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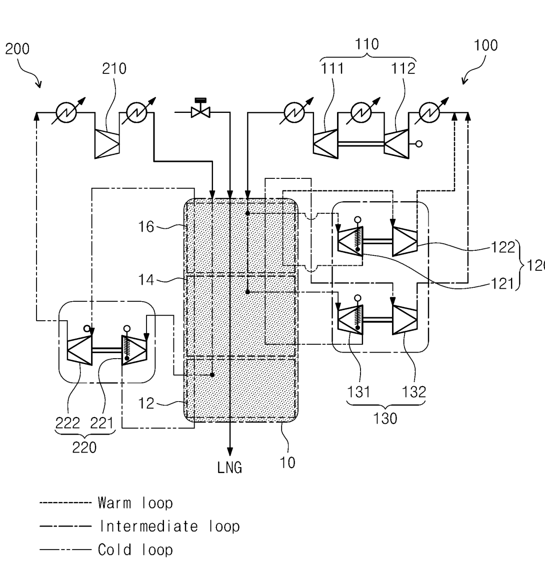
(54) **NATURAL GAS LIQUEFACTION APPARATUS**

(57) Provided is a natural gas liquefaction apparatus including: a cryogenic heat exchanger through which natural gas passes through and is liquefied into liquefied natural gas (LNG) through heat exchange with a first refrigerant and a second refrigerant; a first refrigerant cycle through which the first refrigerant circulates, which has some paths passing through the cryogenic heat exchanger to perform heat exchange, and which has a path of the first refrigerant divided into a plurality of paths after performing heat exchange at the cryogenic heat exchanger and performs expansion and pre-compression of the first refrigerant; and a second refrigerant cycle through which the second refrigerant circulates and which has some paths passing though the cryogenic heat exchanger.

FIG. 1



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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This U.S. non-provisional patent application claims priority under 35 U.S.C. § 119 of Korean Patent Application Nos. 10-2017-0059322, filed on May 12, 2017, and 10-2017-0178604, filed on December 22, 2017, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

[0002] The present invention disclosed herein relates to a natural gas liquefaction apparatus, and more particularly, to a natural gas liquefaction apparatus for liquefying natural gas through a plurality of cycles using different refrigerants.

BACKGROUND ART

[0003] In general, natural gas is transported in a gas state through land or marine gas piping, or is stored in an LNG transport ship in a state of liquefied natural gas (LNG) and transported.

[0004] At this point, natural gas is obtained by being cooled to an ultra low temperature and has a volume reduced to about 1/600 of that of gas-state natural gas, and is therefore very suitable for long distance marine transportation.

[0005] In addition, conventionally used liquefaction methods for natural gas have been performed by allowing the natural gas to pass through one or more heat exchangers so as to be cooled.

[0006] U.S. Patent Publication No. 2014-0245780 discloses a technology using mutually independent heat exchange cycles so that two different refrigerants circulate therethrough.

[0007] However, the technology disclosed in the patent has a limitation in that it is difficult to adjust process variables because cycles are each configured in series in its entirety, and the limitation greatly decreases process efficiency.

[0008] Consequently, a method for solving the limitation is demanded.

DISCLOSURE OF THE INVENTION

TECHNICAL PROBLEM

[0009] The present invention is devised to solve the abovementioned limitation of conventional art, and has the object of providing a natural gas liquefaction apparatus which facilitates the adjustment of process variables and is capable of maximizing heat exchange efficiency.

[0010] The object of the present invention is not limited to the aforesaid, but other objects not described herein will be clearly understood by those skilled in the art from descriptions below.

TECHNICAL SOLUTION

[0011] To achieve the aforementioned object, a natural gas liquefaction apparatuses according to the present invention includes: a cryogenic heat exchanger through which natural gas passes through and is liquefied into LNG through heat exchange with a first refrigerant and a second refrigerant; a first refrigerant cycle through which the first refrigerant circulates, which has some paths passing through the cryogenic heat exchanger to perform heat exchange, and which has a path of the first refrigerant divided into a plurality of paths after performing heat exchange at the cryogenic heat exchanger and performs expansion and pre-compression of the first refrigerant; and a second refrigerant cycle through which the second refrigerant circulates and which has some paths passing though the cryogenic heat exchanger.

[0012] The first refrigerant cycle may include: a first refrigerant first compression part provided upstream of the cryogenic heat exchanger and configured to compress the first refrigerant to a high pressure; a first refrigerant first turbo expander including a first refrigerant first expansion part provided downstream of the cryogenic heat exchanger and configured to expand the first flow among the two divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant first pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant first expansion part and have passed through the cryogenic heat exchanger again; and a first refrigerant second turbo expander including a first refrigerant second expansion part provided downstream of the cryogenic heat exchanger and configured to expand the second flow among the two divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant second pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant second expansion part and have passed through the cryogenic heat exchanger again.

[0013] In addition, the first refrigerant cycle may include: a first refrigerant first compression part provided upstream of the cryogenic heat exchanger and configured to compress the first refrigerant to a high pressure; a first refrigerant first turbo expander including a first refrigerant first expansion part provided downstream of the cryogenic heat exchanger and configured to expand the first flow among the three divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant first pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant first expansion part and has passed through the cryogenic heat exchanger again; a first refrigerant second turbo expander including a first refrigerant second expansion part provided downstream of the cryogenic heat exchanger and configured to expand the second flow among the three divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant second pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant second expansion part and has passed through the cryogenic heat exchanger again; and a first refrigerant third turbo expander including a first refrigerant third expansion part provided downstream of the cryogenic heat exchanger and configured to expand the third flow among the three divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant third pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant third expansion part and has passed through the cryogenic heat exchanger again.

[0014] In addition, the first refrigerant first compression part may be provided in plurality.

[0015] In addition, the second refrigerant cycle may include a second refrigerant compression part provided upstream of the cryogenic heat exchanger and configured to compress the second refrigerant to a high pressure; and a second refrigerant turbo expander including a second refrigerant expansion part provided downstream of the cryogenic heat exchanger and configured to expand the second refrigerant having passed through the cryogenic heat exchanger, and a second refrigerant pre-compression part configured to pre-compress the second refrigerant which has been expanded by the second refrigerant expansion part and has passed through the cryogenic heat exchanger again.

ADVANTAGEOUS EFFECTS

[0016] The natural gas liquefaction apparatus of the present invention for solving the abovementioned limitation has the following effects.

[0017] First, there is a merit in that a portion of the first refrigerant cycle divides the flow of the first refrigerant so that expansion and pre-compression for each flow of the first refrigerant may be separately performed, and thus process variables are easily adjusted.

[0018] Secondly, there is a merit in that due to excellent heat exchange efficiency, the yield can be increased and energy may be saved.

[0019] Thirdly, there is a merit in that the flow rate of the second refrigerant can be reduced compared to that in conventional arts.

[0020] Effects to be obtained by the present invention are not limited to the aforesaid, but other effects not described herein will be clearly understood by those skilled in the art from descriptions below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

FIG. 1 is a view illustrating the configuration of a natural gas liquefaction apparatus according to a first embodiment of the present invention.

FIG. 2 is a graph illustrating a composite curve of a conventional natural gas liquefaction apparatus.

FIG. 3 is a view illustrating a composite curve of a natural gas liquefaction apparatus according to the first embodiment of the present invention.

FIG. 4 is a view illustrating the configuration of a natural gas liquefaction apparatus according to a second embodiment of the present invention.

MODE FOR CARRYING OUT THE INVENTION

[0022] Hereinafter, preferable embodiments of the present invention with which the purpose of the present invention may specifically be achieved will be described with reference to the accompanying drawings. In describing the embodiments, like names and reference symbols are used for the same elements, and the additional description thereon will not be provided.

[0023] FIG. 1 is a view illustrating the configuration of a natural gas liquefaction apparatus according to a first embodiment of the present invention.

[0024] As illustrated in FIG.1, a natural gas liquefaction apparatus according to a first embodiment of the present invention includes an ultra low temperature heat exchange 10, a first refrigerant cycle 100, and a second refrigerant cycle 200.

[0025] The cryogenic heat exchanger 10 allows natural gas passing therethrough to be liquefied into LNG by the heat exchange with the first refrigerant circulating in first refrigerant cycle 100 and the second refrigerant cycle 200 circulating in the second refrigerant cycle 200.

[0026] At this point, in case of the present embodiment, methane serves as the first refrigerant and nitrogen serves as the second refrigerant. However, embodiments are not limited to the present embodiment, other refrigerants may of course be used as the first and second refrigerants.

[0027] In addition, as described above, the first refrigerant circulates through the first refrigerant cycle 100, some paths of which perform heat exchange via the cryogenic heat exchanger 10.

[0028] At this point, after performing the heat exchange at the cryogenic heat exchanger 10, the path of the first refrigerant cycle 100 is divided into a plurality of paths so that expansion and pre-compression of the first refrigerant may be performed. That is, the first refrigerant cycle 100 has a parallel structure because the path of the first refrigerant is divided after passing through the cryogenic heat exchanger 10.

[0029] In particular, in the present embodiment, the first refrigerant cycle 100 includes a first refrigerant compression part 110, a first turbo expander 120, and a second turbo expander 130.

[0030] The first refrigerant first compression part 110 is provided upstream of the cryogenic heat exchanger 10 in the entire first refrigerant cycle 100, and compresses the first refrigerant to a high pressure (for example, about 50-60 barg). In case of the present embodiment, the first refrigerant first compression part 110 is provided as a plurality of compression parts 111 and 112.

[0031] In addition, the first turbo expander 120 includes a first refrigerant first expansion part 121 and a first refrigerant first pre-compression part 122.

[0032] The first refrigerant first expansion part 121 is provided downstream of the cryogenic heat exchanger 10 in the entire first refrigerant cycle 100, and expands a first flow which is a portion of the two divided flows of the first refrigerant after passing through the cryogenic heat exchanger 10.

[0033] By means of the first expansion part 121, the first flow of the first refrigerant may be expanded to, for example, about 10-12 barg. The expanded first flow of the first refrigerant may be cooled to, for example, about -55°C to about -75°C. The expanded and cooled first flow of the first refrigerant by the first refrigerant first expansion part 121 circulates to the cryogenic heat exchanger 10 side to perform heat exchange.

[0034] The first flow of the first refrigerant flowing into the cryogenic heat exchanger 10 from the first refrigerant first expansion part 121 may be configured to pass through a warm heat exchange region 16 (upstream region of inner region of the heat exchanger 10 with respect to the flow of natural gas) inside the cryogenic heat exchanger 10.

[0035] The first refrigerant first pre-compression part 122 is also provided downstream of the cryogenic heat exchanger 10 in the entire first refrigerant cycle 100. The first refrigerant first pre-compression part 122 and the first refrigerant first expansion part 121 may operate linked with each other.

[0036] The first refrigerant first pre-compression part 122 pre-compresses, for example to about 20-25 barg, the first flow of the first refrigerant, which have been expanded by the first refrigerant first expansion part 121 and have passed through the cryogenic heat exchanger 10 again, and then supplies the first flow to the first refrigerant first compression part 110 described above.

[0037] In addition, the second turbo expander 130 includes a first refrigerant second expansion part 131 and a first refrigerant second pre-compression part 132.

[0038] The first refrigerant second expansion part 131 is provided downstream of the cryogenic heat exchanger 10 in the entire first refrigerant cycle 100, and expands a second flow which is a portion of the two divided flows of the first refrigerant after passing through the cryogenic heat exchanger 10.

[0039] The first refrigerant first expansion part 121 and the first refrigerant second expansion part 131 are configured to sequentially receive the first flow and the second flow, which flow into the cryogenic heat exchanger 10 via the same refrigerant line from the first refrigerant first compression part 110 and which are heat-exchanged inside the cryogenic heat exchanger 10.

[0040] By means of the second expansion part 131, the second flow of the first refrigerant may be expanded to, for example, about 15-20 barg. The expanded second flow of the first refrigerant may be cooled to, for example, about -90°C to about -115°C. The second flow of the first refrigerant expanded and cooled by the first refrigerant first expansion part 131 circulates to the cryogenic heat exchanger 10 side to perform heat exchange.

[0041] The second flow of the first refrigerant flowing into the cryogenic heat exchanger 10 from the first refrigerant second expansion part 131 may be configured to sequentially pass through an intermediate heat exchange region 14 (midstream region of the inner region of the heat exchanger 10 with respect to the flow of natural gas) and a warm heat exchange region 16 inside the cryogenic heat exchanger 10.

[0042] The first refrigerant second pre-compression part 132 is also provided downstream of the cryogenic heat exchanger 10 in the entire first refrigerant cycle 100. The first refrigerant second pre-compression part 132 and the first refrigerant second expansion part 131 may operate linked with each other.

[0043] The first refrigerant second pre-compression part 132 pre-compresses, for example to about 20-25 barg, the second flow of the first refrigerant, which have been expanded by the first refrigerant second expansion part 131 and have passed through the cryogenic heat exchanger 10 again, and then supplies the second flow to the first refrigerant first compression part 110 described above.

[0044] The first flow of the first refrigerant pre-compressed by the first refrigerant first pre-compression part 122 and the second flow of the first refrigerant second pre-compression part 132 may be mixed in a mixing pipe and transferred to the first refrigerant first compression part 110.

[0045] In the embodiment, the pressure of the first refrigerant discharged from the first refrigerant first pre-compression part 122 and the pressure of the first refrigerant discharged from the first refrigerant second pre-compression part 132 may be mixed at the same pressure, and then the mixed flow is allowed to flow into the first refrigerant first compression part 110. Thus, the compression efficiency of the first refrigerant may be enhanced.

[0046] As described above, in the present embodiment, the first refrigerant compressed at the first refrigerant first compression part 110 is divided into two flows and circulate through mutually different paths, and thus, there is a merit in that not only process variables may easily be adjusted, but also the heat exchange efficiency is very excellent.

[0047] In addition, in the present embodiment, the first turbo expander 120 and the second turbo expander 130 cools the first refrigerant to mutually different temperatures, and the flow rate is configured such that about 25-45% is divided to the side of relatively high process temperature and about 55-75% is divided to the side of relatively low temperature.

[0048] As such, the first refrigerant with divided flows are introduced into the cryogenic heat exchanger 10 and a pre-cooling (from about -55 °C to -75°C, to about 30°C to 45°C) and a partial liquefaction (from about -90 °C to -115°C, to about 30°C to 45°C) may be separated and efficiently performed.

[0049] For example, the first turbo expander 120 may adjust the temperature difference between the first refrigerant and a fluid in a warm region corresponding to -65 °C to -30°C with the first flow rate of the first refrigerant to adjust the process of the pre-cooling.

[0050] The second turbo expander 130 may adjust the temperature difference between the first refrigerant and a fluid in an intermediate region corresponding to -110 °C to -65°C with the second flow rate of the first refrigerant to adjust the process of the liquefaction (partial liquefaction).

[0051] Meanwhile, as described above, the second refrigerant circulates through the second refrigerant cycle 200, some paths of which perform heat exchange via the cryogenic heat exchanger 10.

[0052] In the present embodiment, the second refrigeration cycle 200 includes a second refrigerant compression part 210 and the second refrigerant turbo expander 220.

[0053] The second refrigerant compression part 210 is provided upstream of the cryogenic heat exchanger 10 in the entire second refrigerant cycle 200, and compresses the second refrigerant to a high pressure (for example, about 50-60 barg).

[0054] In addition, the second refrigerant turbo expander 220 includes a second refrigerant expansion part 221 and a second refrigerant pre-compression part 222.

[0055] The second refrigerant expansion part 221 is provided downstream of the cryogenic heat exchanger 10 in the entire second refrigerant cycle 200, is in charge of a remaining liquefaction process (from about -165 °C to -150°C, to about 30°C to 45°C), and expands the second refrigerant having passed through the cryogenic heat exchanger 10.

[0056] The second refrigerant may be expanded to about 12-18 barg by the second refrigerant expansion part 221. The flow of the expanded second refrigerant may be cooled to about -150 °C to -165°C. The flow of the second refrigerant expanded and cooled by the second refrigerant expansion part 221 circulates to the cryogenic heat exchanger 10 side to perform heat exchange. Here, the second refrigerant is in charge of a process of a cold loop (from -165 °C to -150°C, to 30 °C to 45°C including an ultra cold section (-165°C to -110°C) in which heat exchange may not be performed with the first refrigerant.

[0057] The flow of the second refrigerant flowing into the cryogenic heat exchanger 10 from the second refrigerant expansion part 221 may be configured to sequentially pass through, in the cryogenic heat exchanger 10, a cold heat exchange region 12 (downstream region inside the heat exchanger 10 with respect to the flow of natural gas), an intermediate heat exchange region 14 (midstream region of the inner region of the heat exchanger 10 with respect to the flow of natural gas) and a warm heat exchange region 16.

[0058] The second refrigerant pre-compression part 222 is also provided downstream of the cryogenic heat exchanger 10 in the entire second refrigerant cycle 200, and pre-compresses the second refrigerant, having passed through the cryogenic heat exchanger 10 again, to about 15-20 barg, for example.

[0059] The entirety of the pre-cooling, liquefaction, and subcooling which are liquefaction process of a fluid may be adjusted by the first turbo expander 120, the second turbo expander 130 and the second refrigerant turbo expander 220.

[0060] As described above, the present invention has an additional merit in that the flow rate of the second refrigerant of the second refrigerant cycle 200 may be reduced compared to that in the conventional art through an efficient process of the first refrigerant cycle 100.

[0061] FIG. 2 is a graph illustrating a composite curve of a related natural gas liquefaction apparatus, and FIG. 3 is a view illustrating a composite curve of a natural gas liquefaction apparatus according to the first embodiment of the present invention. Here, x-axes of the graphs illustrated in FIGS. 2 and 3 indicate heat flow transferred in a heat exchanger through the heat amount of each of the turbo expanders and the compression parts, and y-axes indicates temperatures.

[0062] In addition, the hot composite of natural gas located on the upper side is depicted in a solid line and the cold composite of the refrigerant located on the lower side is depicted in a dotted line.

[0063] First, examining the composite curve illustrated in the graph of FIG. 2, it may be confirmed that the temperature difference between the hot composite as natural gas and the cold composite as the refrigerant is large in a range of about -40°C to about -100ºC, and thus, it may be found that the area formed between the hot composite and the cold composite is larger than that of the cold region.

[0064] This is because the first refrigerant cycle and the second refrigerant cycle are entirely formed in series and has only one adjustable inflection point and thus there is a limit in optimizing a system.

[0065] Conversely, examining the composite curve illustrated in the graph of FIG. 3, it may be confirmed that the temperature difference between the hot composite as natural gas and the cold composite as the refrigerant is large in a range of about -40°C to about -100°C, and thus, the area formed between the hot composite and the cold composite may be minimized.

[0066] This is because the first refrigerant cycle is formed, unlike that in the conventional art, in series as a pre-cooling section (30 °C to about -65°C) and a partial liquefaction (30°C to about -110°C), and a plurality of adjustable inflection points are present.

[0067] A natural gas liquefaction apparatus of the present invention has a first refrigerant cycle composed of a warm loop and an intermediate loop, and a second refrigerant cycle composed of a cold loop. In FIG. 1, the warm loop is illustrated in dotted lines, the intermediate loop is illustrated in alternate long and short dash lines, and the cold loop is illustrated in alternate long and two short dash lines.

[0068] Each loop is operated in various temperature ranges considering the composite curve. For example, the intermediate loop through which the first refrigerant circulates is cooled to about -90°C to -115°C and may be operated until reaching about 25°C to 45°C, the warm loop through which the first refrigerant circulates is cooled to about -55°C to -75°C and may be operated until reaching about 25°C to 45°C, and the cold loop through which the first refrigerant circulates is cooled to about -150°C to -165°C and may be operated until reaching about 25°C to 45°C.

[0069] Changes in the amounts or ratios of the first refrigerant and the second refrigerant which circulate through respective loops may substantially affect the composite curve. More specifically, a change in the second flow rate of the first refrigerant circulating through the intermediate loop may substantially affect a liquefaction region between about -115°C to -90°C. In addition, a change in the first flow rate circulating through the warm loop may mainly have influence at about -90°C or higher.

[0070] As such, according to the natural gas liquefaction apparatus of the present invention, by adjusting the first and second flow rates of the first refrigerant and the flow rate of the second refrigerant, and adjusting the temperatures of the respective loops, the difference between the composite curves of the fluid (natural gas) and the refrigerants may effectively be reduced in the temperature sections mainly dealt with the respective loops.

[0071] In addition, the efficiency of a liquefaction process of a fluid may be improved by reducing the energy consumed for liquefying the fluid by enhancing the compression efficiency of the refrigerant and effectively cooling the fluid with a simple process.

[0072] The log mean temperature differences (LMTDs) illustrated in FIGS. 2 and 3 are log mean temperature differences between the hot composite of natural gas and the cold composite of the refrigerant. The LMTD, with which the entire heat exchange process inside a heat exchange is analyzed by a mean temperature, is a value representing the temperature difference between the natural gas and the refrigerant. When $\Delta T1$ is the difference between the inlet side temperature of natural gas and the outlet side temperature of a refrigerant in a heat exchanger, and $\Delta T2$ is the difference between the outlet side temperature of the natural gas and the inlet side temperature of the refrigerant in a heat exchanger, the LMTD may be calculated as the value of $[(\Delta T1-\Delta T2)/\{(\ln\Delta T1)-(\ln\Delta T2)\}]$.

[0073] Referring to FIGS. 2 and 3, when comparing the LMTDs of the composite curves of actual two processes, it may be found that the difference between the hot composite of the natural gas and the cold composite of the refrigerant is about 4.309°C and is smaller in the present embodiment than about 4.685°C in a conventional device, and this means that the cooling efficiency becomes better.

[0074] In addition, in the present embodiment, unlike in conventional arts, since a cooling process of at least -110°C is efficiently performed in the first refrigerant cycle, the flow rate of the second refrigerant required in the second refrigerant cycle is reduced, and thus, unlike the conventional arts, there is a merit in that sufficient pressurization may be performed only with a single second refrigerant compression part and the number of apparatuses may also be reduced.

[0075] In FIGS. 2 and 3, the portions depicted by shadow represent a portion of the pre-cooling process of natural gas and liquefaction/partial liquefaction process. Comparing with FIG. 2, according to the embodiment of the present invention, it may be confirmed that the difference between the composite curve of the natural gas and the composite curve of the refrigerant in the pre-cooling process is reduced in the liquefaction/partial liquefaction processes (portions depicted by shadow in FIG. 3).

[0076] This is because the first refrigerant cycle is formed in parallel as the pre-cooling section (about 30°C to -65°C) and the partial liquefaction section (about 30°C to - 110°C), so that the pre-cooling section (about 30°C to -65°C) may be adjusted by the first flow rate of the first refrigerant, and the partial liquefaction section (about 30°C to -110°C) may be adjusted by the second flow rate of the first refrigerant, and a plurality of adjustable inflection points are present in the pre-cooling section (about 30°C to -65°C) and the partial liquefaction section (about 30°C to -110°C), and the pre-cooling and partial liquefaction processes may be separated and efficiently performed.

[0077] That is, according to the embodiment of the present invention, the heat exchange (subcooling process) between the natural gas and the refrigerant in the ultra cold section (about -165°C to -110°C) may be adjusted by the second refrigerant cycle in which the second refrigerant circulates through the cold loop, the heat exchange (liquefaction/partial liquefaction process) between the natural gas and the refrigerant in the intermediate section (about -110°C to -65°C) may be adjusted by the first refrigerant cycle in which the second flow of the first refrigerant circulates through the intermediate loop, and the heat exchange (pre-cooling process) between the natural gas and the refrigerant in the warm section (about -65°C to -30°C) may be adjusted by the first refrigerant cycle in which the first flow of the first refrigerant circulates through the warm loop

[0078] Thus, according to the embodiment of the present invention, the first flow rate of the first refrigerant circulating through the warm loop, the second flow rate of the first refrigerant circulating through the intermediate loop, and the flow rate of the second refrigerant circulating through the cold loop are each adjusted, so that the temperature differences between the fluid and the refrigerants for each loop is adjusted, and the distance between the composite curves of the fluid (natural gas) and the refrigerants may effectively reduced in the temperature section mainly dealt with by each loop.

[0079] In addition, the pressure of the first refrigerant discharged from the first refrigerant first pre-compression part 122 and the pressure of the first refrigerant discharged from the first refrigerant second pre-compression part 132 may be mixed at the same pressure, and then the mixed flow is allowed to flow into the first refrigerant first compression part 110. Thus, the compression efficiency of the refrigerant may be enhanced. That is, according to the embodiment of the present invention, the efficiency of a liquefaction process of a fluid may be improved by reducing the energy consumed for liquefying the fluid by enhancing the compression efficiency of the refrigerant and effectively cooling the fluid with a simple process.

[0080] In Table 1 provided below, the yields and energy efficiencies of the natural gas liquefaction apparatuses according to a conventional art and the present embodiment are compared.

[Table 1]

	Conventional art	Present embodiment
Compressor Duty [MW]	40.0	40.0
LNG Production [MTPA]	1.005	1.183
Efficiency [kW/(ton/day)]	14.42	12.23

[0081] Examining Table 1 above, the production was performed on the basis of available capacity of about 40.0 MW, and it may be confirmed that the present embodiment may increase the yield as much as about 17.8% from about 1.005 MTPA to 1.183 MTPA in the conventional art.

[0082] In addition, it may be confirmed that energy is reduced to about 12.23 kW from about 14.42 kW of energy consumed for LNG production of about 1 ton/day, and thus about 17.8 % of energy may be saved.

[0083] FIG. 4 is a view illustrating the configuration of a natural gas liquefaction apparatus according to a second embodiment of the present invention.

[0084] In the second embodiment of the present invention illustrated in FIG. 4, the entirety of components is configured in the same manner as the first embodiment. However, the present embodiment is different from the abovementioned first embodiment in that the flow of a first refrigerant having passed through a cryogenic heat exchanger 10 is divided into three flows in the first refrigerant cycle 100.

[0085] Accordingly, in the present embodiment, a first flow among the three divided flows of the first refrigerant is supplied to a first refrigerant first turbo expander 120 side, and the second flow among the three divided flows of the first refrigerant is supplied to a first refrigerant second turbo expander 130 side.

[0086] In addition, in the present embodiment, a first refrigerant third turbo expander 140 is further provided, and a third flow among the three divided flows of the first refrigerant is supplied to the first refrigerant third turbo expander 140 side.

[0087] In addition, the first refrigerant third turbo expander 140 may include: a first refrigerant third expansion part 141 which expands the third flow among the three divided flows of the first refrigerant; and a first refrigerant third pre-compression part 142 which pre-compresses the first refrigerant which has been expanded by the first refrigerant third expansion part 141 and has passed through again the cryogenic heat exchanger 10.

[0088] As such, it may be found that in the present invention, the flow of the first refrigerant may be divided into a plurality of paths more than two divided paths.

[0089] So far, preferable embodiments of the present invention have been described, and it would be obvious to those skilled in the art that the present invention may be implemented in other specific s\forms without departing from the spirit and scope of the invention aside from the abovementioned embodiments. Therefore, embodiments described above should not be construed as limitative but illustrative, and thus, the present invention is not limited to the above description, and may also be modified within the scope of claims and equivalent scope thereto.

Claims

1. A natural gas liquefaction apparatus comprising:

a cryogenic heat exchanger through which natural gas passes through and is liquefied into liquefied natural gas through heat exchange with a first refrigerant and a second refrigerant;
a first refrigerant cycle through which the first refrigerant circulates, which has some paths passing through the cryogenic heat exchanger to perform heat exchange, and which has a path of the first refrigerant divided into a plurality of paths after performing heat exchange at the cryogenic heat exchanger, and performs expansion and pre-compression of the first refrigerant; and
a second refrigerant cycle through which the second refrigerant circulates and which has some paths passing though the cryogenic heat exchanger.

2. The natural gas liquefaction apparatus of claim 1, wherein the first refrigerant cycle comprises:

a first refrigerant first compression part provided upstream of the cryogenic heat exchanger and configured to compress the first refrigerant to a high pressure;
a first refrigerant first turbo expander comprising a first refrigerant first expansion part provided downstream of the cryogenic heat exchanger and configured to expand the first flow among the two divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant first pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant first expansion part and has passed through the cryogenic heat exchanger again; and
a first refrigerant second turbo expander comprising a first refrigerant second expansion part provided downstream of the cryogenic heat exchanger and configured to expand the second flow among the two divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant second pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant second expansion part and has passed through the cryogenic heat exchanger again.

3. The natural gas liquefaction apparatus of claim 1, wherein the first refrigerant cycle comprises:

a first refrigerant first compression part provided upstream of the cryogenic heat exchanger and configured to compress the first refrigerant to a high pressure;
a first refrigerant first turbo expander comprising a first refrigerant first expansion part provided downstream of the cryogenic heat exchanger and configured to expand the first flow among the three divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant first pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant first expansion part and has passed through the cryogenic heat exchanger again;
a first refrigerant second turbo expander comprising a first refrigerant second expansion part provided downstream of the cryogenic heat exchanger and configured to expand the second flow among the three divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant second pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant second expansion part and has passed through the cryogenic heat exchanger again; and
a first refrigerant third turbo expander comprising a first refrigerant third expansion part provided downstream of the cryogenic heat exchanger and configured to expand the third flow among the three divided flows of the first refrigerant having passed through the cryogenic heat exchanger, and a first refrigerant third pre-compression part configured to pre-compress the first refrigerant which has been expanded by the first refrigerant third expansion part and has passed through the cryogenic heat exchanger again.

4. The natural gas liquefaction apparatus of claim 2 or claim 3, wherein first refrigerant first compression part is provided in plurality.

5. The natural gas liquefaction apparatus of claim 1, wherein the second refrigerant cycle comprises:

a second refrigerant compression part provided upstream of the cryogenic heat exchanger and configured to compress the second refrigerant to a high pressure; and
a second refrigerant turbo expander comprising a second refrigerant expansion part provided downstream of the cryogenic heat exchanger and configured to expand the second refrigerant having passed through the cryogenic heat exchanger, and a second refrigerant pre-compression part configured to pre-compress the second refrigerant which has been expanded by the second refrigerant expansion part and has passed through the cryogenic heat exchanger again.

FIG. 1

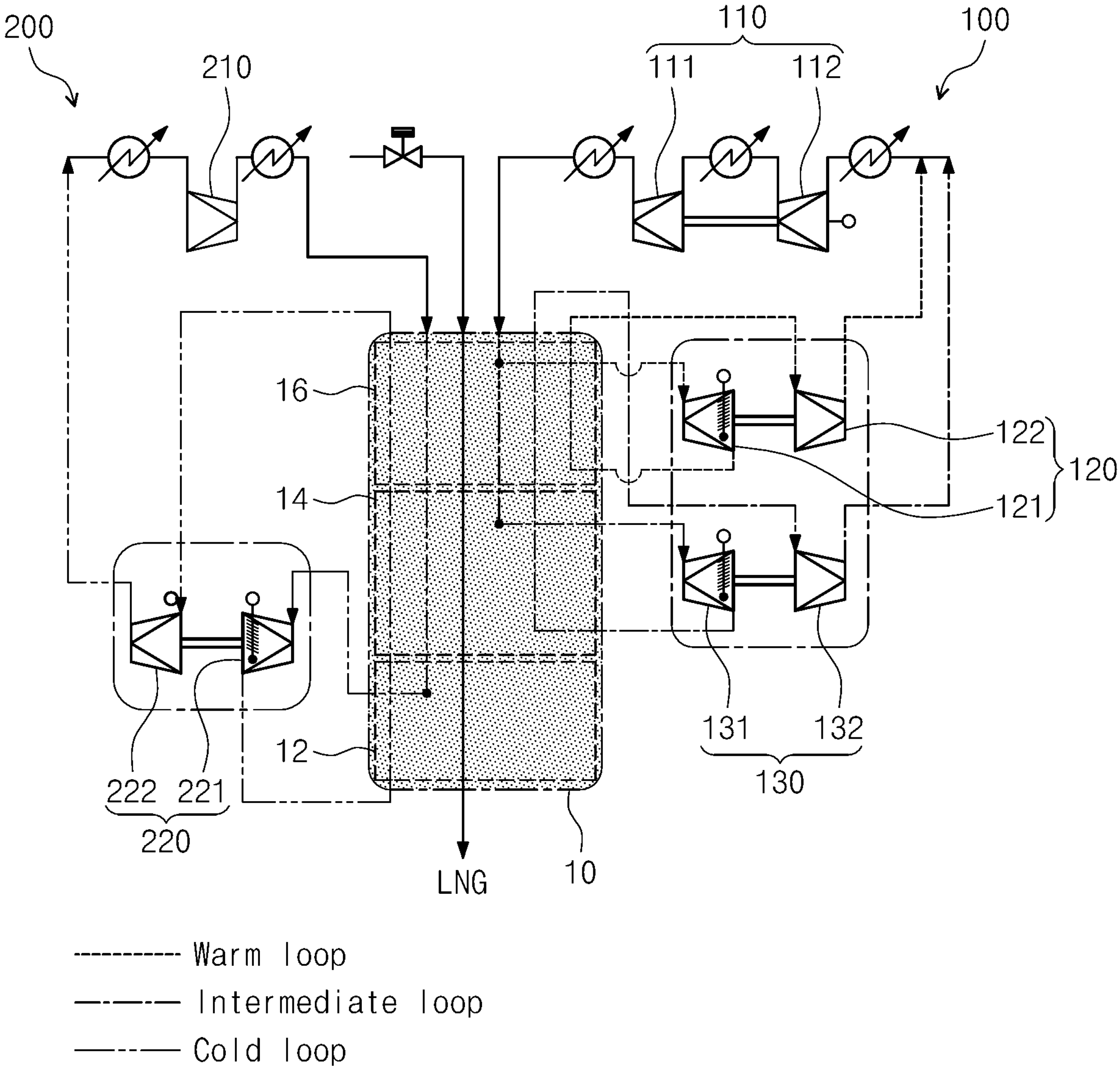
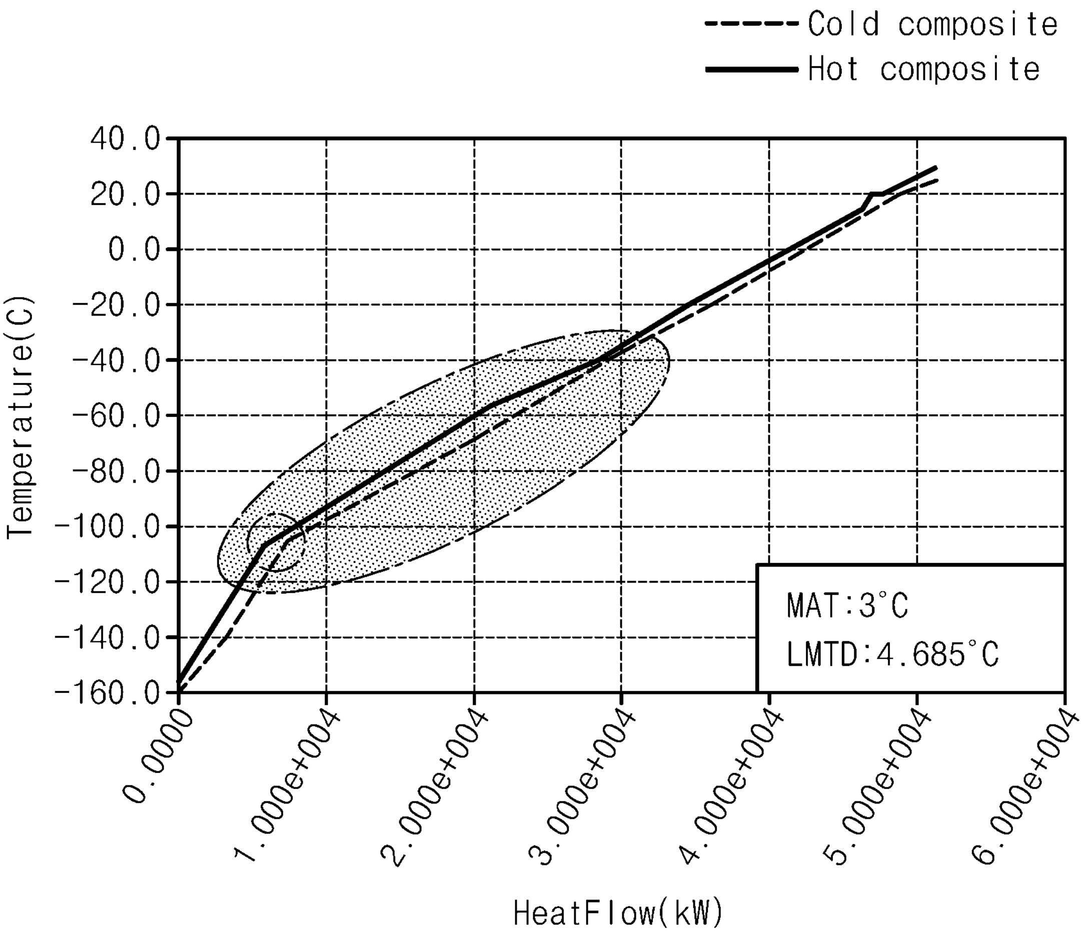

200
210
110
111
112
100
16
14
12
122
120
121
222
221
220
131
132
130
LNG
10
Warm loop
Intermediate loop
Cold loop

FIG. 2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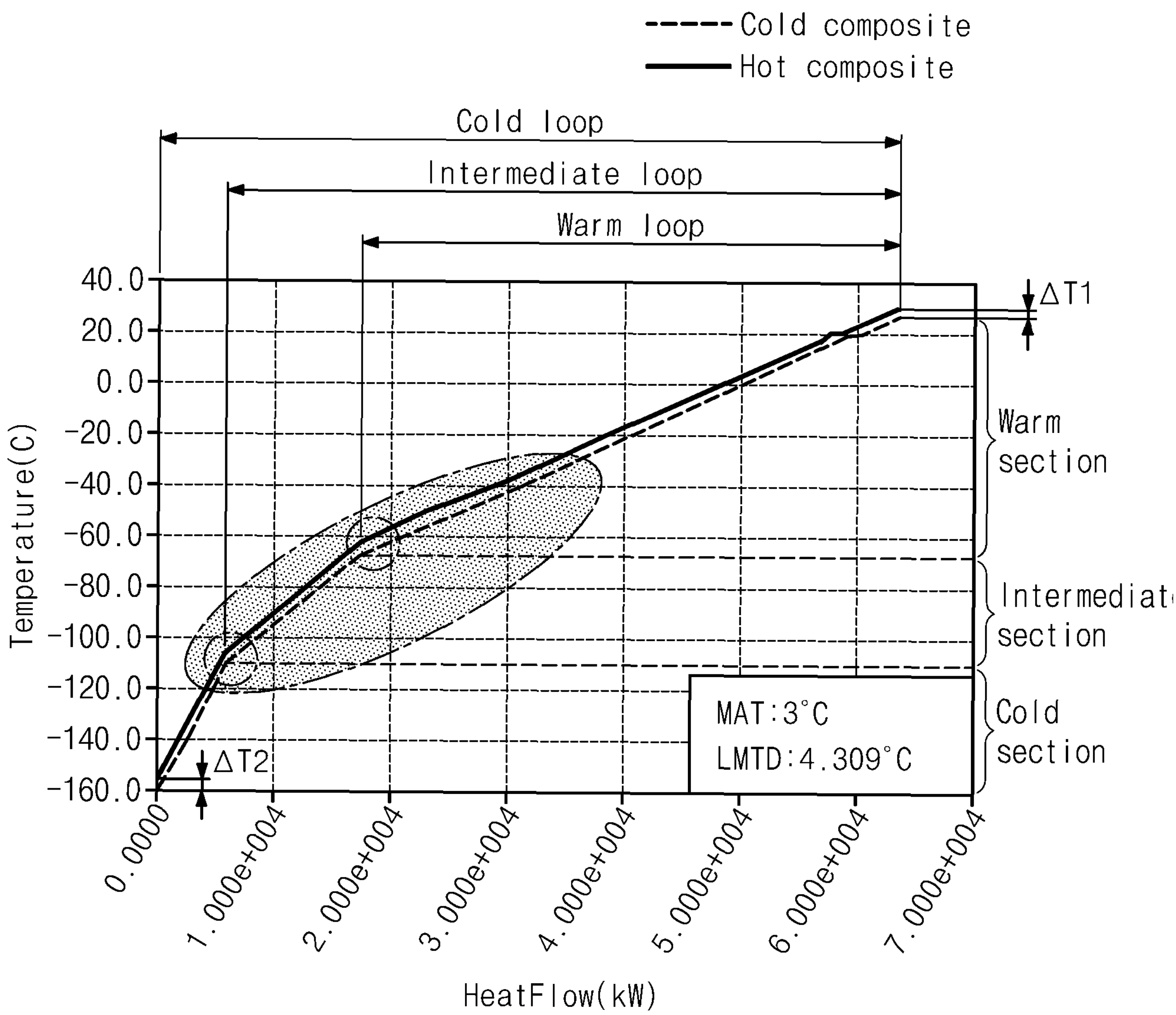
Hot composite
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
Temperature(C)
MAT:3°C
LMTD:4.685°C
0.0000
1.000e+004
2.000e+004
3.000e+004
4.000e+004
5.000e+004
6.000e+004
HeatFlow(kW)

FIG. 3


Cold composite
Hot composite
Cold loop
Intermediate loop
Warm loop
ΔT1
ΔT2
Warm section
Intermediate section
Cold section
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LMTD:4.309°C
Temperature(C)
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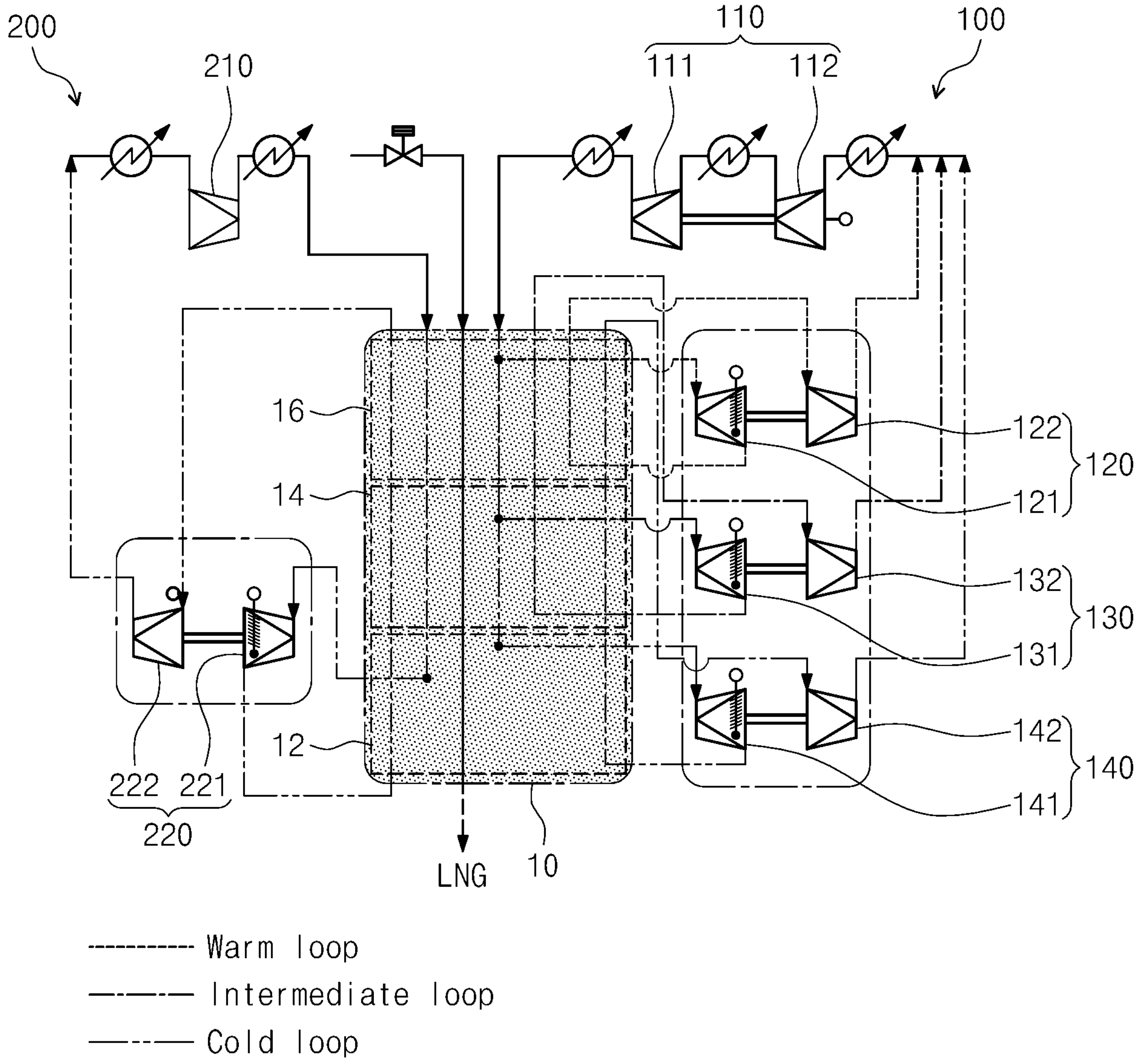
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-120.0
-140.0
-160.0
0.0000
1.000e+004
2.000e+004
3.000e+004
4.000e+004
5.000e+004
6.000e+004
7.000e+004
HeatFlow(kW)

FIG. 4


200
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112
100
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14
12
122
121
120
132
131
130
142
141
140
222
221
220
LNG
10
Warm loop
Intermediate loop
Cold loop

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2018/000701

A. CLASSIFICATION OF SUBJECT MATTER

F25J 1/00(2006.01)i, F25J 1/02(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 1/02; C10L 3/12

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: natural gas, liquefaction, heat exchanger, coolant, cycle

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KR 10-0786135 B1 (ABB LUMMUS GLOBAL, INC.) 21 December 2007 See paragraphs [0021]-[0033] and figures 1-4.	1-5
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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 MAY 2018 (01.05.2018)	**04 MAY 2018 (04.05.2018)**

Name and mailing address of the ISA/KR	Authorized officer
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