



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
17.05.2017 Bulletin 2017/20

(51) Int Cl.:
F25J 1/00 (2006.01)

(21) Application number: **16201992.1**

(22) Date of filing: **26.12.2014**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **26.12.2013 JP 2013270011**
13.03.2014 JP 2014050786

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
14873799.2 / 3 091 319

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Remarks:

This application was filed on 02-12-2016 as a divisional application to the application mentioned under INID code 62.

(54) **SYSTEM AND METHOD FOR LIQUEFACTION OF NATURAL GAS**

(57) By using the power generated by an expander by an expansion of material gas, the outlet pressure of a compressor is increased, and a requirement on the cooling capacity of a cooler is reduced. The liquefaction system (1) for natural gas comprises a first expander (3) for generating power by expanding natural gas under pressure as material gas; a first cooling unit (11, 12) for cooling the material gas depressurized by expansion in the first expander; a distillation unit (15) for reducing or eliminating a heavy component in the material gas by distilling the material gas cooled by the first cooling unit; a first compressor (4) for compressing the material gas from which the heavy component was reduced or eliminated by the distillation unit by using the power generated in the first expander; a second heat exchanger for exchanging heat between the material gas introduced into the first compressor and the material gas compressed by the first compressor; and a liquefaction unit (21) for liquefying the material gas compressed by the first compressor by exchanging heat with a refrigerant.

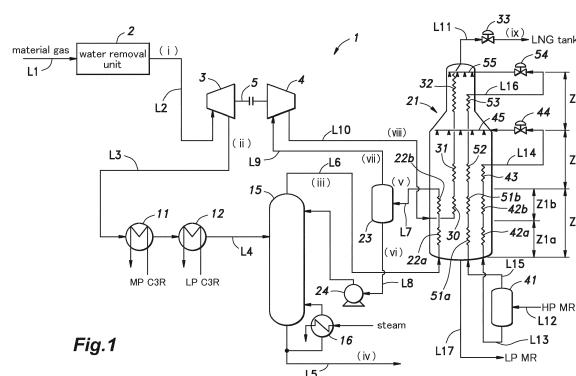


Fig. 1

Description

TECHNICAL FIELD

5 **[0001]** The present invention relates to a system and a method for the liquefaction of natural gas for producing liquefied natural gas by cooling natural gas.

BACKGROUND ART

10 **[0002]** Natural gas obtained from gas fields is liquefied in a liquefaction plant so that the gas may be stored and transported in liquid form. Cooled to about -162 degrees Celsius, the liquid natural gas has a significantly reduced volume as compared to gaseous natural gas, and is not required to be stored under a high pressure. The natural gas liquefaction process at the same time removes impurities such as water, acid gases and mercury contained in the mined natural gas, and after heavier components having relatively high freezing points (C5+ hydrocarbons such as benzene, pentane
15 and other heavier hydrocarbons are removed, the natural gas is liquefied.

[0003] Various technologies have been developed for liquefying natural gas, including those based on expansion processes using expansion valves and turbines and heat exchange processes using low boiling point refrigerants (such as light hydrocarbons such as methane, ethane and propane). For instance, a certain known natural gas liquefaction system (See Patent Document 1) comprises a cooling unit for cooling natural gas from which impurities are removed,
20 an expansion unit for isentropically expanding the cooled natural gas, a distillation unit for distilling the natural gas depressurized by the expansion unit at a pressure lower than the critical pressures of methane and heavier contents, a compressor for compressing the distilled gas from the distillation unit by using the shaft output from the expander, and a liquefaction unit for liquefying the distilled gas compressed by the compressor by exchanging heat with a mixed refrigerant.

PRIOR ART DOCUMENT (S)

PATENT DOCUMENT(S)

30 **[0004]** Patent Document 1: US 4,065,278

SUMMARY OF THE INVENTION

TASK TO BE ACCOMPLISHED BY THE INVENTION

35 **[0005]** In the conventional liquefaction systems for natural gas such as the one disclosed in Patent Document 1, the outlet pressure of the compressor (or the pressure of the feedstock gas that is to be introduced into the liquefaction unit) is desired to be as high as possible in order to reduce the load on the liquefaction unit (in particular, the main heat exchanger thereof) and maximize the efficiency of the liquefaction process.

40 **[0006]** In order to increase the outlet pressure of the compressor, a correspondingly large power is required. However, in the conventional arrangement where the feedstock gas cooled by a cooling unit is expanded by an expander, the power produced from the expander is limited, and is inadequate for increasing the outlet pressure of the compressor to the desired level.

45 **[0007]** In the conventional arrangement, because the feedstock gas is required to be cooled before being expanded in the expander, a relatively large capacity is required for the cooling unit, and this increases the initial costs and the running costs of the cooling unit.

[0008] In the conventional arrangement, because cooling of the feedstock gas will cause condensates to be produced, it is necessary to provide a gas-liquid separator to separate (remove) condensates from the feedstock gas before introducing the feedstock gas from the cooling unit to the expander. Furthermore, because the temperature of the
50 feedstock gas at the outlet end of the compressor is high, a significant temperature difference arises between the intermediate inlet point of the liquefying unit and the refrigerant so that a correspondingly high capacity is required for the cooling unit.

[0009] In view of such problems of the prior art, a primary object of the present invention is to provide a system and a method for the liquefaction of natural gas which can increase the pressure at the outlet end of the compressor by using
55 the power generated in the expander by the expansion of the feedstock gas, and minimize the cooling capacity that is required for the cooling unit.

MEANS TO ACCOMPLISH THE TASK

[0010] A first aspect of the present invention provides a system (1) for the liquefaction of natural gas that cools the natural gas to produce liquefied natural gas, comprising: a first expander (3) for generating power by expanding natural gas under pressure as material gas; a first cooling unit (11, 12) for cooling the material gas depressurized by expansion in the first expander; a distillation unit (15) for reducing or eliminating a heavy component in the material gas by distilling the material gas cooled by the first cooling unit; a first compressor (4) for compressing the material gas from which the heavy component was reduced or eliminated by the distillation unit by using power generated in the first expander; a second heat exchanger for exchanging heat between the material gas introduced into the first compressor and the material gas compressed by the first compressor; and a liquefaction unit (21) for liquefying the material gas compressed by the first compressor by exchanging heat with a refrigerant.

[0011] According to the first aspect of the present invention, the system for the liquefaction of natural gas allows the outlet pressure of the first compressor to be increased and the cooling capacity required for the first cooling unit to be reduced by making use of the power generated by the first expander owing to the expansion of the material gas before being cooled by the first cooling unit.

[0012] A second aspect of the present invention provides a system for the liquefaction of natural gas, further comprising a heat exchanger (69) for exchanging heat between the material gas introduced into the distillation unit and a top fraction of the distillation unit.

[0013] According to the second aspect of the present invention, even when the temperature of the material gas that is introduced into the liquefaction unit is lower than an appropriate range, the temperature of the material gas can be brought close to the temperature at the inlet end of the liquefaction unit by heating the top fraction of the distillation unit by exchanging heat with the material gas that is introduced into the distillation unit.

[0014] A third aspect of the present invention provides a system for the liquefaction of natural gas, further comprising a second heat exchanger (79) for exchanging heat between the material gas to be introduced into the first compressor and the material gas compressed by the first compressor.

[0015] According to the third aspect of the present invention, even when the temperature of the material gas that is compressed by the first compressor and introduced into the liquefaction unit is higher than an appropriate range, the temperature of the material gas can be brought close to the temperature at the inlet end of the liquefaction unit by cooling the material gas from the first compressor by exchanging heat with the material gas that is introduced into the first compressor.

[0016] A fourth aspect of the present invention provides a method for cooling a natural gas feed comprising, (a) reducing the pressure of the natural gas feed to produce a reduced pressure material gas, (b) removing heavy components from the reduced pressure material gas to produce a top fraction and a bottom fraction, (c) cooling the top fraction to produce a cooled top fraction, (d) separating the cooled top fraction into a gas phase component and a liquid phase component, (e) increasing the pressure of the gas phase component to produce a compressed material gas, and (f) exchanging heat between the gas phase component and the compressed material gas to produce at least a cooled compressed material gas.

[0017] Preferably, the method further comprises cooling the reduced pressure material gas of step (a) prior to removing heavy components in step (b).

[0018] Preferably, the method further comprises at least partially liquefying the cooled compressed material gas of step (f).

[0019] Preferably, the method further comprises cooling the compressed material gas of step (e) prior to step (f).

[0020] Preferably, the top fraction is cooled in step (c) by introducing the top fraction in a warm region of a spool wound heat exchanger.

[0021] Preferably, the cooled compressed material gas of step (f) is further cooled by introducing the cooled compressed material gas in an intermediate region of the spool wound heat exchanger.

[0022] Preferably, the removal of heavy components in step (b) is performed in a distillation unit.

[0023] Preferably, the method further comprises recirculating the liquid phase component of step (d) to the distillation unit.

[0024] Preferably, the method further comprises exchanging heat between the top fraction of step (b) and the reduced pressure material gas prior to step (c).

[0025] Preferably, step (f) comprises exchanging heat between the gas phase component of step (d), the compressed material gas of step (e), and the reduced pressure material gas of step (a).

[0026] A fifth aspect of the present invention provides a method for cooling a natural gas feed comprising, (a) reducing the pressure of the natural gas feed to produce a reduced pressure material gas, (b) removing heavy components from the reduced pressure material gas to produce a top fraction and a bottom fraction, (c) exchanging heat between the reduced pressure material gas and the top fraction to produce at least a heat exchanged top fraction, (d) cooling the heat exchanged top fraction to produce a cooled top fraction, (e) separating the cooled top fraction into a gas phase

component and a liquid phase component, (f) increasing the pressure of the gas phase component to produce a compressed material gas, and (g) cooling the compressed material gas.

[0027] Preferably, the method further comprises cooling the reduced pressure material gas of step (a) prior to removing heavy components in step (b).

[0028] Preferably, the compressed material gas is cooled in step (g) by introducing the compressed material gas in one or more heat exchangers.

[0029] Preferably, the removal of heavy components in step (b) is performed in a distillation unit.

[0030] Preferably, the method further comprises recirculating the liquid phase component of step (e) to the distillation unit.

[0031] A sixth aspect of the present invention provides a method for cooling a natural gas feed comprising, (a) reducing the pressure of the natural gas feed to produce a reduced pressure material gas, (b) removing heavy components from the reduced pressure material gas to produce a top fraction and a bottom fraction, (c) cooling the top fraction to produce a cooled top fraction, (d) separating the cooled top fraction into a gas phase component and a liquid phase component, (e) increasing the pressure of the gas phase component to produce a compressed material gas, and (f) exchanging heat between the reduced pressure material gas produced in step (a) and the compressed material gas to produce at least a heat exchanged compressed material gas.

[0032] Preferably, the method further comprises cooling the reduced pressure material gas of step (a) prior to exchanging heat in step (f).

[0033] A seventh aspect of the present invention provides a method for cooling a natural gas feed comprising, (a) reducing the pressure of the natural gas feed to produce a reduced pressure material gas, (b) removing heavy components from the reduced pressure material gas in a distillation unit to produce a top fraction and a bottom fraction, (c) cooling and partially liquefying the top fraction to produce a cooled top fraction, (d) separating the cooled top fraction to produce a gas phase component and a liquid phase component, (e) recirculating the liquid phase component to the distillation unit, (f) exchanging heat between the reduced pressure material gas and the gas phase component to produce at least a heat exchanged gas phase component, and (g) increasing the pressure of the heat exchanged gas phase component to produce a compressed material gas.

[0034] Preferably, the method further comprises cooling the reduced pressure material gas of step (a) prior to exchanging heat in step (f).

[0035] An eighth aspect of the present invention provides a method for cooling a natural gas feed comprising, (a) reducing the pressure of the natural gas feed to produce a reduced pressure material gas, (b) removing heavy components from the reduced pressure material gas to produce a top fraction and a bottom fraction, (c) increasing the pressure of the top fraction to produce a compressed material gas, and (d) exchanging heat between the top fraction and the compressed material gas to produce at least a cooled compressed material gas.

[0036] Preferably, the method further comprises cooling the reduced pressure material gas of step (a) prior to step (b).

[0037] Preferably, the method further comprises cooling the compressed material gas of step (c) prior to exchanging heat in step (d).

[0038] A ninth aspect of the present invention provides a system for liquefaction of a natural gas feed comprising, a first expander to reduce the pressure of the natural gas feed to produce a reduced pressure material gas, a distillation unit for removing heavy components from the reduced pressure material gas to produce a top fraction and a bottom fraction, a first heat exchanger for cooling the top fraction to produce a cooled top fraction, a first gas-liquid separation vessel to separate the cooled top fraction into a gas phase component and a liquid phase component, a first compressor for compressing the gas phase component to produce a compressed material gas, and a second heat exchanger for exchanging heat between the gas phase component and the compressed material gas.

[0039] Preferably, the system further comprises a first cooling unit for cooling the reduced pressure material gas prior to introduction in the distillation unit.

[0040] Preferably, the system further comprises a second cooling unit for cooling the compressed material gas prior to introduction in the second heat exchanger.

[0041] Preferably, the first heat exchanger is a warm region of a spool wound heat exchanger.

[0042] Preferably, the system further comprises a third heat exchanger for cooling the compressed material gas after the compressed material gas passes through the second heat exchanger; wherein the third heat exchanger is an intermediate region of the spool wound heat exchanger.

[0043] Preferably, the system further comprises piping to recirculate the liquid phase component from the first gas-liquid separation vessel as reflux to the distillation unit.

[0044] Preferably, the system further comprises a fourth heat exchanger for exchanging heat between the top fraction from the distillation unit and the reduced pressure material gas.

[0045] Preferably, the second heat exchanger exchanges heat between the gas phase component, the compressed material gas, and the reduced pressure material gas.

[0046] Preferably, the first expander generates power, and the first compressor uses the power generated by the first

expander.

[0047] A tenth aspect of the present invention provides a system for liquefaction of a natural gas feed comprising, a first expander to reduce the pressure of the natural gas feed to produce a reduced pressure material gas, a distillation unit for removing heavy components from the reduced pressure material gas to produce a top fraction and a bottom fraction, a first heat exchanger for exchanging heat between the top fraction and the reduced pressure material gas to produce at least a heat exchanged top fraction, a second heat exchanger for cooling the heat exchanged top fraction to produce a cooled top fraction, a first gas-liquid separation vessel to separate the cooled top fraction into a gas phase component and a liquid phase component, and a first compressor for compressing the gas phase component to produce a compressed material gas.

[0048] Preferably, the system further comprises a first cooling unit for cooling the reduced pressure material gas prior to introduction in the distillation unit.

[0049] A tenth aspect of the present invention provides a system for liquefaction of a natural gas feed comprising, a first expander to reduce the pressure of the natural gas feed to produce a reduced pressure material gas, a first cooling unit for cooling the reduced pressure material gas to produce a cooled reduced pressure material gas, a distillation unit for removing heavy components from the cooled reduced pressure material gas to produce a top fraction and a bottom fraction, a warm region of a spool wound heat exchanger for cooling the top fraction to produce a cooled top fraction, a first gas-liquid separation vessel to separate the cooled top fraction into a gas phase component and a liquid phase component, a piping system for recirculating the liquid phase component to the distillation unit, a first compressor for compressing the gas phase component to produce a compressed material gas, a second cooling unit for cooling the compressed material gas to produce a cooled compressed material gas, a third heat exchanger for exchanging heat between the cooled compressed material gas and the gas phase component to produce a further cooled compressed material gas, and an intermediate region of the spool wound heat exchanger for at least partially liquefying the further cooled compressed material gas.

EFFECT OF THE INVENTION

[0050] As can be appreciated from the foregoing, the liquefaction system for the liquefaction of natural gas according to the present invention allows the outlet pressure of the compressor to be increased by using the power generated by the expander owing to the expansion of the material gas, and the cooling capacity that is required for the cooling unit to be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0051]

Figure 1 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a first embodiment of the present invention;

Figure 2 is a diagram showing a liquefaction process flow in a conventional system for the liquefaction of natural gas given as a first example for comparison;

Figure 3 is a diagram showing a liquefaction process flow in a conventional system for the liquefaction of natural gas given as a second example for comparison; and

Figure 4 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a first modification of the first embodiment;

Figure 5 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a second modification of the first embodiment;

Figure 6 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a third modification of the first embodiment;

Figure 7 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a fourth modification of the first embodiment.

Figure 8 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a second embodiment of the present invention;

Figure 9 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a first modification of the second embodiment; and

Figure 10 is a diagram showing the liquefaction flow in the system for the liquefaction of natural gas of a fifth modification of the first embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0052] Preferred embodiments of the present invention are described in the following with reference to the appended drawings.

(First Embodiment)

[0053] Figure 1 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a first embodiment of the present invention. Table 1 which will be shown hereinafter lists the results of a simulation of the liquefaction process in the system for the liquefaction of natural gas. The same is similarly true with Tables 2 to 12. Table 1 shows the temperature, the pressure, the flow rate and the molar composition of the natural gas that is to be liquefied at each of various points in the liquefaction system of the first embodiment. In Table 1, columns (i) to (ix) show the values at the respective points in the liquefaction system 1 denoted with corresponding roman numerals (i) to (ix) in Figure 1.

[0054] Natural gas containing about 80 to 98 mol% of methane is used as the material gas or the feedstock gas. The material gas also contains at least C5+ hydrocarbons by at least 0.1 mol% or BTX (benzene, toluene, xylene) by at least 1 ppm mol as heavier contents. The contents of the material gas other than methane are shown in column (i) of Table 1. The term "material gas" as used in this specification is not necessarily required to be in gaseous form, but may also be in liquid form according to various stages of liquefaction.

[0055] In this liquefaction system 1, the material gas is supplied to a water removal unit 2 via a line L1, and is freed from moisture in order to avoid troubles due to icing. The material gas supplied to the water removal unit 2 has a temperature of about 20 degrees Celsius, a pressure of about 5,830 kPaA and a flow rate of about 720,000 kg/hr. The water removal unit 2 may consist of towers filled with desiccant (such as a molecular sieve), and can reduce the water content of the material gas to less than 0.1 ppm mol. The water removal unit 2 may consist of any other known unit which is capable of removing water from the material gas below a desired level.

[0056] Although detailed discussion is omitted here, the liquefaction system 1 may employ additional known facilities for performing preliminary process steps preceding the process step in the water removal unit 2, such as a separation unit for removing natural gas condensate, an acid gas removal unit for removing acid gases such as carbon dioxide and hydrogen sulfide and a mercury removal unit for removing mercury. Typically, the water removal unit 2 receives material gas from which impurities are removed by using such facilities. The material gas that is supplied to the water removal unit 2 is pre-processed such that the carbon dioxide (CO₂) content is less than 50 ppm mol, the hydrogen sulfide (H₂S) content is less than 4 ppm mol, the sulfur content is less than 20 mg/Nm³, and the mercury content is less than 10 ng/Nm³.

[0057] The source of the material gas may not be limited to any particular source, but may be obtained, not exclusively, from shale gas, tight sand gas and coal head methane in a pressurized state. The material gas may be supplied not only from the source such as a gas field via piping but also from storage tanks.

[0058] The material gas from which water is removed in the water removal unit 2 is forwarded to a first expander 3 via a line L2. The first expander 3 consists of a turbine for reducing the pressure of the natural gas supplied thereto, and obtaining power (or energy) from the expansion of the natural gas under an isentropic condition. Owing to the expansion step (first expansion step) in the first expander 3, the pressure and the temperature of the material are reduced. The first expander 3 is provided with a common shaft 5 to a first compressor 4 (which will be discussed hereinafter) so that the power generated by the first expander 3 can be used for powering the first compressor 4. If the rotational speed of the first expander 3 is lower than that of the first compressor 4, a suitable step-up gear unit may be placed between the first expander 3 and the first compressor 4. The first expander 3 reduces the temperature and the pressure of the material gas to about 8.3 degrees Celsius, a pressure of about 4,850 kPaA, respectively. Typically, the pressure of the material gas expelled from the first expander 3 is in the range of 3,000 kPaA to 5,500 kPaA (30 barA to 55 barA), or more preferably in the range of 3,500 kPaA to 5,000 kPaA (35 barA to 50 barA).

[0059] The material gas from the first expander 3 is forwarded a cooler 11 via a line L3. A cooling unit (first cooling unit) is formed by connecting another cooler 12 to the downstream end of the cooler 11. The material gas is cooled by exchanging heat with refrigerants (first cooling step) in the first cooling unit 11, 12 in stages. The temperature of the material gas which has been cooled by the first cooling unit 11, 12 is in the range of from -20 to -50 degrees Celsius, or more preferably in the range of from -25 to -35 degrees Celsius. If the material gas introduced into the liquefaction system 1 is relatively high (higher than 100 barA, for instance), the first cooling unit 11, 12 may be omitted as the temperature of the material gas at the outlet of the first expander 3 is relatively low (-30 degrees Celsius, for instance). The possibility of omitting the cooling unit on the upstream side of the distillation unit 15 applies equally to the embodiments illustrated in Figures 5 to 7 which will be discussed hereinafter.

[0060] In the present embodiment, the C3-MR (propane (C3) pre-cooled mixed refrigerant) system is used. The material gas is pre-cooled in the first cooling unit 11, 12 by using propane as the refrigerant, and is later super-cooled to an extremely low temperature for the liquefaction of the material gas in a refrigeration cycle using mixed refrigerants as will

be discussed hereinafter. Propane refrigerants (C3R) for medium pressure (MP) and low pressure (LP) are used for cooling the material gas in a plurality of stages (in two stages in the illustrated embodiment) in the first cooling unit 11, 12. Although not shown in the drawings, the first cooling unit 11, 12 forms a part of a per se known refrigeration cycle including compressors and condensers for the propane refrigerants.

[0061] The liquefaction system 1 is not necessarily required to be based on the C3-MR system, but may use a cascade system in which a plurality of individual refrigeration cycles are formed by using corresponding refrigerants (such as methane, ethane and propane) having different boiling points, a DMR (double mixed refrigerant) system using a mixed medium such as a mixture of ethane and propane for a preliminary cooling process, and a MFC (mixed fluid cascade system) using different mixed refrigerants separately for the individual cycles of preliminary cooling, liquefaction and super cooling, among other possibilities.

[0062] The material gas from the cooler 12 is forwarded to the distillation unit 15 via a line L4. The pressure of the material gas at this point should be below the critical pressures of methane and heavier components by means of the expansion in the first expander 3 and other optional processes. The distillation unit 15 essentially consists of a distillation tower internally provided with a plurality of shelves for removing heavier contents in the material gas (distillation step).

The liquid consisting of the heavier contents is expelled via a line L5 connected to the bottom end of the distillation tower of the distillation unit 15. The liquid consisting of the heavier contents that is expelled from the distillation unit 15 via the line L5 has a temperature of about 177 degrees Celsius and a flow rate of about 20,000 kg/hr. The term "heavier contents" refer to components such as benzene having high freezing points and components having lower boiling points such as C5+ hydrocarbons. The line L5 includes a recirculation unit including a reboiler 16 for heating a part of the liquid expelled from the bottom of the distillation tower of the distillation unit 15 by exchanging heat with steam (or oil) supplied to the reboiler 16 from outside, and recirculating the heated liquid back to the distillation unit 15.

[0063] The top fraction from the distillation unit 15 consisting of the lighter components of the material gas primarily consists of methane having a low boiling point, and this material gas is introduced into the liquefaction unit 21 via the line L6 to be cooled in the piping systems 22a and 22b. The material gas forwarded to the line L5 has a temperature of about -45.6 degrees Celsius and a pressure of about 4,700 kPaA. The material gas freed from the heavier components in the distillation unit 15 contains less than 0.1 mol% of C5+ and less than 1 ppm mol of BTX (benzene, toluene and xylene). By flowing through the piping systems 22a and 22b, the material gas is cooled to about -65.2 degrees Celsius, and is then forwarded from the liquefaction unit 21 to a first gas-liquid separation vessel 23 via a line L7.

[0064] As will be discussed hereinafter, the liquefaction unit 21 essentially consists of a main heat exchanger in the liquefaction system 1, and this heat exchanger consists of a spool-wound type heat exchanger including a shell and coils of heat transfer tubes for conducting the material gas and the refrigerant. The liquefaction unit 21 defines a warm region Z1 situated in the lower part thereof for receiving the mixed refrigerant and having a highest temperature (range), an intermediate region Z2 situated in the intermediate part thereof and having a lower temperature than the warm region Z1 and a cold region situated in the upper part thereof for expelling the liquefied material gas and having a lowest temperature. In the first embodiment, the warm region Z1 consists of a higher warm region Z1a on a higher temperature side and a lower warm region Z1b on a lower temperature side. The piping systems 22a and 22b, as well as the piping systems 42a, 51 a, and 42b and 51b through which the mixed refrigerant is conducted, are formed by the tube bundles provided in the higher warm region Z1a and the lower warm region Z1b, respectively. In the illustrated embodiment, the temperature of the higher warm region Z1a is about -35 degrees Celsius on the upstream side (inlet side) of the material gas that is to be cooled, and about -50 degrees Celsius on the downstream side (outlet side) of the material gas. The temperature of the lower warm region Z1b is about -50 degrees Celsius on the upstream side of the material gas, and about -135 degrees Celsius on the downstream side of the material gas. The temperature of the intermediate region Z2 is about -65 degrees Celsius on the upstream side of the material gas, and about -135 degrees Celsius on the downstream side of the material gas. The temperature of the cold region Z3 is about -135 degrees Celsius on the upstream side of the material gas, and about -155 degrees Celsius on the downstream side of the material gas. The temperatures on the upstream side and the downstream side of each region are not limited to the values mentioned here, and the temperature in each of these parts may vary within a prescribed range (± 5 degrees Celsius, for instance).

[0065] The first gas-liquid separation vessel 23 separates the liquid phase component (condensate) of the material gas, and this liquid essentially consisting of hydrocarbons is recirculated back to the distillation unit 15 by a recirculation pump 24 provided in a line L8. The gas phase component of the material gas obtained in the first gas-liquid separation vessel 23 and mainly consisting of methane is forwarded to a first compressor 4 via a line L9. The material gas is passed through the line L8 at a flow rate of about 83,500 kg/hr, and is passed through the line L6 at a flow rate of about 780,000 kg/hr. The first gas-liquid separation vessel 23 may also be cooled by using a mixed refrigerant or an ethylene refrigerant.

[0066] The first compressor 4 consists of a single stage centrifugal compressor having turbine blades for compressing the material gas, mounted on a shaft 5 common to the first expander 3. The material gas compressed by the first compressor 4 (first compression step) is introduced into the liquefaction unit 21 via a line L10. The material gas that is put out by the first compressor 4 to the line L10 has a temperature of about -51 degrees Celsius and a pressure of about 5,500 kPaA. The material gas introduced into the liquefaction unit 21 is compressed by the first compressor 4 preferably

to a pressure exceeding at least 5,171 kPaA.

[0067] A line L10 is connected to a piping system 30 positioned in the warm region Z1b of the liquefaction unit 21, and the upstream end of this piping system 30 is connected to a piping system 31 in the intermediate region Z2, and then to a piping system 32 positioned in the cold region Z3. After being liquefied and super cooled by flowing through the piping systems 31 and 32, the natural gas is forwarded to an LNG tank for storage purpose not shown in the drawings via an expansion valve 33 provided in a line L11. The material gas subjected to the liquefaction step acquires a temperature of -162 degrees Celsius and a pressure of about 120 kPaA in the downstream end of the expansion valve 33.

[0068] The material gas flowing through the liquefaction unit 21 is cooled by a refrigeration cycle using mixed refrigerants. In the illustrated embodiment, the mixed refrigerants may each contain nitrogen in addition to a mixture of hydrocarbons including methane, ethane and propane, but may also have other per se known compositions as long as the required cooling capability can be achieved.

[0069] In the liquefaction unit 21, a high pressure (HP) mixed refrigerant (MR) is supplied to a refrigerant separator 41 via a line L12. The mixed refrigerant which makes up the liquid phase component in the refrigerant separator 41 is introduced into the liquefaction unit 21 via a line L13, and then flows upward in the liquefaction unit 21 through the piping systems 42a and 42b positioned in the warm regions Z1a and Z1b, respectively, and the piping system 43 positioned in the intermediate region Z2. The mixed refrigerant is then expanded in an expansion valve 44 provided in a line L14, and is partly flash vaporized.

[0070] After passing through the expansion valve 44, the mixed refrigerant is ejected downward (so as to oppose the flow of the material gas in the liquefaction unit 21) from a spray header 45 provided in an upper part of the intermediate region Z2. The mixed refrigerant ejected from the spray header 45 flows downward while exchanging heat with an intermediate tube bundle formed by the piping systems 31, 43 and 52 (the last piping system will be discussed hereinafter) positioned in the intermediate region Z2, and a lower tube bundle formed by the piping systems 22a, 22b, 30, 42a, 42b, 51a and 51b (the last two piping systems will be discussed hereinafter) positioned in the warm region Z1.

[0071] The mixed refrigerant that makes up the gas phase of the refrigerant separator 41 is introduced into the liquefaction unit 21 via a line L15, and then flows upward in the liquefaction unit 21 by flowing through the piping systems 51a and 51b positioned in the warm regions Z1a and Z1b, the piping system 52 in the intermediate region Z2 and the piping system 53 positioned in the cold region Z3. The mixed refrigerant is then expanded in an expansion valve 54 provided in a line L16, and is partly flash vaporized.

[0072] The mixed refrigerant that has passed through the expansion valve 54 is already cooled to a temperature below the boiling point of methane (about -167 degrees Celsius in this case), and is expelled downward from a spray header 55 positioned in an upper part of the cold region Z3 (or flows in opposite direction to the flow of the material gas in the liquefaction unit 21). The mixed refrigerant ejected from the spray header 55 flows downward while exchanging heat with an upper tube bundle formed by the piping systems 32 and 53 positioned in the cold region Z3, and after mixing with the mixed refrigerant ejected from the spray header 45 located below, flows downward while exchanging heat with the intermediate tube bundle formed by the piping systems 31, 43 and 52 positioned in the intermediate region Z2, and the lower tube bundle formed by the piping systems 22a, 22b, 30, 42a, 42b, 51a and 51b positioned in the warm region Z1.

[0073] The mixed refrigerant ejected from the spray headers 45 and 55 is finally expelled via a line L17 connected to the bottom end of the liquefaction unit 21 as low pressure (LP) mixed refrigerant (MP) gas. The facilities for the mixed refrigerant provided in the liquefaction unit 21 (such as the refrigerant separator 41) form a part of a per se known refrigeration cycle for the mixed refrigerant, and the mixed refrigerant put out to the line L17 is recirculated to the refrigerant separator 41 via the line L12 after passing through compressors and condensers.

[0074] As discussed above, the material gas introduced into the liquefaction system 1 is effectively liquefied after being processed in the expansion step, the cooling step, the distillation step, the compression step and the liquefaction step. This liquefaction system can be applied, for instance, to a base load liquefaction plant for producing liquefied natural gas (LNG) mainly consisting of methane from the material gas mined from a gas field.

Table 1

No.	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
vapor phase fraction	1.00	1.00	1.00	0.00	0.93	0.00	1.00	1.00	0.00
temperature[C]	20.08	8.32	-42.58	177.19	-65.24	-65.24	-65.24	-50.99	-161.55
pressure [kPa]	5830.00	4850.00	4700.00	4705.00	4400.00	4400.00	4400.00	5483.00	120.00
molar flow rate [kgmole/h]	42000	42000	45020	313	45020	3334	41686	41686	41700
mass flow rate [kg/h]	719619	719619	783504	19764	783504	83548	699948	699948	698733
molar fraction									
nitrogen	0.008199590			0.000033626					0.008260844
methane	0.949952502			0.043508871					0.956667221
ethane	0.024998750			0.032339550					0.024931118
propane	0.009999500			0.143654595					0.009076200
butane	0.001999900			0.165149865					0.000793571
n-butane	0.001999900			0.232835468					0.000268518
i-pentane	0.000499975			0.066891831					0.000001710
n-pentane	0.000499975			0.067093928					0.000000817
n-hexane	0.000599970			0.080591893					0.000000000
benzene	0.000499975			0.067159786					0.000000000
toluene	0.000099995			0.013432078					0.000000000
p-xylene	0.000049998			0.006716040					0.000000000
n-heptane	0.000499975			0.067160391					0.000000000
n-octane	0.000099995			0.013432079					0.000000000

(First and Second Examples for Comparison)

[0075] Figures 2 and 3 are diagrams showing liquefaction process flows in conventional systems for the liquefaction of natural gas given as a first and a second example for comparison with the first embodiment of the present invention. In the conventional liquefaction systems 101 and 201 for natural gas, the parts corresponding to those of the liquefaction system of the first embodiment are denoted with like numerals. Tables 2 and 3 show the temperature, pressure, flow rate and molar fractions of the material gas in the liquefaction systems of the first and second examples for comparison, respectively. It should be noted that the liquefaction system 201 of the second example for comparison is based on the prior art disclosed in Patent Document 1 (US 4,065,278).

[0076] As shown in Figure 2, the liquefaction system 101 of the first example for comparison is not provided with the first expander 3 and the first compressor 4 used in the liquefaction system 1 of the first embodiment, and the material gas expelled from the water removal unit 2 is forwarded to a cooler 110 via a line L101. A cooler unit is formed by connecting a cooler 11 and a cooler 12 to the downstream end of the cooler 110 in a serial connection so that the material gas is sequentially cooled by exchanging heat in the three coolers 110, 11 and 12 which use a high pressure (HP), a medium pressure (MP) and a low pressure (LP) propane refrigerant, respectively. The material gas expelled from the cooler 12 in the downstream end has a temperature of about -34.5 degrees Celsius and a pressure of about 5,680 kPaA. The material gas is then depressurized by an expansion in an expansion valve 113 in a line L4, and is then introduced into a distillation unit 15.

[0077] In the liquefaction system 101, the material gas forming a gas phase component in the first gas-liquid separation vessel 23 and essentially consisting of methane is introduced into the piping system 31 positioned in the intermediate region Z2 of the liquefaction unit 21 via a line L102. The material gas that is put out from the first gas-liquid separation vessel 23 to a line L12 has a temperature of about -65.3 degrees Celsius and a pressure of about 4,400 kPaA.

Table 2

No.	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
vapor phase fraction	1.00	0.99	1.00	0.00	0.93	0.00	1.00	0.00
temperature[C]	20.08	-34.50	-42.58	176.73	-65.25	-65.25	-65.25	-161.56
pressure [kPa]	5830.00	5680.00	4700.00	4705.00	4400.00	4400.00	4400.00	120.00
molar flow rate (kgmole)	42000	42000	45020	314	45020	3334	41686	41700
mass flow rate[kg/h]	719619	719619	783488	19624	783454	83495	699951	696348
molar fraction								
nitrogen	0.008199590			0.000072318				0.008260784
methane	0.949952502			0.064051796				0.956622861
ethane	0.024998750			0.031841875				0.024947225
propane	0.009999500			0.129428030				0.009100267
butane	0.001999900			0.161816482				0.000796567
n-butane	0.001999900			0.231738008				0.000270095
1-pentane	0.000499975			0.066667173				0.000001771
n-pentane	0.000499975			0.066846201				0.000000423
n-hexane	0.000599970			0.080282498				0.000000003
benzene	0.000499975			0.066901980				0.000000003
toluene	0.000099995			0.013380485				0-000000000
p-xylene	0.000049998			0.006690243				0.000000000
n-heptane	0.000499975			0.066902427				0.000000000
n-octane	0.000099995			0.013380486				0.000000000

[0078] As shown in Figure 3, the liquefaction system 201 of the second example for comparison is an improvement of the liquefaction system 101 of the first example for comparison, and is provided with a first expander 3 and a first compressor 4. However, as opposed to the first expander 3 used in the liquefaction system 1 of the first embodiment, the expander 3 is positioned on the downstream side of the cooling unit (consisting the three coolers 110, 11 and 12 in this case). In the liquefaction system 201, the material gas expelled from the cooler 12 is forwarded to a separator 213 to be separated into gas and liquid components. The material gas that forms the gas phase component in the separator 213 is forwarded to the expander 3 to be expanded therein, and is then forwarded to the distillation unit 15 via a line L204. The part of the material gas that forms the liquid component in the separator 213 is put out to a line L205 provided with an expansion valve 214. The liquid that has been expanded in the expansion valve 214 is then forwarded to the distillation unit 15 via the line L204 along with the material gas from the expander 3.

[0079] The liquefaction system 201 is similar to that of the first embodiment as far as the part thereof downstream of the distillation unit 15 is concerned, and the material gas that has been put out to the line L10 by the compressor 4 has a temperature of about -54.7 degrees Celsius and a pressure of about 5,120 kPaA.

Table 3

No.	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
vapor phase fraction	1.00	1.00	1.00	0.00	0.94	0.00	1.00	1.00	0.00
temperature[C]	20.08	-45.36	-44.83	208.13	-64.56	-64.56	-64.56	-54.74	-161.59
pressure [kPa]	5830.00	4705.00	4700.00	4705.00	4400.00	4400.00	4400.00	5120.00	120.00
molar flow rate [kg	42000	41783	44200	302	44200	2500	41700	41700	41700
mass flow rate[kg/l	719619	709009	764342	19107	764342	63861	700471	700471	694674
molar fraction									
nitrogen	0.008199590			0.000051871					0.008259333
methane	0.949952502			0.053398407					0.956509212
ethane	0.024998750			0.032075932					0.024927984
propane	0.009999500			0.133750785					0.009066826
butane	0.001999900			0.153843084					0.000893180
n-butane	0.001999900			0.230805233					0.000340430
i-pentane	0.000499975			0.069219794					0.000002448
n-pentane	0.000499975			0.069480324					0.000000589
n-hexane	0.000599970			0.083472642					0.000000000
benzene	0.000499975			0.069560398					0.000000000
toluene	0.000099995			0.013912204					0.000000000
p-xylene	0.000049998			0.006956102					0.000000000
n-heptane	0.000499975			0.069561020					0.000000000
n-octane	0.000099995			0.013912205					0.000000000

[0080] As can be appreciated by comparing the first and second examples for comparison with the present invention, the liquefaction system 1 according to the present invention allows a greater power to be produced by expanding material gas of higher temperature and higher pressure because the first expander 3 is positioned on the upstream side of the first cooling unit 11, 12, as compared to the liquefaction system 201 of the second example which has the expander 3 positioned on the downstream side of the cooling unit 110, 11, 12. As a result, the first compressor 4 can be driven with an increased power (or the outlet pressure of the first compressor 4 can be increased) so that the pressure of the material gas introduced into the liquefaction unit 21 can be increased, and the efficiency of the liquefaction process in the liquefaction unit 21 can be advantageously increased.

[0081] The liquefaction system 1 of the illustrated embodiment provides an additional advantage of reducing the required cooling capacity of the cooling unit (thereby allowing the cooler 110 in the second example for comparison to be omitted) because the temperature of the material gas is reduced by the expansion of the material gas in the first expander 3 owing to the positioning of the first expander 3 on the upstream side of the first cooling unit 11, 12. In the liquefaction system 1 of the illustrated embodiment, the gas-liquid separation vessel (separator 213) for removing the condensate of the material gas placed between the cooling unit and the expander 3 may be omitted.

(First, Second, and Third Modifications of the First Embodiment)

[0082] Figures 4, 5 and 6 are diagrams showing liquefaction process flows in systems for the liquefaction of natural gas given as a first, second, and third modifications of the first embodiment, respectively. In the liquefaction systems illustrated in Figures 4, 5 and 6, the parts corresponding to those of the liquefaction system 1 of the first embodiment (as well as the other modifications) are denoted with like numerals and omitted from the following discussion except for the matters that will be discussed in the following.

[0083] As shown in Figures 4, in the liquefaction system 1 of the first modification, a heat exchanger 69 is provided between the line L4 and the line L9. Thus, the material gas that is separated in the first gas-liquid separation vessel 23 as the gas phase component and flows through the line L9 is heated by exchanging heat with the material gas flowing from the cooling unit 12 to the distillation unit 15 via the line L4, before being introduced into the first compressor 4. The material gas compressed by the first compressor 4 is introduced into the liquefaction unit 21 via the line L10. The downstream end of the line L10 is connected to a piping system 30 positioned in the warm region Z1 demonstrating the highest temperature in the liquefaction unit 21. The piping system 30 forms a tube bundle that is positioned in the warm region Z1 jointly with a piping system 22 into which the top fraction of the distillation unit 15 is introduced, and a piping system 42 and a piping system 51 through which a mixed refrigerant flows.

[0084] Owing to this arrangement, in the first modification of the first embodiment, even when the temperature level of the material gas that is introduced into the liquefaction unit 21 via the line L10 should be lower than an appropriate range, the temperature of the material gas can be raised to an appropriate level by exchanging heat in the heat exchanger 69. In other words, in the first modification of the first embodiment, the temperature of the material gas in the line L10 after the compression can be brought close to the temperature at the point of introduction (piping system 30) in the liquefaction unit 21 (preferably with a deviation of less than 10 degrees Celsius) so that the thermal load on the liquefaction unit 21 can be reduced (or the generation of thermal stress can be minimized).

[0085] The arrangement of the heat exchanger 69 in the first modification can be freely changed as long as the temperature of the material gas in the line L10 after the compression can be brought close to the temperature at the introduction point of the liquefaction unit 21. For instance, in the liquefaction system 1 of the second modification shown in Figure 5, the heat exchanger 69 is provided between the line L4 and the line L10. The material gas compressed by the first compressor 4 and flowing through the line L10 is cooled by exchanging heat with the material gas flowing through the line L4 before being introduced into the liquefaction unit 21. In the second modification, because the material gas heated by the heat exchanger 69 is introduced into the liquefaction unit 21 without the intervention of a device such as the first compressor 4, the temperature of the material gas that is introduced into the liquefaction unit 1 can be controlled with ease.

[0086] As shown in Figure 6, in the liquefaction system of the third modification, the heat exchanger 69 is provided between the line L4 and the line L6. Therefore, the material gas that is separated as a top fraction from the distillation unit 15 and flows through the line L6 is heated by exchanging heat with the material gas flowing through the line L4, before being introduced into the liquefaction unit 21 (the piping system 22). In particular, in the third modification, even when the material gas consists of natural gas (lean gas) containing a relatively low level of heavier components (higher hydrocarbons) as shown in Table 1, and the temperature of the material gas flowing through the line L6 following the distillation step may fall below an appropriate range, the temperature of the material gas can be raised to an appropriate level by exchanging heat in the heat exchanger 69.

(Fourth Modification of the First Embodiment)

[0087] Figure 7 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a modification of the first embodiment. In the liquefaction system illustrated in Figure 7, the parts corresponding to those of the liquefaction system 1 of the first embodiment are denoted with like numerals and omitted from the following discussion except for the matters that will be discussed in the following.

[0088] The fourth modification is similar to the third modification, but further modification of the first embodiment includes a heat exchanger 69 that is provided between the line L4 and the line L6. Therefore, the material gas that is separated as a top fraction from the distillation unit 15 and flows through the line L6 is heated by exchanging heat with the material gas flowing through the line L4, before being introduced into the liquefaction unit 21 (the piping system 22). In particular, in the first modification, even when the material gas consists of natural gas (lean gas) containing a relatively low level of heavier components (higher hydrocarbons) as shown in Table 1, and the temperature of the material gas flowing through the line L6 following the distillation step may fall below an appropriate range, the temperature of the material gas can be raised to an appropriate level by exchanging heat in the heat exchanger 69.

[0089] The modification further includes a heat exchanger 79 provided between the line L9 and the line L10. A cooler 80 using a low pressure (LP) propane refrigerant (C3R) is further provided in the line L10. As a result, the material gas expelled from the first compressor 4 is cooled by exchanging heat with the material gas flowing through the line L9 before being introduced into the liquefaction unit 21. The downstream end of the line L10 is connected to a piping system 31 positioned in the intermediate region Z2.

[0090] In the fourth modification, the material gas expelled from the first compressor 4 can be introduced into the intermediate region Z2. Therefore, the tube bundle in the warm region Z1 can be formed by the three piping systems 22, 42 and 51, and the tube bundle in the intermediate region Z2 can be formed by the three piping systems 31, 43 and 52. As a result, in the fourth modification, when the liquefaction unit 21 is formed by using a spool-wound heat exchanger, the arrangement of the piping systems in the warm region Z1 and the intermediate region Z2 can be optimized (by uniformly spreading the piping systems among the different regions) as compared to the arrangement of the third modification so that the size of the liquefaction unit 21 is prevented from becoming excessively great. The fifth cooler 80 uses a propane refrigerant similarly to the first and second coolers 11 and 12 in the illustrated embodiment, by may also use other forms of air-cooled or water-cooled coolers.

(Fifth Modification of the First Embodiment)

[0091] Figure 10 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a fifth modification of the first embodiment of the present invention. In the liquefaction system illustrated in Figure 10, the parts corresponding to those of the liquefaction system 1 of the first embodiment (including the modifications thereof) are denoted with like numerals and omitted from the following discussion except for the matters that will be discussed in the following.

[0092] The fifth modification is similar to the fourth modification discussed above, but the fifth cooler 80 of the fourth modification is omitted, and a heat exchanger 100 is added between the line L6 leading from the distillation unit 15 and the line L10 leading from the first compressor 4. As a result, the material gas expelled from the first compressor 4 to the line L10 is cooled by the material gas (top fraction) expelled from the distillation unit 15 to the line L6, instead of being cooled by the fifth cooler 80, and is introduced into a heat exchanger 79 similarly to that of the fourth modification. Meanwhile, the material gas expelled from the distillation unit 15 is introduced into the liquefaction unit 21 via the line L6 following the heat exchange, and is then cooled by the piping system 22. Owing to this arrangement, in the fifth modification, the cooling of the material gas by the fifth cooler 80 as in the fourth embodiment may be augmented or replaced by the heat exchange in the heat exchanger 100. In the eighth embodiment, the heat exchanger 69 that was used in the fifth embodiment is omitted, but it is also possible to arrange such that the material gas expelled from the distillation unit 15 to the line L6 is introduced into the heat exchanger 100 via the heat exchanger 69.

(Second Embodiment)

[0093] Figure 8 is a diagram showing a liquefaction process flow in a system for the liquefaction of natural gas given as a second embodiment of the present invention. In the liquefaction system illustrated in Figure 8, the parts corresponding to those of the liquefaction system 1 of the first embodiment is denoted with like numerals and omitted from the following discussion except for the matters that will be discussed in the following.

[0094] In the liquefaction system 1 of the second embodiment, rich gas containing 88 mol% of methane is used as the material gas. In this liquefaction system, the material gas that is separated as a top fraction in the distillation unit 15 is directly introduced into the first compressor 4 to be compressed thereby via a line L19. The material gas is then pre-cooled in the piping system 22 in the warm region Z1, and forwarded to a first gas-liquid separation vessel 23 via a line L21.

[0095] The first gas-liquid separation vessel 23 separates a liquid phase component (condensate) of the material gas, and the hydrocarbons in liquid form forming the liquid phase component is recirculated to the distillation unit 15 via an expansion valve 89 provided in a line L22. Meanwhile, the material gas mainly consisting of methane and forming the liquid phase component in the first gas-liquid separation vessel 23 is forwarded to the piping system 31 in the liquefaction unit 21 via a line L23.

[0096] In the liquefaction system 1 of the second embodiment, because the first gas-liquid separation vessel 23 is provided on the downstream side of the first compressor 4, and the material gas expelled from the first compressor 4 is introduced into the first gas-liquid separation vessel 23 via the piping system 22 positioned in the warm region Z1, the temperature of the material gas can be brought close to the temperature level of the warm region Z1 of the liquefaction unit 21. Furthermore, because the material gas is cooled in the warm region Z1 (piping system 22) of the liquefaction unit 21, and the gas phase component expelled from the first gas-liquid separation vessel 23 is introduced into the intermediate region Z2 (piping system 31), the temperature of the material gas can be brought close to the temperature level of the intermediate region Z2 of the liquefaction unit 21 with ease. Also, because the material gas expelled from the first gas-liquid separation vessel 23 can be placed under pressure by the first compressor 4, the recirculation pump 24 provided in the recirculation line (line L21) extending from the first gas-liquid separation vessel 23 to the distillation unit 15 in some of the embodiments including the first embodiment can be omitted.

[0097] In the liquefaction of the material gas in the liquefaction unit 21, raising the outlet pressure of the compressor 4 (or increasing the pressure of the material gas that is introduced into the liquefaction unit 21) is advantageous. However, when the top fraction of the distillation unit 15 is cooled in the liquefaction unit 21, separated in the first gas-liquid separation vessel 23, and the separated gas phase component is compressed by the first compressor 4 before being introduced into the liquefaction unit 21 as was the case with the first embodiment, because the temperature of the material gas is increased by the first compressor 4 preceding the liquefaction unit 21, depending the conditions associated with the composition, pressure and feed rate of the material gas, the temperature level of the material gas may deviate from a suitable range for introduction into the liquefaction unit 21 so that the thermal load on the liquefaction unit 21 may become excessive. Such a problem can be resolved by changing the point of introducing the material gas into the liquefaction unit 21, but when the main heat exchanger consists of a kind such as a spool-wound heat exchanger which does not allow the point of introduction to be changed with ease, it may not be the case. Thus, if the material gas separated as the top fraction in the distillation unit 15 is forwarded directly to the first compressor 4 via the line L19 to be compressed, the material gas compressed by the first compressor 4 is cooled in the warm region Z1 of the liquefaction unit 21, the cooled material gas is separated in the first gas-liquid separation vessel 23, and the separated gas phase component of the material gas is introduced into the intermediate region Z2 (downstream of the warm region Z1) of the liquefaction unit 21, as is the case with the present embodiment, the temperature of the material gas can be maintained within an appropriate range (or the temperature of the material gas can be brought close to the temperature level at the introduction point of the liquefaction unit 21).

(First Modification of the Second Embodiment)

[0098] Figure 9 is diagrams showing liquefaction process flows in systems for the liquefaction of natural gas given as a first embodiment of the present invention. In the liquefaction systems illustrated in Figure 9, the parts corresponding to those of the liquefaction system 1 of the first embodiment is denoted with like numerals and omitted from the following discussion except for the matters that will be discussed in the following.

[0099] As shown in Figure 9, the liquefaction system 1 of the first modification includes a heat exchanger 69 positioned between the line L4 and the line L20 so that the material gas expelled from the first compressor 4 and conducted through the line L20 is heated by the exchange of heat with the material gas flowing through the line L4, and is then introduced into the piping system positioned in the warm region Z1 of the liquefaction unit 21. In the first modification of the second embodiment, the material gas heated in the heat exchanger 69 is directly introduced into the liquefaction unit 21 without the intervention of the first compressor 4 so that the temperature of the material gas that is introduced into the liquefaction unit 21 can be controlled with ease.

[0100] The positioning of the heat exchanger 69 in the first modifications of the second embodiment can be changed variously without departing from the spirit of the present invention as long as the temperature of the material gas in the line L20 following the compression can be brought close to the temperature at the introduction point of the liquefaction unit 21.

[0101] The present invention has been described in terms of specific embodiments, but these embodiments are only examples, and do not limit the present invention in any way. The various components of the liquefaction systems and the liquefaction methods for the liquefaction of the natural gas according to the present invention are not necessarily entirely indispensable, but may be suitably substituted and omitted without departing from the spirit of the present invention.

GLOSSARY

[0102]

5	1	liquefaction system
	2	water removal unit
	3, 3a	first expander
	3b	second expander
	4, 4a	first compressor
10	4b	third compressor
	5	shaft
	10, 11, 12	first cooler
	15	distillation unit
	21	liquefaction unit
15	23	first gas-liquid separation vessel
	33	expansion valve
	41	refrigerant separator
	44	expansion valve
	45	spray header
20	54	expansion valve
	55	spray header
	69	heat exchanger
	79	heat exchanger
	80	cooler
25	Z1	warm region
	Z2	intermediate region
	Z3	cold region

30 **Claims**

1. A method for cooling a natural gas feed comprising:

- 35 a) reducing the pressure of the natural gas feed to produce a reduced pressure material gas;
 b) removing heavy components from the reduced pressure material gas to produce a top fraction and a bottom fraction;
 c) cooling the top fraction to produce a cooled top fraction;
 d) separating the cooled top fraction into a gas phase component and a liquid phase component;
 e) increasing the pressure of the gas phase component to produce a compressed material gas; and
 40 f) exchanging heat between the gas phase component and the compressed material gas to produce at least a cooled compressed material gas.

2. The method of claim 1 further comprising cooling the reduced pressure material gas of step (a) prior to removing heavy components in step (b).

45 3. The method of claim 1 further comprising at least partially liquefying the cooled compressed material gas of step (f).

4. The method of claim 1 further comprising cooling the compressed material gas of step (e) prior to step (f).

50 5. The method of claim 1 wherein the top fraction is cooled in step (c) by introducing the top fraction in a warm region of a spool wound heat exchanger.

6. The method of claim 5 wherein the cooled compressed material gas of step (f) is further cooled by introducing the cooled compressed material gas in an intermediate region of the spool wound heat exchanger.

55 7. The method of claim 1 wherein the removal of heavy components in step (b) is performed in a distillation unit and the liquid phase component of step (d) is recirculated to the distillation unit.

8. The method of claim 1 further comprising exchanging heat between the top fraction of step (b) and the reduced pressure material gas prior to step (c).

9. The method of claim 1 wherein step (f) comprises exchanging heat between the gas phase component of step (d), the compressed material gas of step (e), and the reduced pressure material gas of step (a).

10. A system for liquefaction of a natural gas feed comprising:

a first expander to reduce the pressure of the natural gas feed to produce a reduced pressure material gas;
a distillation unit for removing heavy components from the reduced pressure material gas to produce a top fraction and a bottom fraction;
a first heat exchanger for cooling the top fraction to produce a cooled top fraction;
a first gas-liquid separation vessel to separate the cooled top fraction into a gas phase component and a liquid phase component;
a first compressor for compressing the gas phase component to produce a compressed material gas; and
a second heat exchanger for exchanging heat between the gas phase component and the compressed material gas.

11. The system of claim 10 further comprising a first cooling unit for cooling the reduced pressure material gas prior to introduction in the distillation unit.

12. The system of claim 10 further comprising a second cooling unit for cooling the compressed material gas prior to introduction in the second heat exchanger.

13. The system of claim 10 wherein the first heat exchanger is a warm region of a spool wound heat exchanger.

14. The system of claim 13 further comprising a third heat exchanger for cooling the compressed material gas after the compressed material gas passes through the second heat exchanger; wherein the third heat exchanger is an intermediate region of the spool wound heat exchanger.

15. The system of claim 10 further comprising a fourth heat exchanger for exchanging heat between the top fraction from the distillation unit and the reduced pressure material gas.

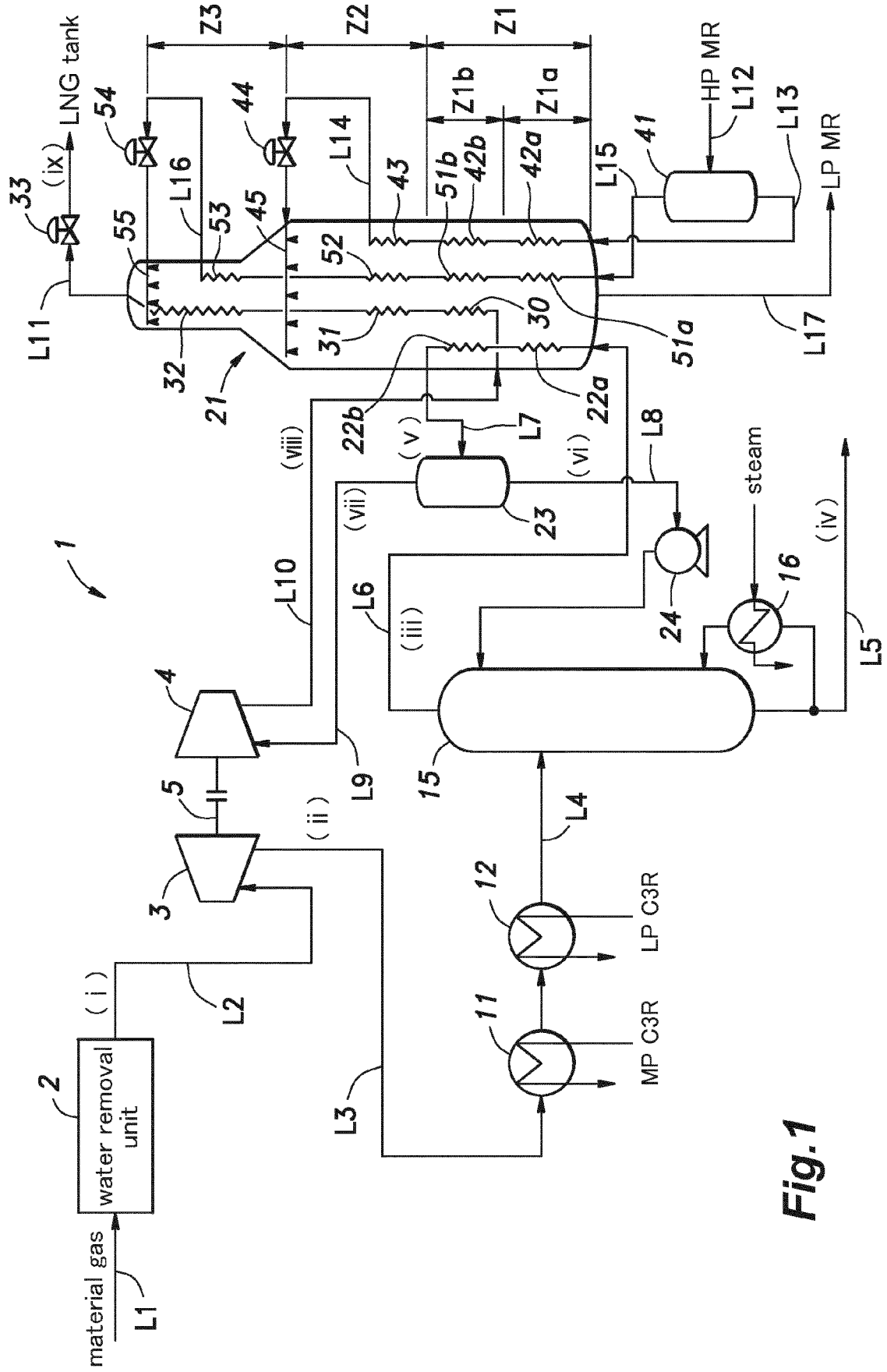
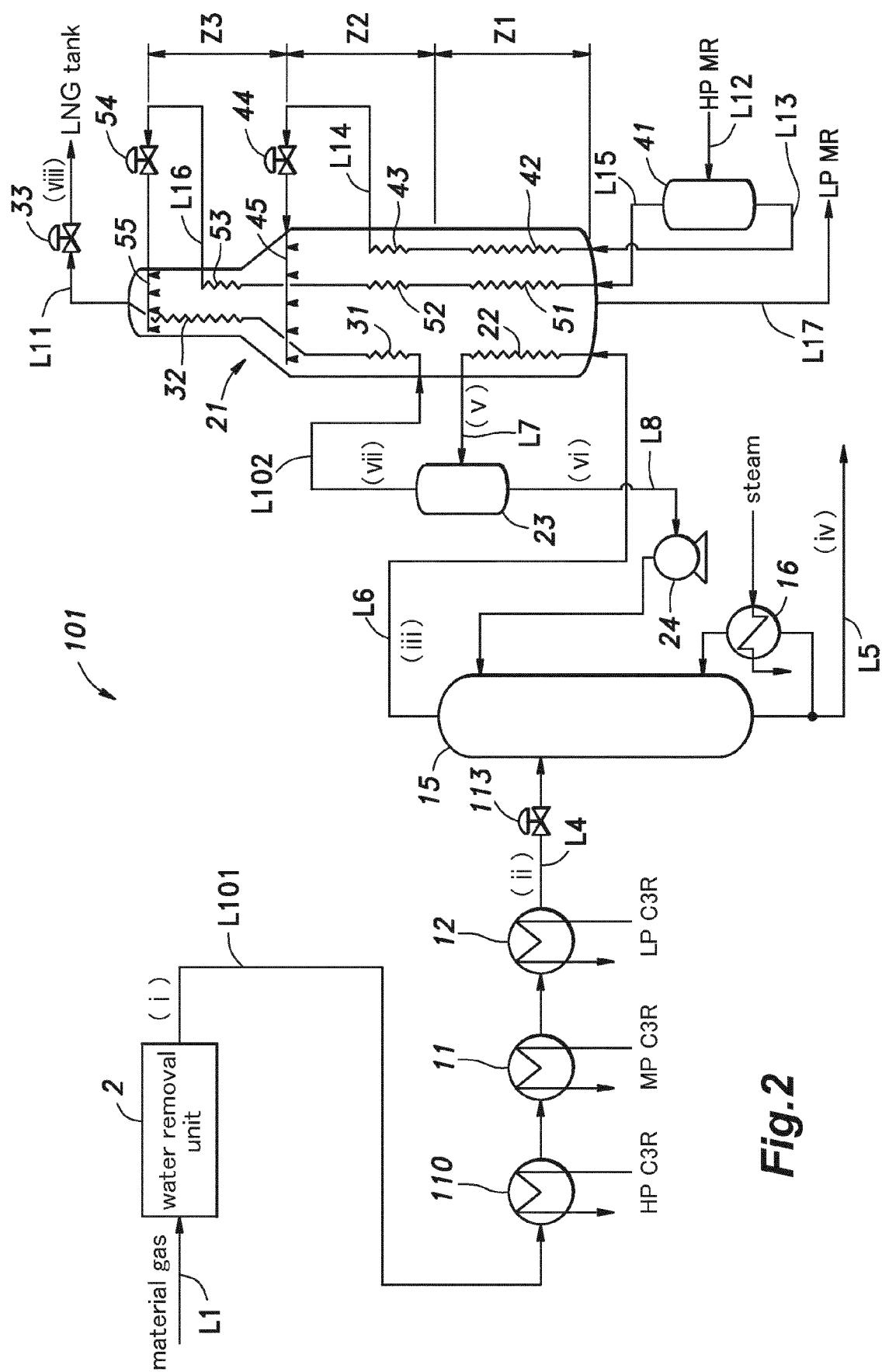


Fig.1



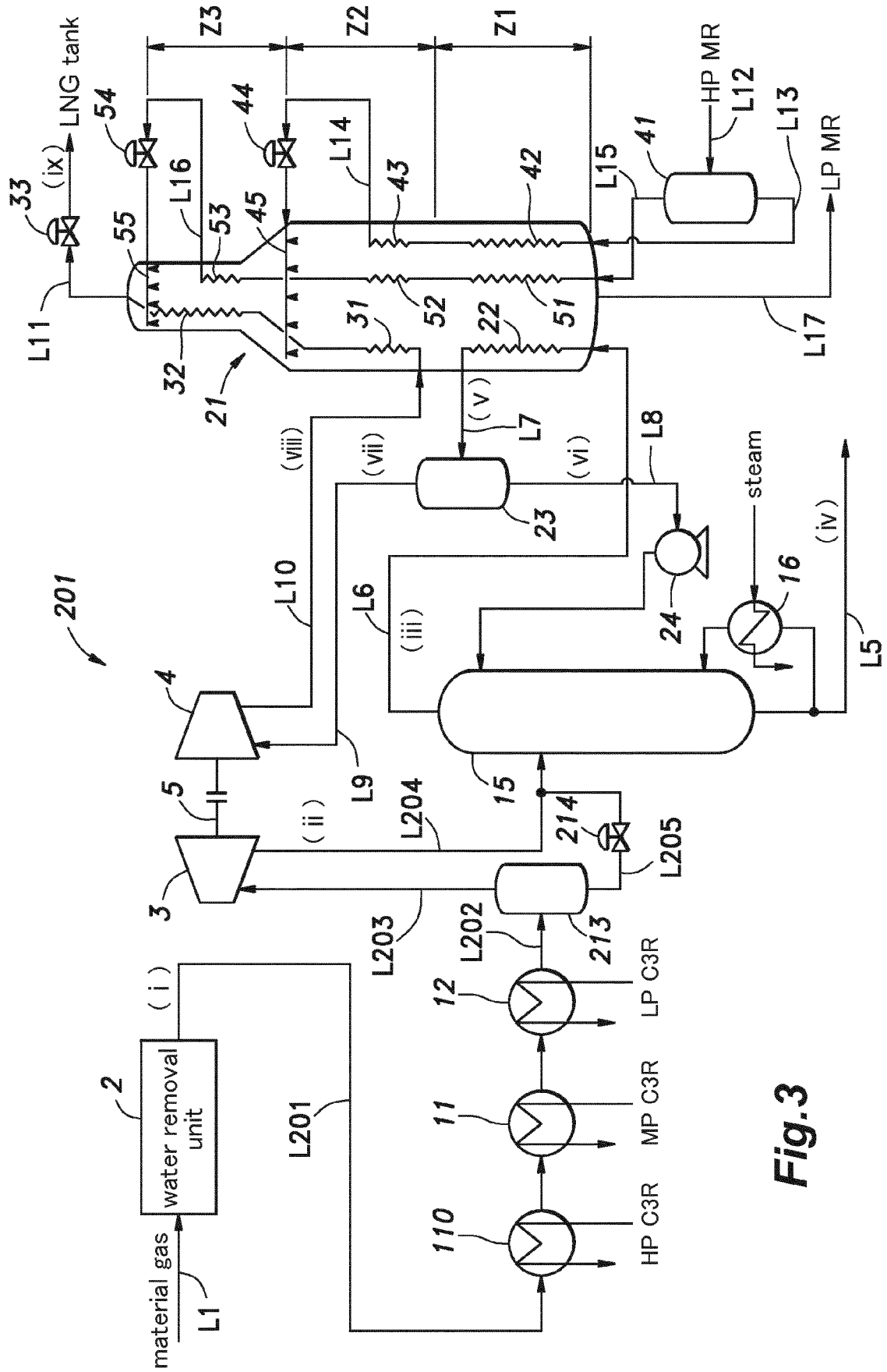


Fig.3

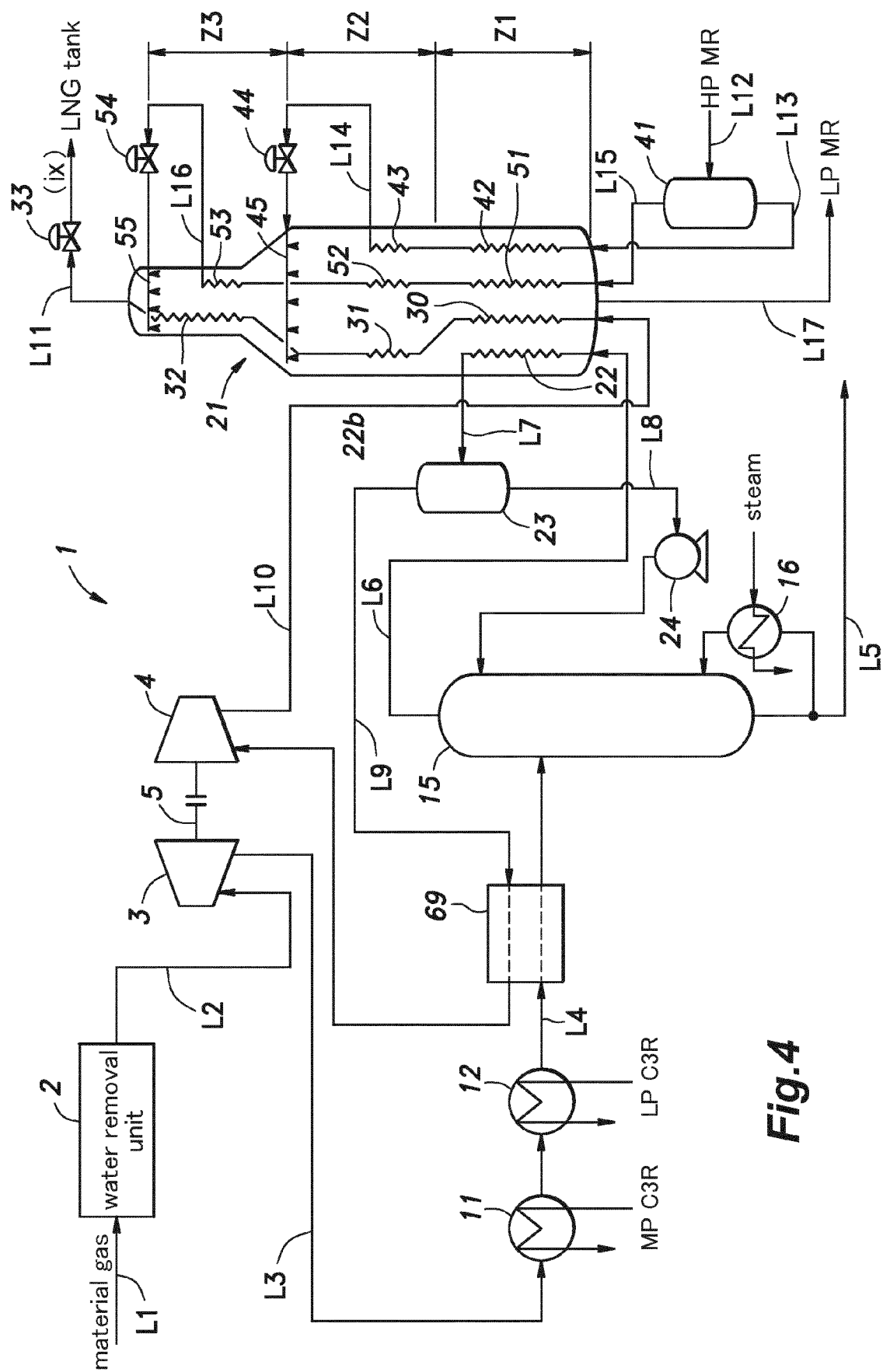
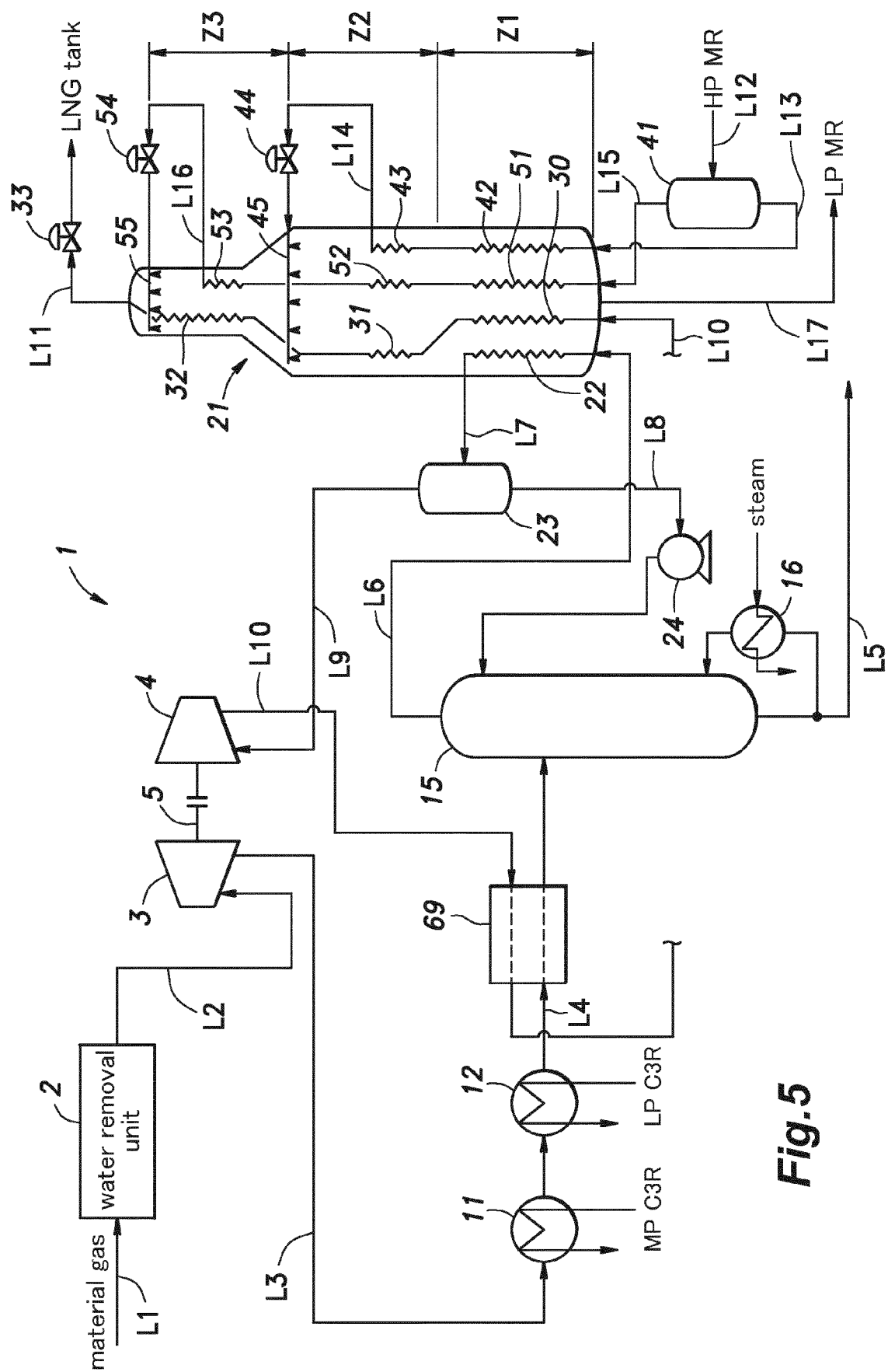


Fig.4



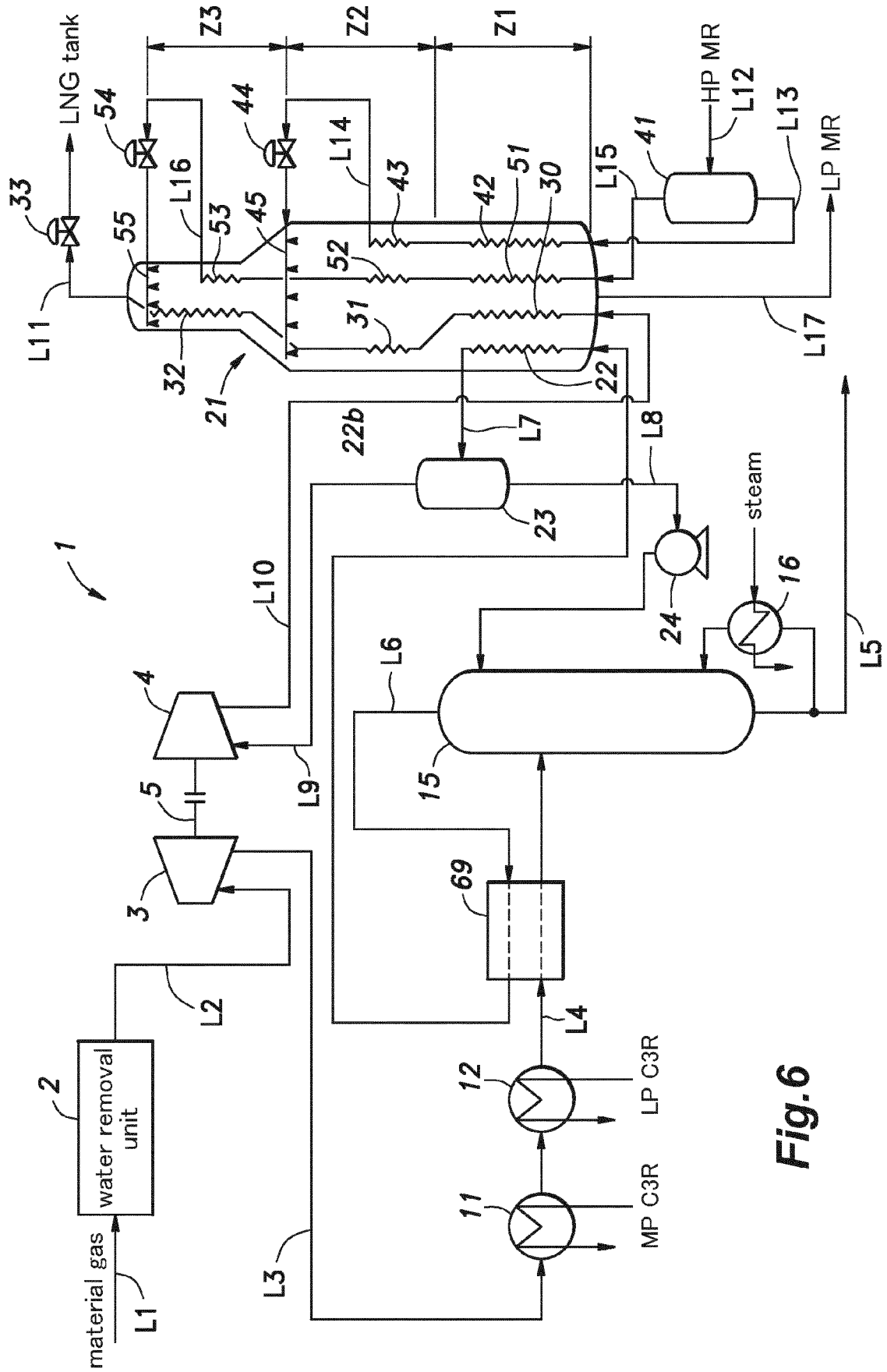


Fig.6

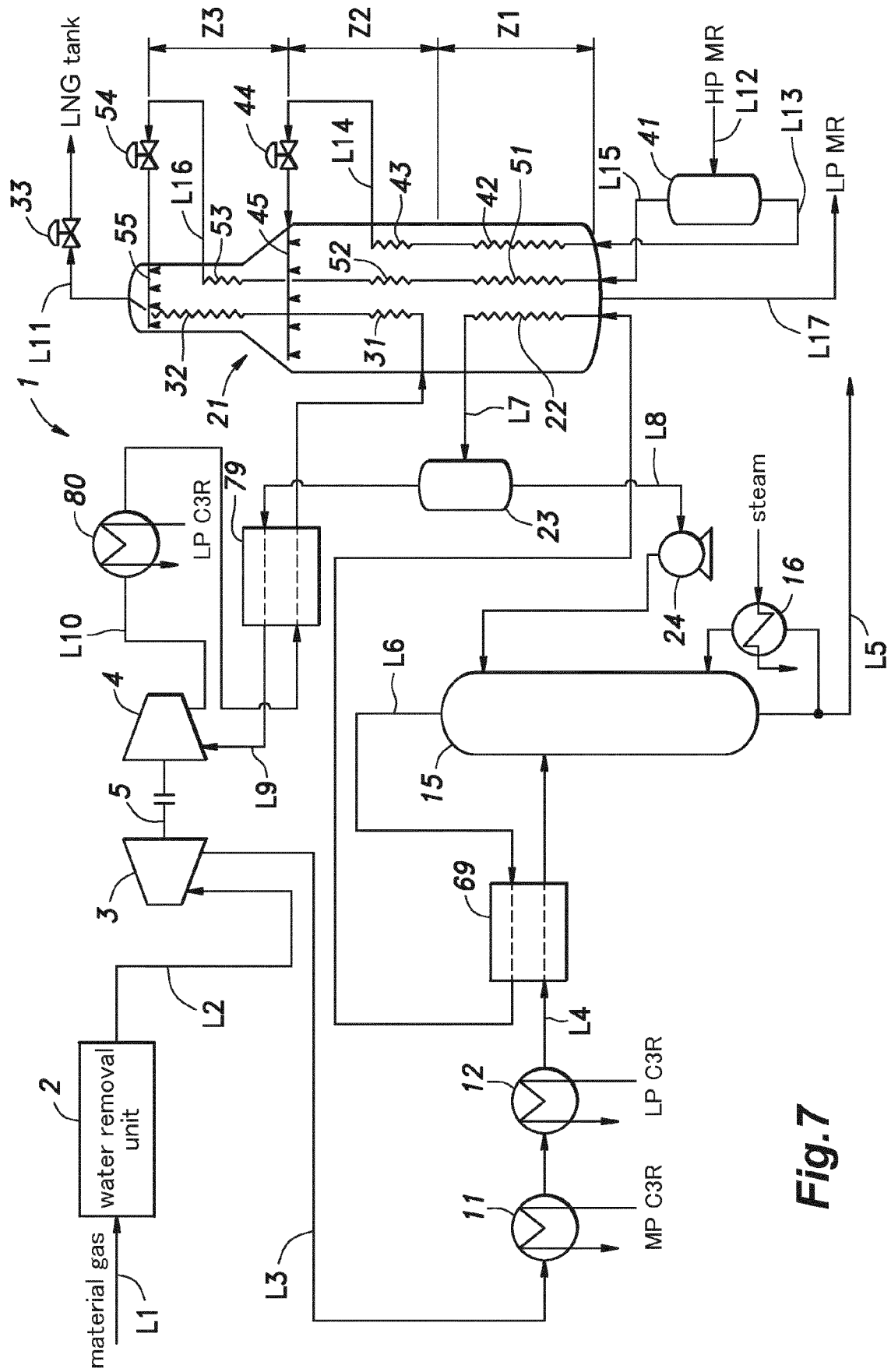
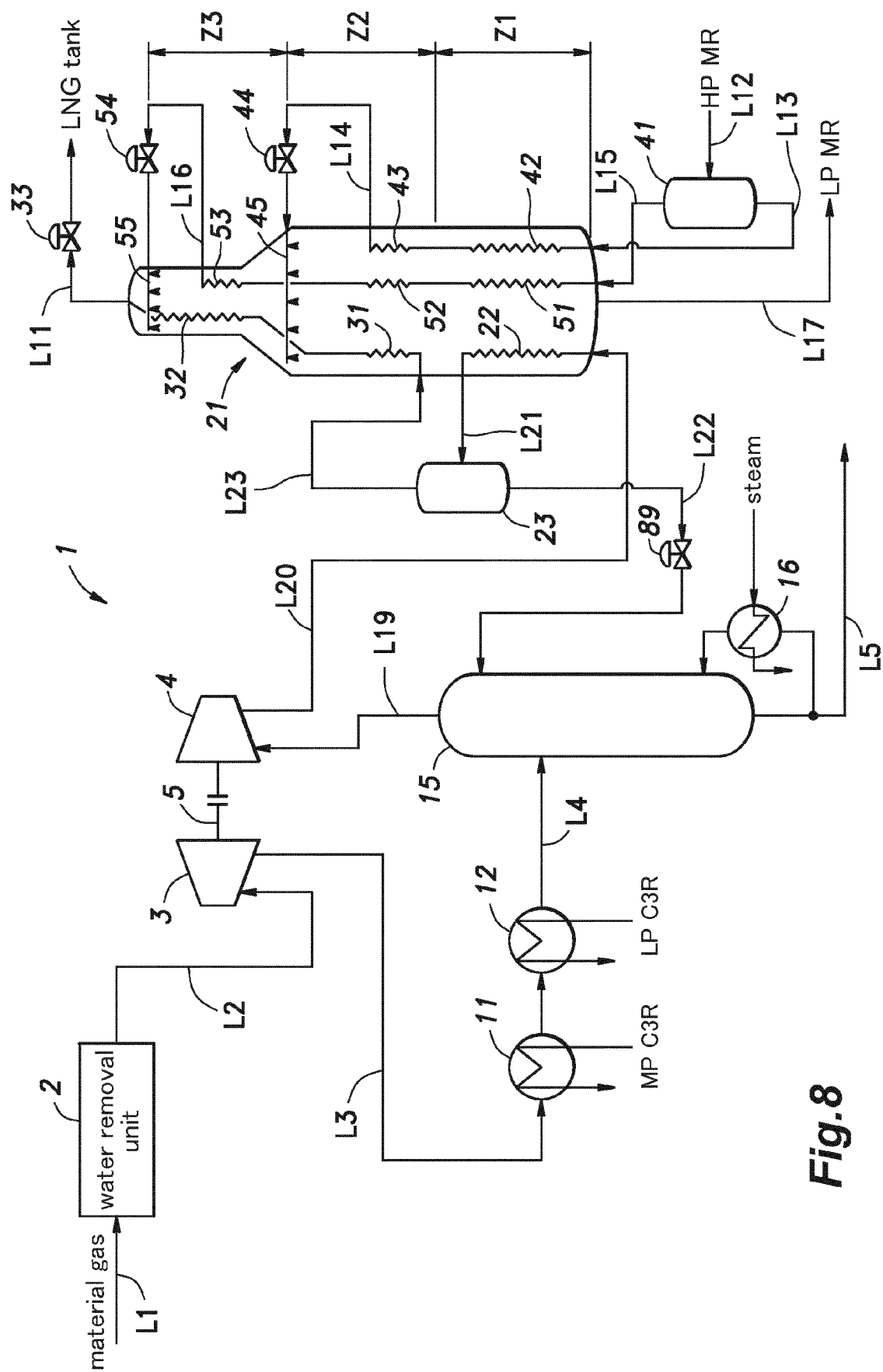


Fig. 7



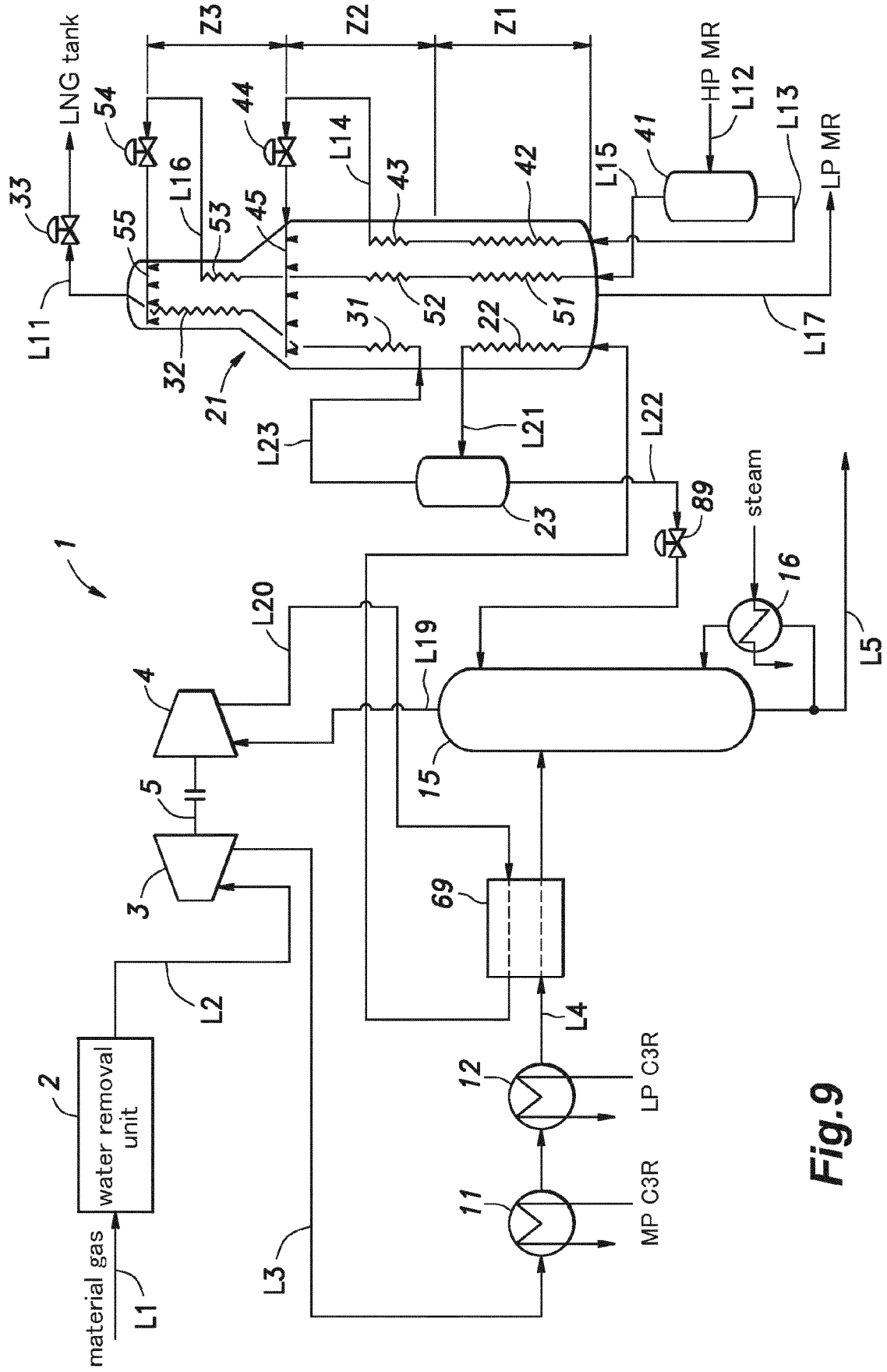


Fig.9

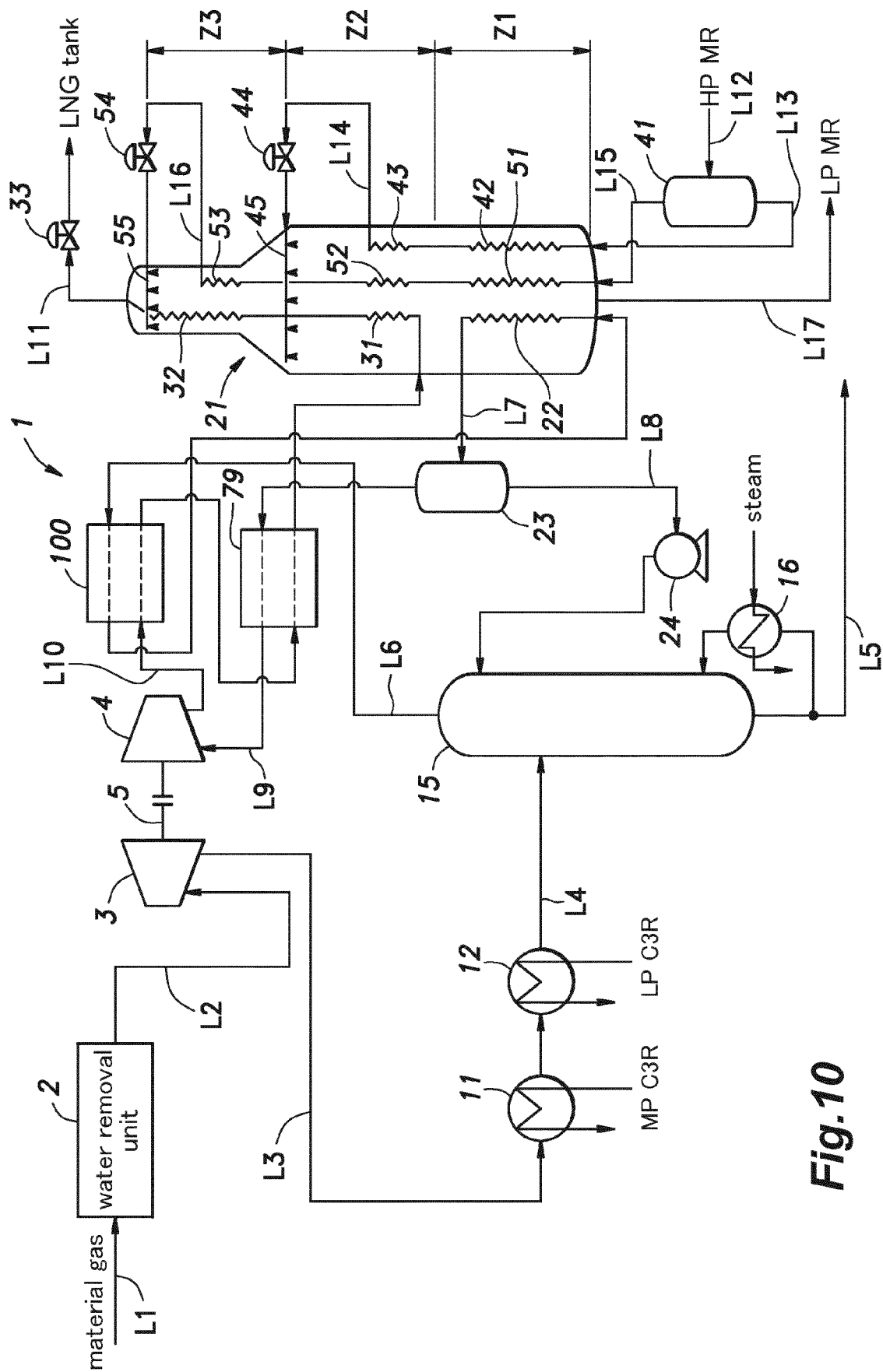


Fig.10



EUROPEAN SEARCH REPORT

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A	JP S54 72203 A (AIR PROD & CHEM) 9 June 1979 (1979-06-09) * figure 1 *	1-15	
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Place of search Munich		Date of completion of the search 7 April 2017	Examiner Schopfer, Georg
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