may be applied to a process in which a single closed-loop refrigeration cycle is used to cool natural gas up to a liquefaction temperature, thereby producing liquefied natural gas (LNG). Particularly, the liquefaction process may be applied to a natural gas liquefaction process in which natural gas is primarily cooled in a first heat exchange part and then secondarily cooled in a second heat exchange part distinguished from the first heat exchange part by using a single closed-loop refrigeration cycle using a mixed refrigerant or multi-component refrigerant. In addition, the liquefaction process according to the current embodiment may further include a refrigeration cycle for additionally cooling the mixed refrigerant or the natural gas.

[0012] Hereinafter, the liquefaction process according to Embodiment 1 of the present invention will be described in more detail with reference to FIG. 1. First, a mixed refrigerant (a main stream that will be described below) is partially condensed (a condensation step). That is, the mixed refrigerant is partially condensed through a series of compression processes. Thus, the mixed refrigerant includes a liquid phase refrigerant and a gas phase refrigerant. Then, the mixed refrigerant is introduced into a separation unit 111 and separated into a first stream having a liquid phase and a second stream having a gas phase (a first separation step). Here, the separation unit 111 may be a normal vapor-liquid separator. This may be equally applied to a different separation unit that will be described below.

[0013] The first stream is introduced into a first heat exchange part 121 through a conduit 211 (a first introduction step). Then, the first stream is discharged from the first heat exchange part 121 and then introduced into an expansion unit 131 and expanded (a first expansion step). Thus, the first stream decreases in temperature. The expansion unit may include a Joule-Thomson (J-T) valve. For example, the expansion unit may include a normal expansion valve. Alternatively, the expansion unit may include an expander. This may be equally applied to a different expansion unit that will be described below. The J-T valve may reduce all of a pressure and a temperature of the stream through a J-T effect.

[0014] The first stream decreases in temperature due to the expansion and is introduced again into the first heat exchange part 121 through a conduit 212 to cool the natural gas (NG) in the first heat exchange part 121 (a first cooling step). The first stream introduced into the first heat exchange part 121 through the conduit 212 cools the natural gas together with the first stream introduced into the first heat exchange part 121 through the conduit 211 and the second stream introduced into the first heat exchange part 121 through a conduit 221. The natural gas may be pre-cooled through the above-described cooling. As described above, the first stream performs the cooling in the first heat exchange part 121 and then is recovered from the first heat exchange part 121 (a first recovery step). The first stream is recovered from the first heat exchange part 121 and then transferred for the condensation step through the conduit 213.

[0015] The second stream is introduced into the first heat exchange part 121 through the conduit 221 (a second introduction step). In the first heat exchange part 121, the second stream is cooled by the first stream introduced into the first heat exchange part 121 through the conduit 212. Then, the second stream is introduced into a second heat exchange part 122 through a conduit 222 (a third introduction step). Then, the second stream is discharged from the second heat exchange part 122 and then introduced into the expansion unit 132 and expanded (a second expansion step). Thus, the second stream decreases in temperature through the above-described expansion.

[0016] The second stream decreases in temperature due to the expansion and is introduced again into the second heat exchange part 122 through a conduit 223 to cool the natural gas in the second heat exchange part 122 (a second cooling step). The natural gas may be liquefied through the above-described cooling. As described above, the second stream performs the cooling in the second heat exchange part 122 and then is recovered from the second heat exchange part 122 (a second recovery step). The second stream is recovered from the second heat exchange part 122 and then transferred for the condensation step through a conduit 224.

[0017] For reference, it is preferable that the first heat exchange part 121 includes a spiral wound heat exchanger (SWHE)-type heat exchanger. This may be equally applied to the second heat exchange part 122. In more detail, in case of the natural gas liquefaction process, a plate fin heat exchanger (PFHE)-type heat exchanger or a spiral wound heat exchanger (SWHE)-type heat exchanger is generally used for the heat exchanging. In case of the PFHE-type heat exchanger, a stream for cooling a different stream may be provided in plurality, and a stream cooled by a different stream may be provided in plurality. On the other hand, in case of the SWHE-type heat exchanger, a stream for cooling a different stream is provided in one, or a stream cooled by a different stream is provided in one.

[0018] Thus, the liquefaction process using the SWHE-type heat exchanger may be different from that using the PFHE-type heat exchanger. That is, the liquefaction process based on the PFHE-type heat exchanger may not be applied to that using the SWHE-type heat exchanger as it is. In case of the current embodiment, a single stream (a main stream that will be described below) is separated into two streams (a first stream and a second stream), and then the two streams are respectively used for cooling the natural gas in the first and second heat exchange parts 121 and 122. Thus, in case of the current embodiment, it is necessary to distinguish the first heat exchange part 121 from the second heat exchange part 122 so as to use the SWHE-type heat exchanger. That is, the first heat exchange part 121 may be provided as one SWHE-type heat exchanger, and the second heat exchange part 122 may be provided as the other SWHE-type heat exchanger. In addition, the SWHE-type heat exchanger is advantageous when a liquefaction system has large capacity. Also, the SWHE-type heat exchanger is advantageous for maintaining and repairing the liquefaction system.

[0019] As described above, in the liquefaction process according to the current embodiment, the natural gas is liquefied by using the single closed-loop refrigeration cycle. Thus, the liquefaction process according to the current embodiment has advantages in that the liquefaction process is simplified in structure and easily operated. Also, in the liquefaction process according to the current embodiment, a single stream is separated into two streams, and then, each of the two streams cools the natural gas. Thus, although the liquefaction process according to the current embodiment includes a single refrigeration cycle, the liquefaction process may have an effect as if the natural gas is cooled through two refrigeration cycles. As a result, the liquefaction process may have excellent efficiency.

[0020] The condensation step may be described in more detail as follows. The second stream is recovered from the second heat exchange part 122 and then introduced into a compression unit 141 through a conduit 224 and compressed (a first compression step). Here, the compression unit 141 may be a normal compressor. Alternatively, the compression unit 141 may be a multistage compressor. This may be equally applied to a different compression unit that will be described below. Then, the second stream is introduced into a cooling unit 151 through a conduit 231 and cooled. Here, the cooling unit 151 may be a water cooling type or air cooling type cooler. This may be equally applied to a different cooling unit that will be described below. Here, the cooling unit 151 may be selectively provided. That is, the cooling unit 151 may be provided when it is necessary to cool the compressed stream. This may be equally applied to a different cooling unit.

[0021] The second stream is mixed with the first stream after the above-described cooling. That is, the first stream is recovered from the first heat exchange part 121 and then mixed with the second stream (a first mixing step). The above-described mixing may be achieved by connecting on conduit 213 to the other conduit 232. Alternatively, a separate constituent for the mixing may be provided. The main stream may be formed through the mixing. That is, the main stream may be a stream in which the first stream and the second stream are mixed with each other. The main stream is compressed by a compression unit 142 (a second compression step). Then, the main stream is introduced into a cooling unit 152 through a conduit 233 and cooled. The main stream is partially condensed through the series of processes and introduced into a separation unit 111 through a conduit 234.

[0022] For reference, the mixing may be a relative concept. That is, the first and second streams may be mixed with each other, or the second stream may be mixed with the first stream according to the structure of the conduit. Also, the first and second streams may be independently introduced into the compression unit 142 and then mixed with each other in the compression unit 142. Also, the above-described conduits may be different from each other or the same according to the reference numerals. That is, for convenience of description, two reference numerals may be given to only one conduit. On the other hand, for convenience of description, only one reference numeral may be given to two conduits.

[0023] The liquefaction process according to the current embodiment may be modified as illustrated in FIG. 2. FIG. 2 is a flowchart illustrating a first modified example of the natural gas liquefaction process of FIG. 1. As illustrated in FIG. 2, in the liquefaction process according to the modified example, the condensation process basically further includes a third compression step and a fourth compression step. In more detail, a main stream in the liquefaction process according to the modified example is cooled by a cooling unit 152 and then introduced into a compression unit 143 through a conduit 2341 and compressed (a third compression step). Then, the main stream is introduced into a cooling unit 153 through a conduit 2342 and cooled.

[0024] Then, the main stream is introduced into a separation unit 112 through a conduit 2343 and then separated into a third stream having a liquid phase and a fourth stream having a gas phase (a second separation step). Then, the third stream is mixed with the main stream within the conduit 2341 through a conduit 2344 (a second mixing step). Here, the third stream is expanded by an expansion unit and then mixed with the main stream. Then, the third stream is introduced into the compression unit 143 together with the main stream. Also, the fourth stream is introduced into a compression unit 144 through a conduit 2345 and compressed (a fourth compression step). Then, the fourth stream is introduced into a cooling unit 154 through a conduit 2346 and cooled. The fourth stream is partially condensed through the series of processes and introduced into a separation unit 111 through a conduit 2347.

[0025] Here, it is preferable that the compression unit (for example, the compression unit expressed by reference numeral 144) receives a gas refrigerant. However, when the refrigerant is mixed, or the refrigerant is compressed or cooled like the mixture of the first and second streams, a liquid refrigerant may be generated. Thus, when the separation unit 112 is used as described in the modified example, only the gas refrigerant may be supplied into the compression unit.

[0026] Also, the liquefaction process according to the current embodiment may be modified as illustrated in FIG. 3. FIG. 3 is a flowchart illustrating a second modified example of the natural gas liquefaction process of FIG. 1. As illustrated in FIG. 3, the second stream is recovered from the second heat exchange part 122 and then introduced into a compression unit 141 through a conduit 224 and compressed (a first compression step). Then, the second stream is introduced into a cooling unit 151 through a conduit 231 and cooled.

[0027] The second stream is mixed with the first stream after the cooling. That is, the first stream is recovered from the first heat exchange part 121 and then mixed with the second stream (a first mixing step). The main stream may be formed through the mixing. As described above, the main stream is introduced into a separation unit 112 through a conduit 2321 and then separated into a third stream having a liquid phase and a fourth stream having a gas phase (a second separation step). The fourth stream is introduced into a compression unit 142 through a conduit 2322 and compressed (a second compression step). Then, the fourth stream is mixed with the third stream (a second mixing step). Here, the third stream may be forcibly transferred into a conduit 2324 by a pump 161. Then, the third stream and the fourth stream (the main stream) are introduced into a cooling unit 152 through a conduit 2324 and cooled. The main stream is partially condensed through the series of processes and introduced into a separation unit 111 through a conduit 234. The liquid refrigerant which may be generated while the refrigerant is compressed may be increased in pressure by using a refrigerant pump because the liquid refrigerant is not increased in pressure by using a refrigerant compressor.

[0028] Also, the liquefaction process according to the current embodiment may be modified as illustrated in FIG. 4. FIG. 4 is a flowchart illustrating a first modified example of the natural gas liquefaction process of FIG. 1. As illustrated in FIG. 4, in the liquefaction process according to the modified example, a compression unit 1411 may be further provided. In more detail, when the first and second streams are mixed with each other to form a main stream, the main stream is introduced into the compression unit 1411 through a conduit 1231 and compressed. Then, the main stream is introduced into a cooling unit 1511 through a conduit 1232 and cooled. Then, the main stream is introduced into a separation unit 112 through a conduit 1233. The liquid refrigerant which may be generated while the refrigerant is additionally compressed may be increased in pressure by using a refrigerant pump, like the additional compression stage as described in the modified example, because the liquid refrigerant is not increased in pressure by using a refrigerant compressor.

[0029] Furthermore, the liquefaction process according to the current embodiment may be modified as illustrated in FIG. 5. FIG. 5 is a flowchart illustrating a first modified example of the natural gas liquefaction process of FIG. 1. As illustrated in FIG. 5, in the liquefaction process according to the modified example, the second stream is recovered from the second heat exchange part 122 and then introduced into a compression unit 141 through a conduit 224 and compressed (a first compression step). Then, the second stream is introduced into a cooling unit 151 through a conduit 231 and cooled. Also, the first stream is recovered from the first heat exchange part 121 and then introduced into a compression unit 142 through a conduit 213 and compressed (a second compression step). Then, the first stream is introduced into a cooling unit 152 through a conduit 291 and cooled.

[0030] Then, the first stream is mixed with the second stream within the conduit 292 through a conduit 232 (a first mixing step). The main stream may be formed through the mixing. That is, the main stream may be a stream in which the first stream and the second stream are mixed with each other. The main stream is compressed by the compression unit 143 (a third compression step). Then, the main stream is introduced into a cooling unit 153 through a conduit 233 and cooled. The main stream is partially condensed through the series of processes and introduced into a separation unit 111 through a conduit 234.

[0031] In the liquefaction process according to the modified example, the main stream is separated into the first and second streams by the separation unit 111, and then, the first and second streams are not mixed with each other until the first and second streams are compressed by the compression units 141 and 142. Thus, conditions different from each other (for example, pressure conditions) may be applied to the first and second streams. Therefore, the liquefaction process according to the modified example may be very advantageous for optimizing the liquefaction process.

[0032] Also, the liquefaction process according to the current embodiment may be modified as illustrated in FIG. 6. FIG. 6 is a flowchart illustrating a fifth modified example of the natural gas liquefaction process of FIG. 1. As illustrated in FIG. 6, in the liquefaction process according to the modified example, the second stream is recovered from the second heat exchange part 122 and then introduced into a compression unit 141 through a conduit 224 and compressed (a first compression step). Then, the second stream is introduced into a cooling unit 151 through a conduit 241 and cooled. Also, the first stream is recovered from the first heat exchange part 121 and then introduced into a compression unit 142 through a conduit 213 and compressed (a second compression step). Then, the first stream is introduced into a cooling unit 152 through a conduit 251 and cooled. Also, the second stream is introduced into a compression unit 143 through a conduit 242 and compressed (a third compression step). Then, the second stream is introduced into a cooling unit 153 through a conduit 243 and cooled.

[0033] Then, the second stream is mixed with the first stream. That is, the first stream is mixed with the second stream within the conduit 252 through a conduit 244 (a first mixing step). The main stream may be formed through the mixing. As described above, the main stream is introduced into a separation unit 112 and then separated into a third stream having a liquid phase and a fourth stream having a gas phase (a second separation step). Then, the third stream is mixed with the second stream within the conduit 245 through a conduit 242 (a second mixing step). Here, the third stream is expanded by an expansion unit and then mixed with the second stream. Then, the third stream is introduced into the compression unit 143 together with the second stream. Also, the fourth stream is introduced into a compression unit 144 through a conduit 246 and compressed (a fourth compression step). Then, the fourth stream is introduced into a cooling unit 154 through a conduit 247 and cooled. The fourth stream is partially condensed through the series of processes and introduced into a separation unit 111 through a conduit 248.

[0034] The liquefaction process according to the modified example may have the same characteristics as that according to the forgoing fourth modified example. That is, in the liquefaction process according to the modified example, the fourth stream is separated into the first and second streams by the separation unit, and then, the first and second streams are not mixed with each other until the first and second streams are compressed by the compression unit. In addition, the liquefaction process according to the modified example may have the same characteristics as that according to the forgoing first modified example. That is, in the liquefaction process according to the modified example, only the gas refrigerant may be supplied by using the compression unit.

[0035] Furthermore, the liquefaction process according to the current embodiment may be modified as illustrated in FIG. 7. FIG. 7 is a flowchart illustrating a sixth modified example of the natural gas liquefaction process of FIG. 1. As illustrated in FIG. 7, in the liquefaction process according to the modified example, the second stream is recovered from the second heat exchange part 122 and then introduced into a compression unit 141 through a conduit 224 and compressed (a first compression step). Then, the second stream is introduced into a cooling unit 151 through a conduit 231 and cooled. Also, the first stream is recovered from the first heat exchange part 121 and then introduced into a compression unit 142 through a conduit 213 and compressed (a second compression step). Then, the first stream is introduced into a cooling unit 152 through a conduit 291 and cooled.

[0036] Then, the first stream is mixed with the second stream within the conduit 292 through a conduit 2331 (a first mixing step). The main stream may be formed through the mixing. The main stream is introduced into a separation unit 112 and then separated into a third stream having a liquid phase and a fourth stream having a gas phase (a second separation step). The fourth stream is introduced into a compression unit 143 through a conduit 2332 and compressed (a third compression step). Then, the fourth stream is mixed with the third stream (a second mixing step). Here, the third stream may be forcibly transferred into a conduit 2334 by a pump 161. Then, the main stream is introduced into a cooling unit 153 through a conduit 2334 and cooled. The main stream is partially condensed through the series of processes and introduced into a separation unit 111 through a conduit 234. A compressor has to be used for increasing a pressure of the refrigerant mixed in the first mixing step. However, if the liquid refrigerant is generated in the first mixing step, it is impossible to directly introduce the liquid refrigerant into the compressor. Thus, the generated liquid refrigerant has to be separated and then increased in pressure by using the pump.

Embodiment 2

[0037] FIG. 8 is a flowchart illustrating a natural gas liquefaction process according to Embodiment 2 of the present invention. As illustrated in FIG. 8, the liquefaction process according to the current embodiment may be similar to that according to the foregoing Embodiment 1, particularly, the fifth modified example. However, the liquefaction process according to the current embodiment is the same as the forgoing fifth modified example except for a third heat exchange part. For reference, the same (equivalent) component as that according to the foregoing embodiment is given by the same (equivalent) reference number, and thus, their detailed description will be omitted.

[0038] As illustrated in FIG. 8, in the liquefaction process according to the current embodiment, a second stream is introduced into a third heat exchange part 123 through a conduit 2211 (a second introduction step). In the third heat exchange part 123, the second stream is cooled by the second stream introduced into the third heat exchange part 123 through a conduit 2214. Then, the second stream is introduced into a second heat exchange part 122 through a conduit 2212 (a third introduction step). Then, the second stream is discharged from the second heat exchange part 122 and then introduced into an expansion unit 132 and expanded (a second expansion step). Thus, the second stream decreases in temperature through the above-described expansion.

[0039] The second stream decreases in temperature due to the expansion and is introduced again into the second heat exchange part 122 through a conduit 2213 to cool natural gas in the second heat exchange part 122 (a second cooling step). The natural gas may be liquefied through the above-described cooling. As described above, the second stream performs the cooling in the second heat exchange part 122 and then is recovered from the second heat exchange part 122 through a conduit 2214 and introduced again into the third heat exchange part 123 (a fourth introduction step). The second stream may have some cool energy after the natural gas is cooled in the second heat exchange part 122. Thus, the liquefaction process according to the current embodiment is characterized in that the cool energy is used in the third heat exchange part 123. That is, in the third heat exchange part 123, the second stream cools the second stream introduced into the third heat exchange part 123 through the conduit 2211. The second stream performs the cooling in the second heat exchange part and then recovered from the third heat exchange part 123 (a second recovery step). The second stream is recovered from the third heat exchange part 123 and then transferred for the condensation step through a conduit 2215.

[0040] For reference, it is preferable that each of the first and second heat exchange parts 121 and 122 includes an SWHE-type heat exchanger. However, the third heat exchange part 123 may be an SWHE-type heat exchange or PFHE-type heat exchanger. That is, the third heat exchange part 123 is not particularly limited to the type of heat exchanger. However, the third heat exchange part 123 may be separately provided with respect to the first heat exchange part 121. (The third heat exchange part may be integrated with the second heat exchange part)

[0041] The liquefaction process according to the current embodiment may be modified as illustrated in FIG. 9. FIG. 9 is a flowchart illustrating a modified example of the natural gas liquefaction process of FIG. 8. As illustrated in FIG. 9, in the liquefaction process according to the modified example, the second stream is separated into a first portion and a second portion. The above-described branch may be achieved by branching the other conduit 2216 from one conduit 2211. Alternatively, a separate constituent for the branch may be provided.

[0042] Here, the first portion may be introduced into the third heat exchange part 123. That is, in the liquefaction process according to Embodiment 2, the whole second stream is supplied into the third heat exchange part 123. However, in the liquefaction process according to the modified example, only a portion of the second stream is supplied into the third heat exchange 123. Also, the second portion is introduced into the first heat exchange part 121 through a conduit 2216. Here, the second portion is cooled by the first stream introduced into the first heat exchange part 121 through the conduit 212. Then, the first and second portions are mixed again with each other and then introduced into the second heat exchange part 122 (see the conduits 2212 and 2217).

[0043] In the liquefaction process according to the modified example, the first portion of the second stream is cooled in the third heat exchange part 123, and the second portion of the second stream is cooled in the first heat exchange part 121. That is, in the liquefaction process according to the modified example, the second stream is separated into the two portions, and then, the two portions are respectively cooled in the heat exchange parts different from each other. Thus, the liquefaction process according to the modified example, it is unnecessary to cool the whole second stream in the third heat exchange part 123. Therefore, the liquefaction process according to the modified example may be suitable when it is difficult to cool the whole second stream in the third heat exchange part 123.

Embodiment 3

[0044] FIG. 10 is a flowchart illustrating a natural gas liquefaction process according to Embodiment 3 of the present invention. As illustrated in FIG. 10, the liquefaction process according to the current embodiment may be similar to that according to the foregoing Embodiment 1, particularly, the fifth modified example. However, the liquefaction process according to the current embodiment is the same as the forgoing fifth modified example except for a third heat exchange part. For reference, the same (equivalent) component as that according to the foregoing embodiment is given by the same (equivalent) reference number, and thus, their detailed description will be omitted.

[0045] As illustrated in FIG. 10, in the liquefaction process according to the current embodiment, a second stream is introduced into a first heat exchange part 121 through a conduit 2311 (a second introduction step). In the first heat exchange part 121, the second stream is cooled by a first stream introduced into the first heat exchange part 121 through a conduit 212. Then, the second stream is introduced into a second heat exchange part 122 through a conduit 2312 (a third introduction step). Then, the second stream is discharged from the second heat exchange part 122 and then introduced into an expansion unit 132 and expanded (a second expansion step). Thus, the second stream decreases in temperature through the above-described expansion.

[0046] The second stream decreases in temperature due to the expansion and is introduced again into the second heat exchange part 122 through a conduit 2313 to cool natural gas in the second heat exchange part 122 (a second cooling step). The natural gas may be liquefied through the above-described cooling. As described above, the second stream performs the cooling in the second heat exchange part 122 and then is recovered from the second heat exchange part 122 through a conduit 2314 and introduced into the third heat exchange part 123. The second stream may have some cool energy after the natural gas is cooled in the second heat exchange part 122. Thus, the liquefaction process according to the current embodiment is characterized in that the cool energy is used in the third heat exchange part 123. That is, in the third heat exchange part 123, the second stream cools the natural gas introduced into the third heat exchange part 123 through a conduit 311 (a third cooling step). The natural gas may be pre-cooled through the above-described cooling. The second stream performs the cooling in the second heat exchange part and then is recovered from the third heat exchange part 123 (a second recovery step). The second stream is recovered from the third heat exchange part 123 and then transferred for the condensation step through a conduit 2315.

[0047] As described above, the natural gas is primarily cooled in the third heat exchange part 123 and then supplied into the second heat exchange part 122 through a conduit 312. Then, the natural gas is secondarily cooled in the second heat exchange part 122. As a result, the natural gas may be liquefied. For reference, it is preferable that each of the first and second heat exchange parts 121 and 122 includes an SWHE-type heat exchanger. However, the third heat exchange part 123 may be an SWHE-type heat exchange or PFHE-type heat exchanger. That is, the third heat exchange part 123 is not particularly limited to the type of heat exchanger. However, the third heat exchange part 123 may be separately provided with respect to the first heat exchange part 121. (The third heat exchange part may be integrated with the second heat exchange part)

[0048] The liquefaction process according to the current embodiment may be modified as illustrated in FIG. 11. FIG. 11 is a flowchart illustrating a modified example of the natural gas liquefaction process of FIG. 10. As illustrated in FIG. 11, in the liquefaction process according to the modified example, the natural gas is separated into a first portion and a second portion. The above-described branch may be achieved by branching one conduit into two conduits. Alternatively, a separate constituent for the branch may be provided.

[0049] Here, the first portion may be introduced into the third heat exchange part 123. That is, in the liquefaction process according to Embodiment 3, the whole natural gas is supplied into the third heat exchange part 123. However, in the liquefaction process according to the modified example, only a portion of the natural gas is supplied into the third heat exchange 123. Also, the second portion is introduced into the first heat exchange part 121 through a conduit 313. Here, the second portion is cooled by the first stream introduced into the first heat exchange part 121 through the conduit 212. Then, the first and second portions are mixed again with each other and then introduced together into the second heat exchange part 122 (see the conduits 312 and 314).

[0050] In the liquefaction process according to the modified example, the first portion of the natural gas is cooled in the third heat exchange part 123, and the second portion of the natural gas is cooled in the first heat exchange part 121. That is, the liquefaction process according to the modified example is characterized in that the natural gas is separated into the two portions, and then, the two portions are respectively cooled (pre-cooled) in the heat exchange parts different from each other.

Claims

1. A natural gas liquefaction process in which natural gas is primarily cooled in a first heat exchange part and secondarily cooled in a second heat exchange part distinguished from the first heat exchange part by using a single closed-loop refrigeration cycle using a mixed refrigerant, the closed-loop refrigeration cycle comprising:

    a condensation step of partially condensing the mixed refrigerant;
    a first separation step of separating the mixed

refrigerant into a first stream having a liquid phase and a second stream having a gas phase after the condensation step;
a first introduction step of introducing the first stream into the first heat exchange part after the first separation step;
a first expansion step of expanding the first stream discharged from the first heat exchange part after the first introduction step;
a first cooling step of introducing the first stream again into the first heat exchange part to cool the natural gas in the first heat exchange part through the first stream after the first expansion step;
a first recovery step of recovering the first stream from the first heat exchange part after the first cooling step;
a second introduction step of introducing the second stream into the first heat exchange part after the first separation step;
a third introduction step of introducing the second stream discharged from the first heat exchange part into the second heat exchange part after the second introduction step;
a second expansion step of expanding the second stream discharged from the second heat exchange part after the third introduction step;
a second cooling step of introducing the second stream again into the second heat exchange part to cool the natural gas in the second heat exchange part through the second stream after the second expansion step; and
a second recovery step of recovering the second stream from the second heat exchange part after the second cooling step,
wherein the first stream is transferred for the condensation step after the first recovery step, and the second stream is transferred for the condensation step after the second recovery step.

2. The natural gas liquefaction process of claim 1, wherein the condensation step comprises:

a first compression step of compressing the second stream;
a first mixing step of mixing the first stream with the second stream to form a main stream after the first compression step; and
a second compression step of compressing the main stream after the first mixing step.

3. The natural gas liquefaction process of claim 1, wherein the condensation step comprises:

a first compression step of compressing the second stream;
a first mixing step of mixing the first stream with the second stream to form a main stream after the first compression step;
a second separation step of separating the main stream into a third stream having a liquid phase and a fourth stream having a gas phase after the first mixing step;
a second compression step of compressing the fourth stream after the second separation step; and
a second mixing step of transferring the third stream by using a pump to mix the third stream with the fourth stream, which is formed after the second compression step, after the second separation step,
wherein the third stream and the fourth stream are transferred together for the first separation step after the second mixing step.

4. The natural gas liquefaction process of claim 1, wherein the condensation step comprises:

a first compression step of compressing the second stream;
a second compression step of compressing the first stream;
a first mixing step of mixing the first stream with the second stream to form a main stream after the first and second compression steps; and
a third compression step of compressing the main stream after the first mixing step.

5. The natural gas liquefaction process of claim 1, wherein the condensation step comprises:

a first compression step of compressing the second stream;
a second compression step of compressing the first stream;
a third compression step of compressing the second stream after the first compression step;
a first mixing step of mixing the first stream with the second stream to form a main stream after the second and third compression steps;
a second separation step of separating the main stream into a third stream having a liquid phase and a fourth stream having a gas phase after the first mixing step;
a second mixing step of mixing the third stream with the second stream after the second separation step; and
a fourth compression step of compressing the fourth stream after the second separation step,
wherein the third stream is transferred for the third compression step together with the second stream after the second mixing step, and the fourth stream is transferred for the first separation step after the fourth compression step.

6. The natural gas liquefaction process of claim 1,

wherein
a first compression step of compressing the second stream;
a second compression step of compressing the first stream;
a first mixing step of mixing the first stream with the second stream to form a main stream after the first and second compression steps;
a second separation step of separating the main stream into a third stream having a liquid phase and a fourth stream having a gas phase after the first mixing step;
a third compression step of compressing the fourth stream after the second separation step; and
a second mixing step of transferring the third stream by using a pump to mix the third stream with the fourth stream, which is formed after the third compression step, after the second separation step,
wherein the third and fourth streams are transferred together for the first separation step after the second mixing step.

7. The natural gas liquefaction process of any one of claims 1 to 6, wherein each of the first and second heat exchange parts comprises a spiral wound heat exchanger (SWHE)-type heat exchanger.

8. A natural gas liquefaction process in which natural gas is primarily cooled in a first heat exchange part and secondarily cooled in a second heat exchange part distinguished from the first heat exchange part by using a single closed-loop refrigeration cycle using a mixed refrigerant, the closed-loop refrigeration cycle comprising:

a condensation step of partially condensing the mixed refrigerant;
a first separation step of separating the mixed refrigerant into a first stream having a liquid phase and a second stream having a gas phase after the condensation step;
a first introduction step of introducing the first stream into the first heat exchange part after the first separation step;
a first expansion step of expanding the first stream discharged from the first heat exchange part after the first introduction step;
a first cooling step of introducing the first stream again into the first heat exchange part to cool the natural gas in the first heat exchange part through the first stream after the first expansion step;
a first recovery step of recovering the first stream from the first heat exchange part after the first cooling step;
a second introduction step of introducing the second stream into a third heat exchange part which is distinguished from the first heat exchange part after the first separation step;
a third introduction step of introducing the second stream discharged from the third heat exchange part into the second heat exchange part after the second introduction step;
a second expansion step of expanding the second stream discharged from the second heat exchange part after the third introduction step;
a second cooling step of introducing the second stream again into the second heat exchange part to cool the natural gas in the second heat exchange part through the second stream after the second expansion step; and
a fourth introduction step of recovering the second stream from the second heat exchange part to introduce the recovered second stream again into the third heat exchange part after the second cooling step; and
a second recovery step of recovering the second stream from the third heat exchange part after the fourth introduction step,
wherein the first stream is transferred for the condensation step after the first recovery step, and the second stream is transferred for the condensation step after the second recovery step.

9. The natural gas liquefaction process of claim 8, further comprising:

a third separation step of separating the second stream into a first portion and a second portion after the first separation step; and
a fifth introduction step of introducing the second portion into the first heat exchange part,
wherein the second introduction step comprises introducing the first portion into the third heat exchange part, and
the third introduction step comprises introducing the first and second portions together into the second heat exchange part after the second and fifth introduction steps.

10. A natural gas liquefaction process in which natural gas is liquefied by using a single closed-loop refrigeration cycle using a mixed refrigerant, the closed-loop refrigeration cycle comprising:

a condensation step of partially condensing the mixed refrigerant;
a first separation step of separating the mixed refrigerant into a first stream having a liquid phase and a second stream having a gas phase after the condensation step;
a first introduction step of introducing the first stream into the first heat exchange part after the first separation step;
a second introduction step of introducing the second stream into the first heat exchange part

after the first separation step;
a first expansion step of expanding the first stream discharged from the first heat exchange part after the first introduction step;
a first cooling step of introducing the first stream again into the first heat exchange part to cool the second stream in the first heat exchange part through the first stream after the first expansion step;
a first recovery step of recovering the first stream from the first heat exchange part after the first cooling step;
a third introduction step of introducing the second stream discharged from the first heat exchange part into a second heat exchange part which is distinguished from the first heat exchange part after the first cooling step;
a second expansion step of expanding the second stream discharged from the second heat exchange part after the third introduction step;
a second cooling step of introducing the second stream again into the second heat exchange part to cool the natural gas in the second heat exchange part through the second stream after the second expansion step;
a third cooling step of recovering the second stream from the second heat exchange part to introduce the recovered second stream into a third heat exchange part which is distinguished from the first heat exchange part, thereby cooling the natural gas in the third heat exchange part through the second stream after the second cooling step; and
a second recovery step of recovering the second stream from the third heat exchange after the third cooling step,
wherein the first stream is transferred for the condensation step after the first recovery step, and the second stream is transferred for the condensation step after the second recovery step, and
the natural gas is primarily cooled in the third heat exchange part and secondarily cooled in the second heat exchange part, thereby being liquefied.

11. The natural gas liquefaction process of claim 10, further comprising:

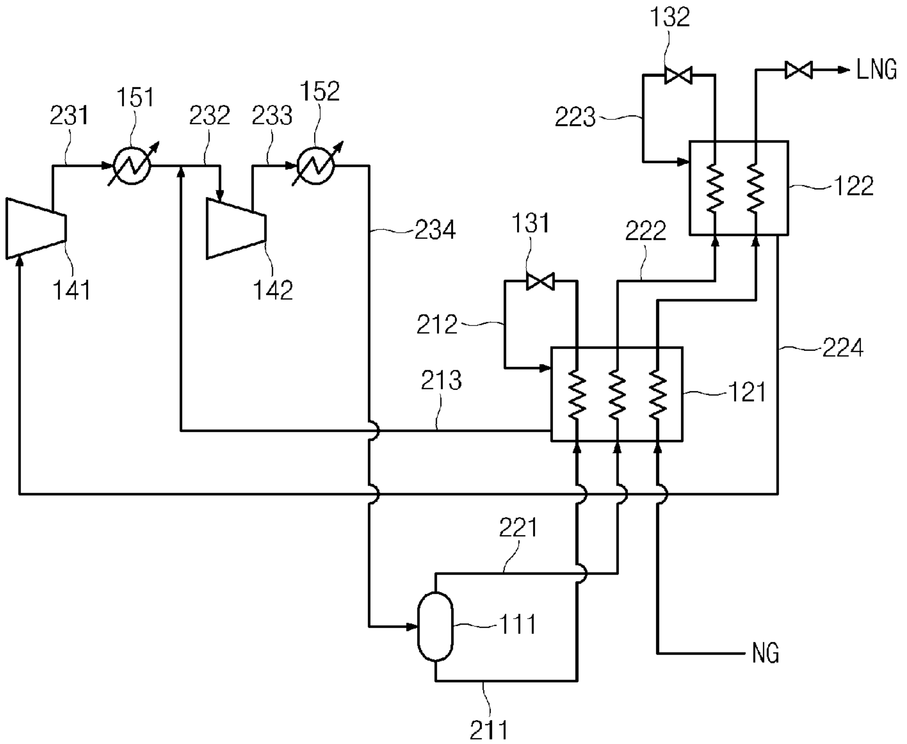
a step of separating the natural gas into a first portion and a second portion;
a first natural gas introduction step of introducing the first portion into the third heat exchange part;
a second natural gas introduction step of introducing the second portion into the first heat exchange part;
a natural gas mixing step of mixing the first portion with the second portion after the first and second natural gas introduction steps; and
a third natural gas introduction step of introducing the first portion together with the second portion into the second heat exchange part after the natural gas mixing step.

12. The natural gas liquefaction process of any one of claims 8 to 11, wherein the condensation step comprises:

a first compression step of compressing the second stream;
a second compression step of compressing the first stream;
a third compression step of compressing the second stream after the first compression step;
a first mixing step of mixing the first stream with the second stream to form a main stream after the second and third compression steps;
a second separation step of separating the main stream into a third stream having a liquid phase and a fourth stream having a gas phase after the first mixing step;
a second mixing step of mixing the third stream with the second stream after the second separation step; and
a fourth compression step of compressing the fourth stream after the second separation step,
wherein the third stream is transferred for the third compression step together with the second stream after the second mixing step, and
the fourth stream is transferred for the first separation step after the fourth compression step.

13. The natural gas liquefaction process of any one of claims 8 to 11, wherein each of the first and second heat exchange parts comprises a spiral wound heat exchanger (SWHE)-type heat exchanger.

[Fig. 1]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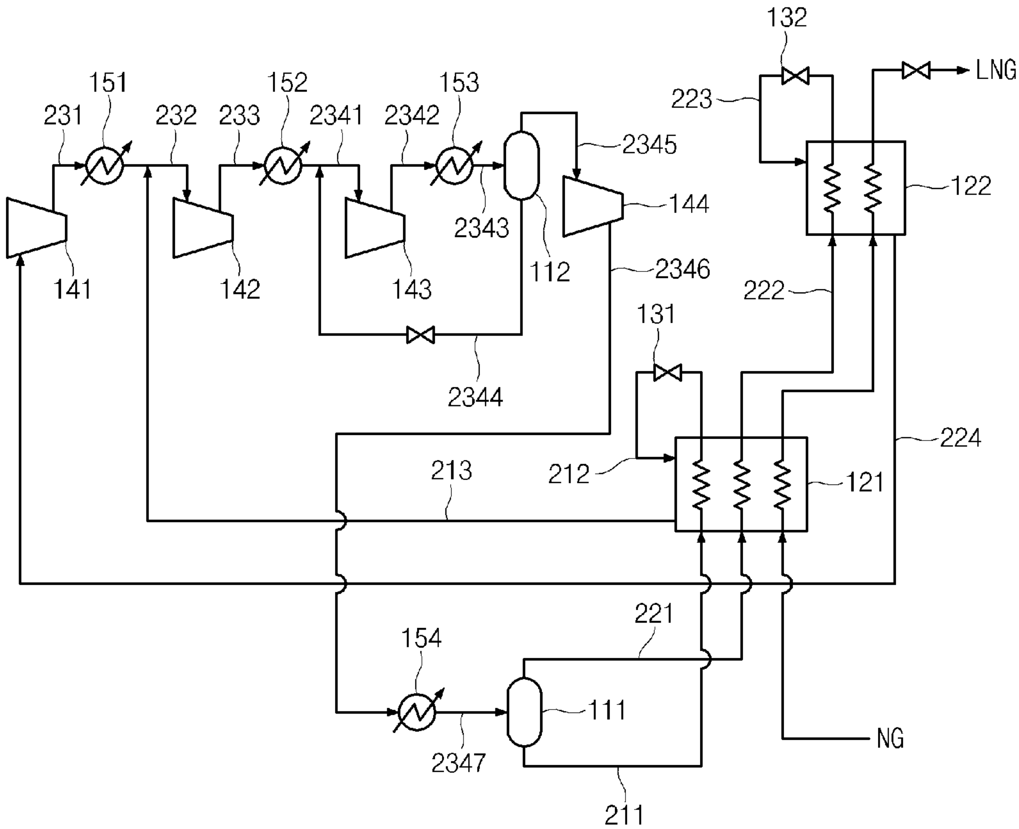
[Fig. 2]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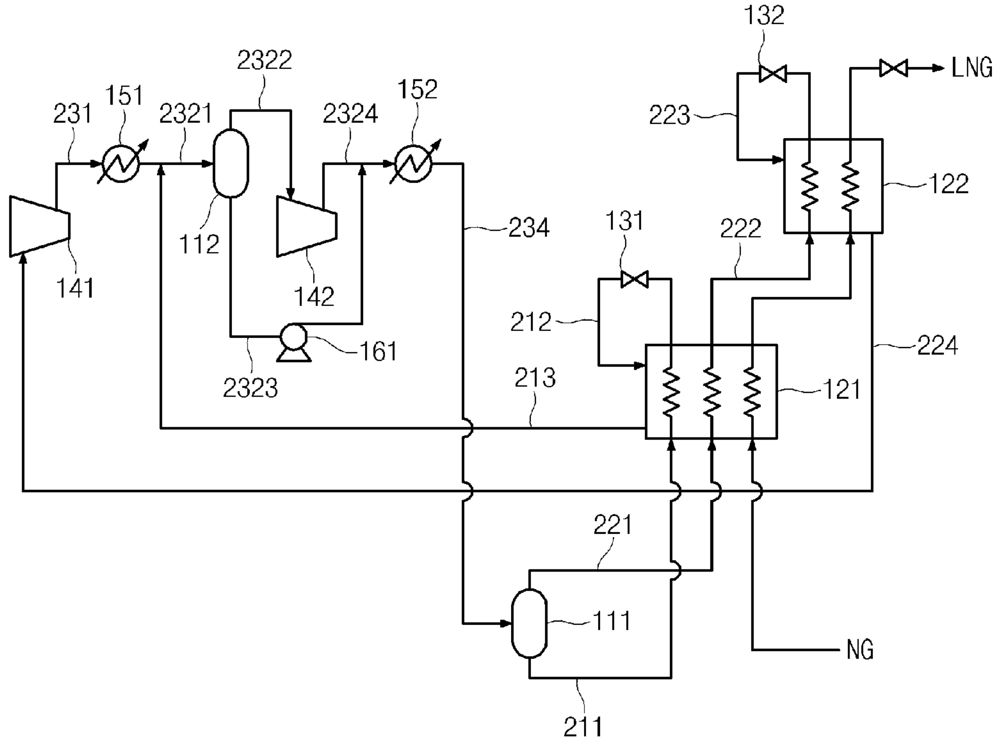
[Fig. 3]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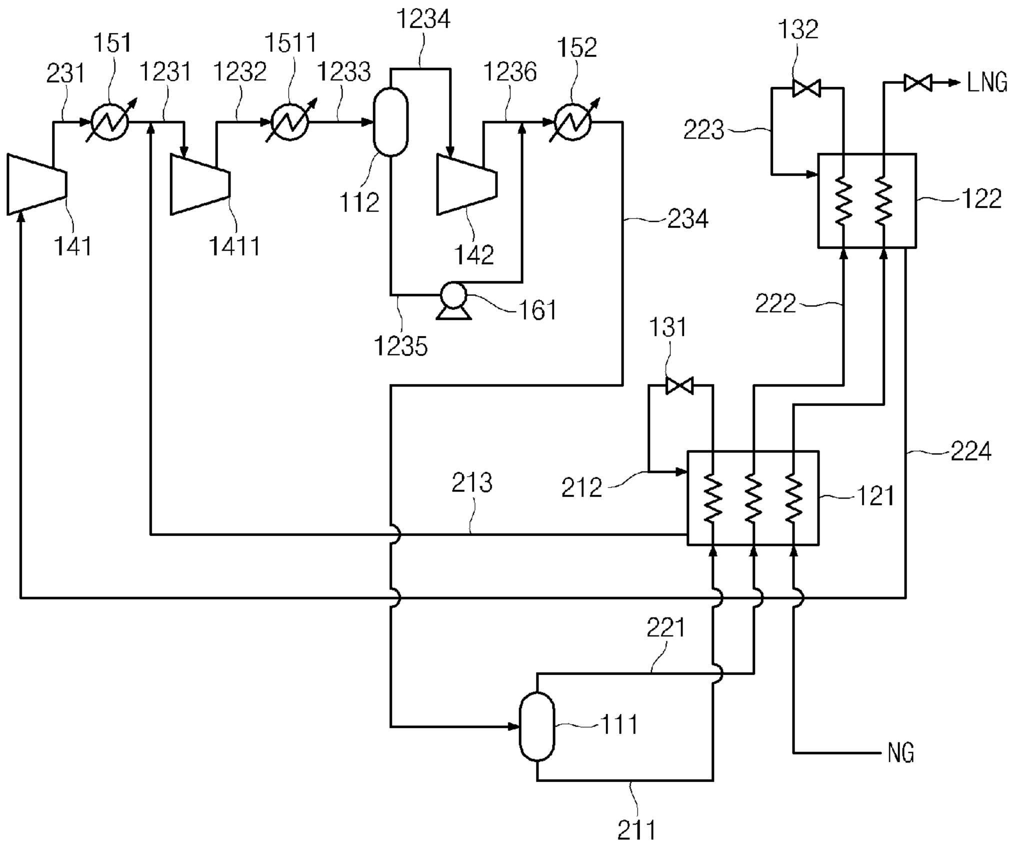
[Fig. 4]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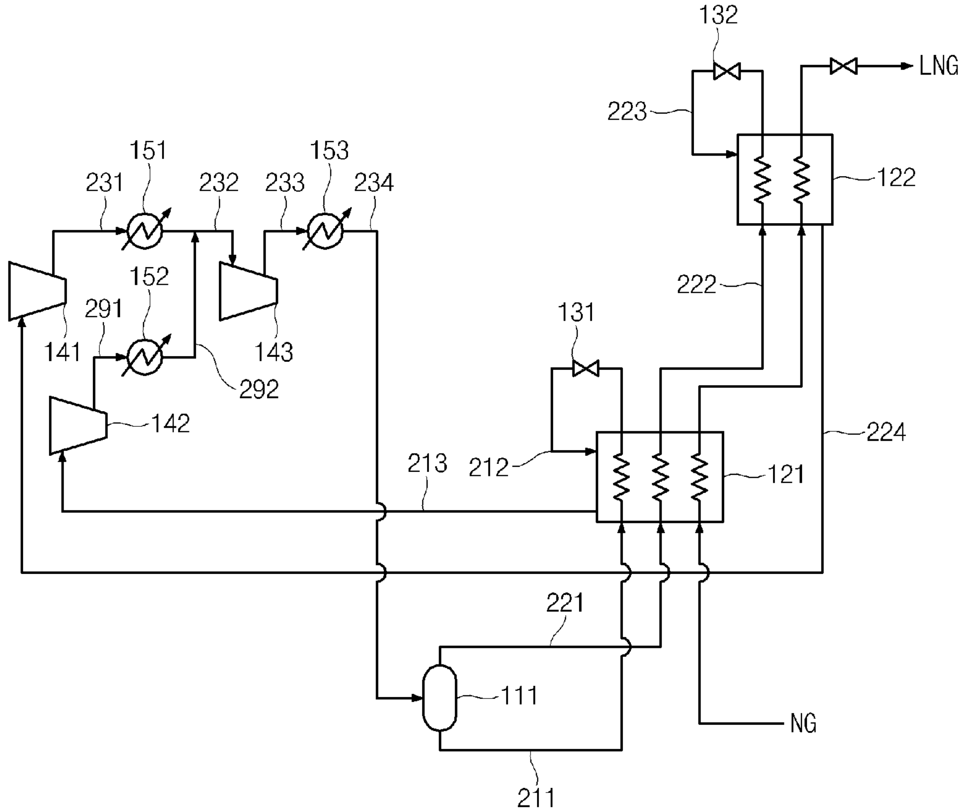
[Fig. 5]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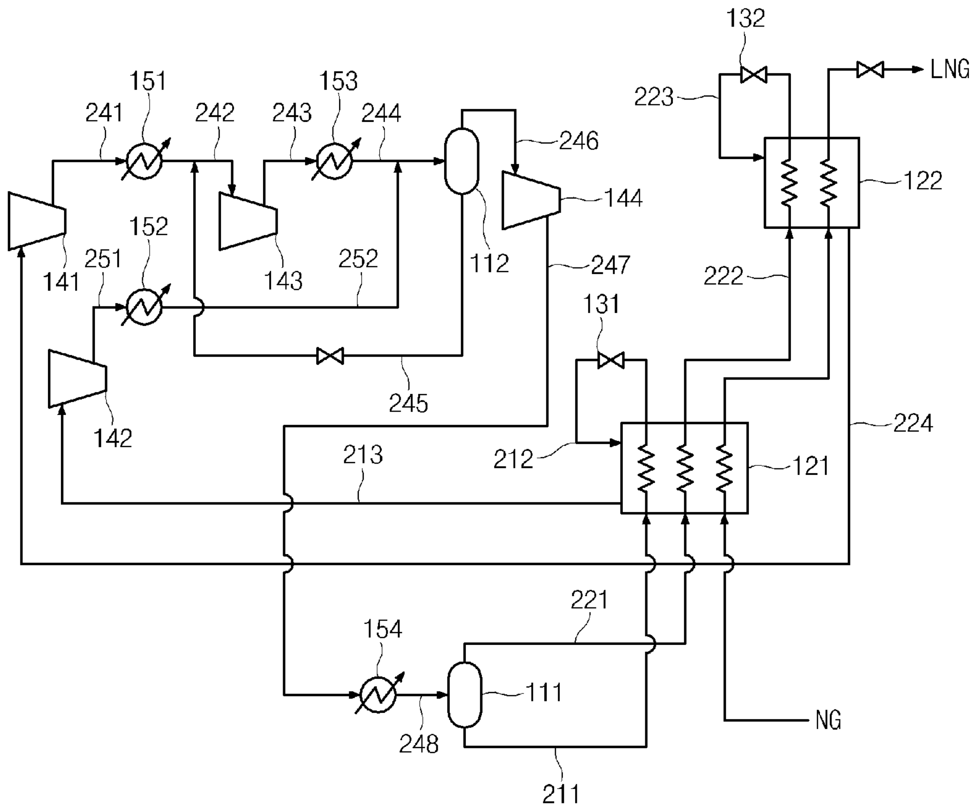
[Fig. 6]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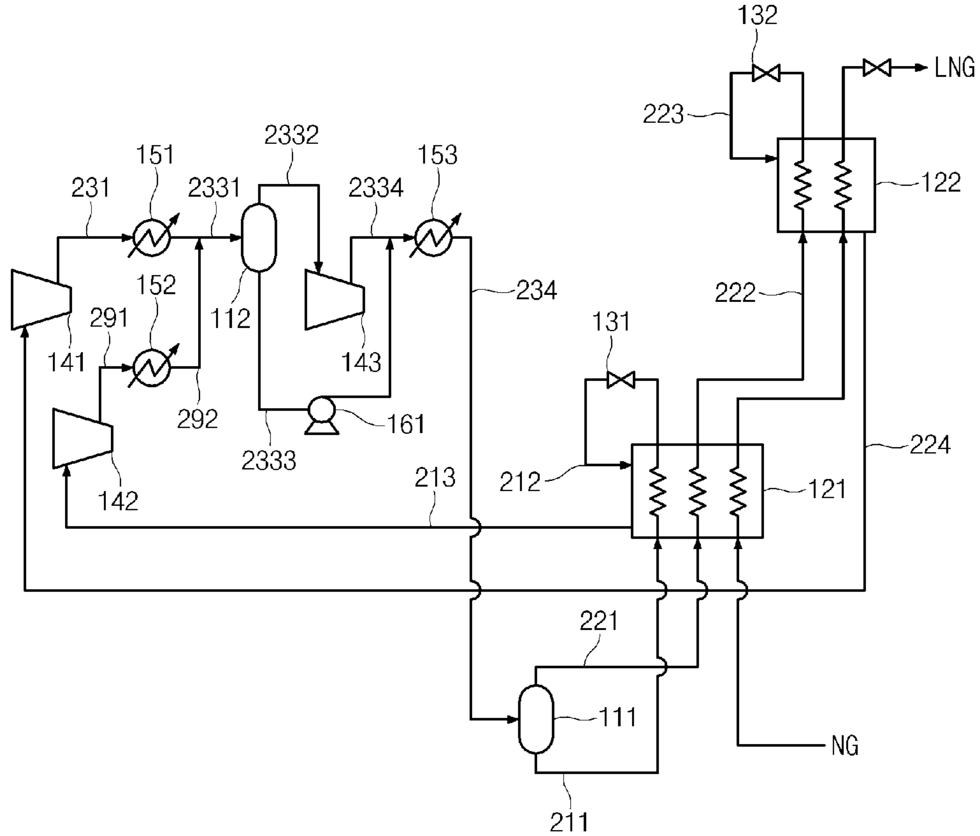
[Fig. 7]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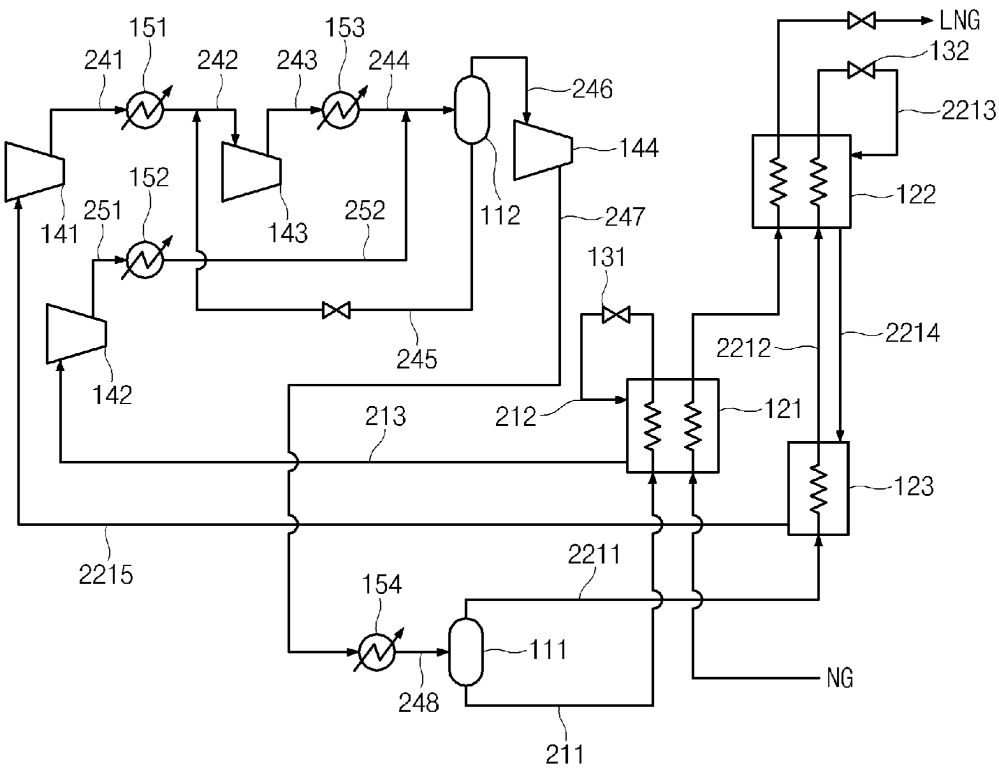
[Fig. 8]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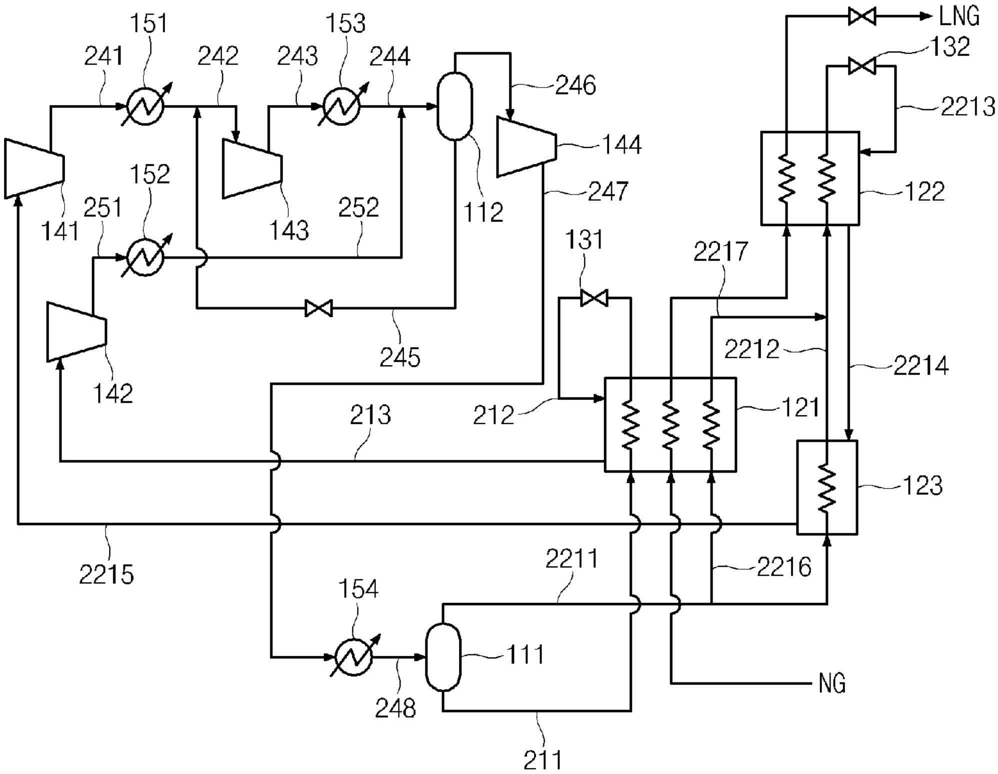
[Fig. 9]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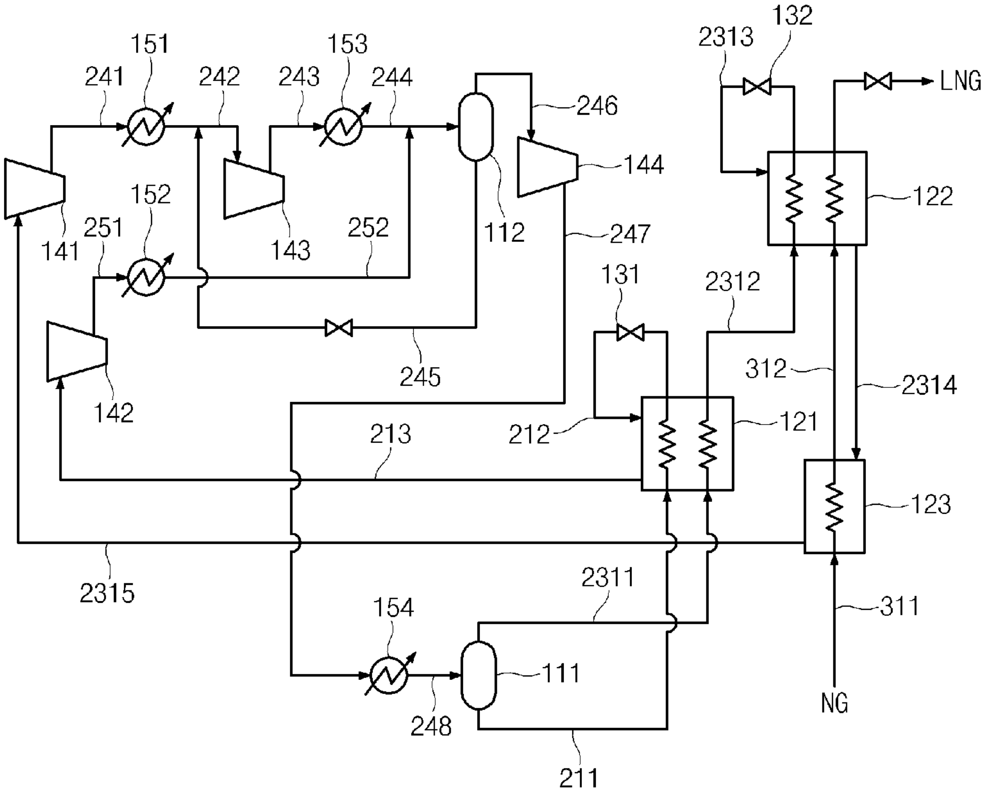
[Fig. 10]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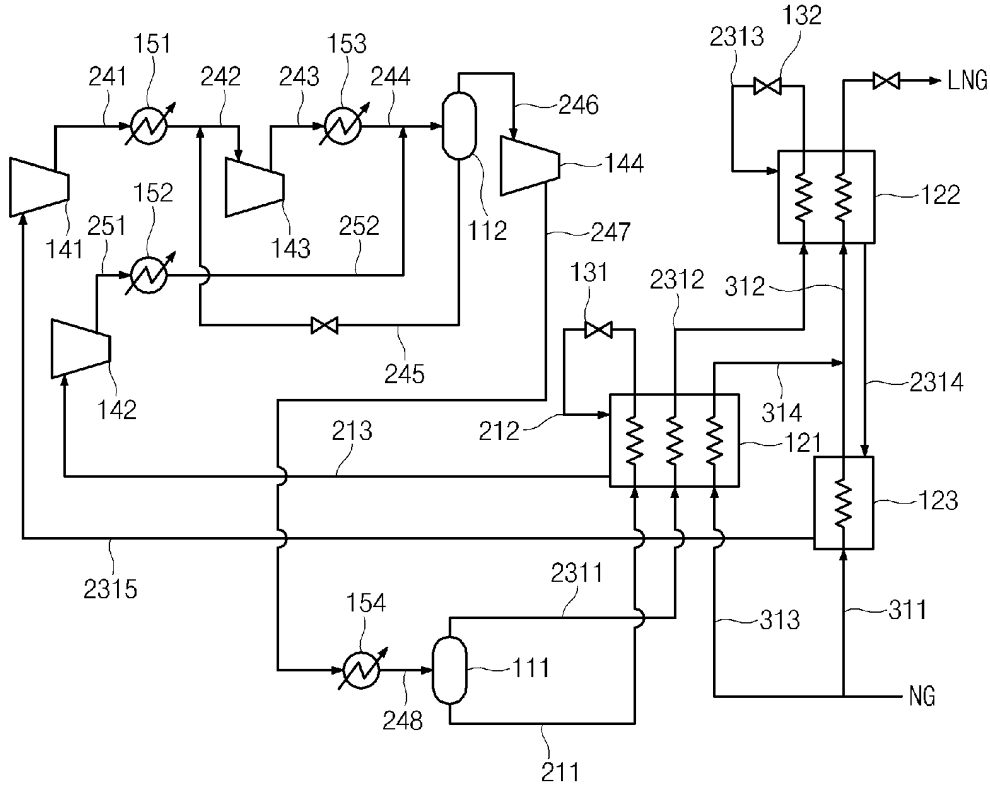
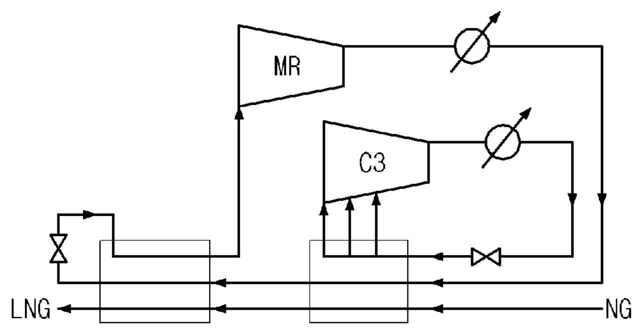
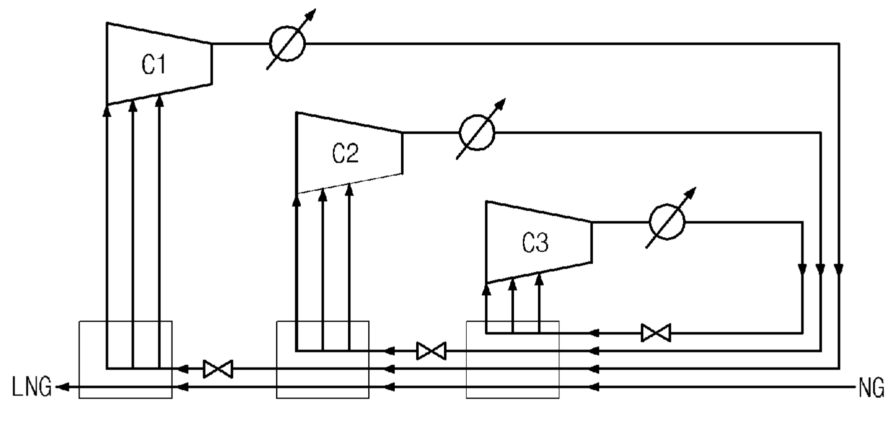
[Fig. 11]



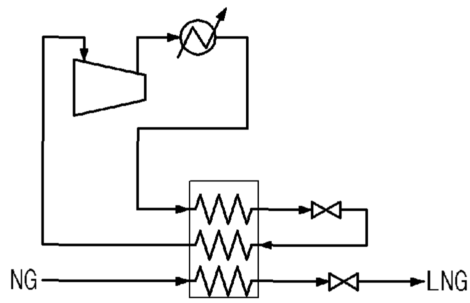
[Fig. 12]



[Fig. 13]



[Fig. 14]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2014/004503

A. CLASSIFICATION OF SUBJECT MATTER

F25J 1/00(2006.01)i, F25J 5/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25J 1/00; F25J 3/00; F25J 5/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models: IPC as above
Japanese Utility models and applications for Utility models: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS (KIPO internal) & Keywords: closed loop, refrigeration cycle, natural gas, liquefaction, condensation, separation, heat exchange, expansion, cooling, collection, mixed refrigerants

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 2010-0186445 A1 (MINTA, Moses et al.) 29 July 2010 See abstract, claim 1, paragraphs [0018] - [0022], [0024], [0025], [0027], and figure 1.	1-13
A	US 2010-0122551 A1 (ROBERTS, Mark Julian et al.) 20 May 2010 See abstract, claim 1, paragraphs [0031] - [0038], and figure 1.	1-13
A	US 2005-0056051 A1 (ROBERTS, Mark Julian et al.) 17 March 2005 See abstract, claim 1, paragraphs [0111] - [0113], and figure 1.	1-13
A	US 5657643 A (PRICE, Brian C.) 19 August 1997 See abstract, claim 1, column 2, line 47 - column 3, line 46, column 5, line 39 - column 6, line 29, and figure 3.	1-13

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
14 AUGUST 2014 (14.08.2014)	**18 AUGUST 2014 (18.08.2014)**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office Government Complex-Daejeon, 189 Seonsa-ro, Daejeon 302-701, Republic of Korea Facsimile No. 82-42-472-7140	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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