(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 579 164 A2**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
02.07.2025 Bulletin 2025/27

(21) Application number: **24222338.6**

(22) Date of filing: **20.12.2024**

(51) International Patent Classification (IPC):
F25J 1/00 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
F25J 1/0022; F25J 1/004; F25J 1/005; F25J 1/0072; F25J 1/0205; F25J 1/021; F25J 1/0262; F25J 1/0271; F25J 2210/66; F25J 2230/30; F25J 2230/60; F25J 2245/90

(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 ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH MA MD TN

(30) Priority: **28.12.2023 CZ 20230516**

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(54) DEVICE FOR METHANE LIQUEFACTION

(57) The invention relates to a device for methane liquefaction comprising a cooling module (A) which is provided with an inlet of gaseous methane, to the outlet of the cooling module (A) being associated a condensing and separating module (B) provided with an outlet (702) of liquid methane. The cooling module (A) comprises at least one heat recovery exchanger (1, 3) and a cooler (2) coupled to a cooling device (8), wherein the downstream condensing and separating module (B) comprises a condensing cooling device (9) and at least one heat recovery exchanger (5), which is connected to a methane gas/liquid phase separator (7), upstream of which a throttling device (6) is included, wherein the methane gas/liquid phase separator (7) is provided with an outlet (703) of methane gas phase, to which are associated return pipelines (R1, R2, R3), passing through the heat recovery exchangers (1, 3, 5) as far as to an end return pipeline (R4).

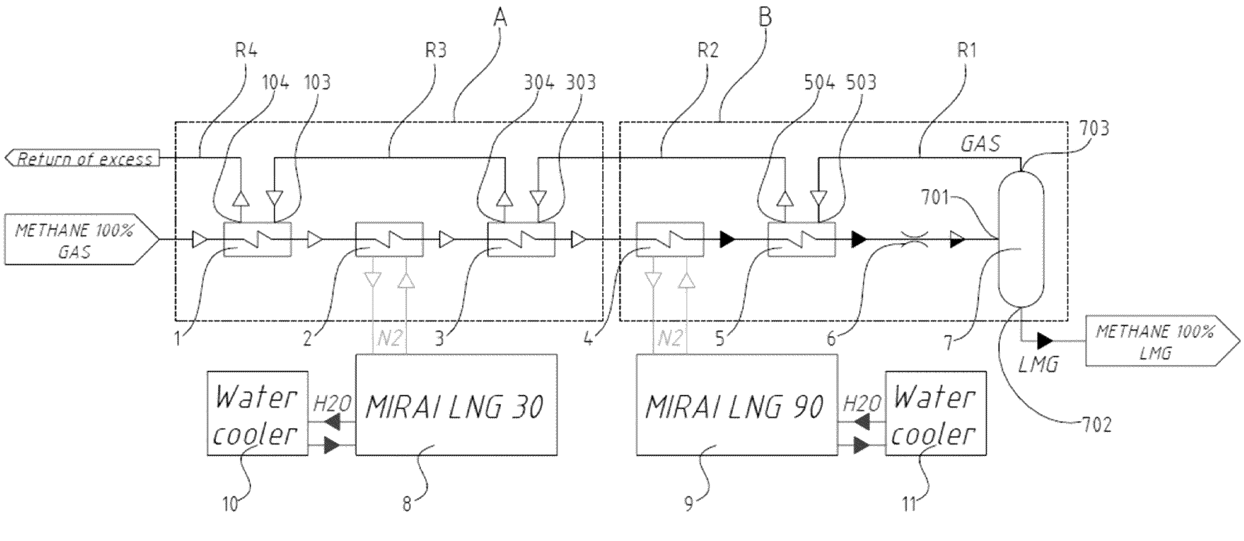

Fig. 1

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Description

Technical field

[0001] The invention relates to a device for methane liquefaction comprising a cooling module provided with an inlet of gaseous methane, to the outlet of which is associated a condensing and separating module provided with an outlet of liquid methane.

Background art

[0002] Methane is one of the simplest hydrocarbons, it is part of natural gas, which contains 70 to 90 % of methane, and biogas, which contains about 50 to 55 % of methane, but by purification it can be converted into biomethane, which contains at least 95 % of methane. Methane occurs in gaseous form at normal temperatures, but it can be liquefied, and in the liquid state it occupies 600 times less volume than in its gaseous state.

[0003] Methane liquefaction has several advantages. Liquefied methane is easy to store and transport. As a result, methane can be used as a fuel for cars, buses and ships. Liquefied methane also has lower carbon dioxide emissions than gasoline and diesel, making it a cleaner fuel. In addition, liquefaction of methane allows it to be used as a refrigerant in industry.

[0004] The critical state of a substance is one in which the difference (boundary) between its liquid and gaseous phases disappears, i.e., they have the same basic properties. For every substance there is a temperature above which it cannot be converted into liquid by any increase in pressure. This temperature is called the critical temperature. Saturation vapour pressure corresponding to critical temperature is called critical pressure. The volume of vapour at critical temperature and pressure is called critical volume. The critical parameters for methane are a pressure of 4.6 MPa and a temperature of -82 °C. Methane cannot be liquefied at pressures above the critical value. In order to be liquefied at atmospheric pressure (0.1 MPa), methane must be cooled to a temperature below -161 °C. Many of the known cooling devices that could provide this temperature level are of low efficiency and the pressure increases when the condensing temperature rises above -161 °C. Therefore, the idea was conceived to develop a system which searches for the optimal temperature for using known cooling technology.

[0005] Methane liquefaction technology is known, for example, from US 2021/0364228, which discloses a device comprising a generator for producing methane from hydrogen and carbon dioxide arranged in series, followed by a device for drying the gas mixture from the generator and purification means for removing carbon dioxide from the gas mixture. A methane condenser is arranged downstream of the purification means, downstream of which a separator for liquid methane and hydrogen gas is arranged, with the liquid methane being led from the separator to a liquid methane storage tank. From the separator and the storage tank, the gaseous components of hydrogen and methane are fed back to the inlet of the generator for methane generation. The liquid methane tank serves to fill transport tanks.

[0006] US 2021/0364228 discloses a general principle of methane liquefaction in which methane is generated by a chemical reaction of hydrogen and carbon dioxide and is subsequently separated from the hydrogen. This document does not describe in detail the heat and cold sources and their arrangements, so it cannot be used to develop a specific methane liquefaction system and/or a device that would be capable of liquefying methane in the long term without gaseous methane loss and with minimum energy requirements.

[0007] CN 204648828 discloses a cooling system for methane liquefaction, in which the gas for liquefaction is fed to a tank to which is connected a methane compressor, from which the compressed methane is fed to a methane cooler, from which the methane passes into a polypropylene cooling system, which is followed by an ethylene cooling system and a storage tank of liquid methane. The liquid methane is fed from the storage tank to a methane heat exchanger which serves to cool an unillustrated cooling system and from which the heated methane is fed back into the tank. This invention relates to cooling machines and cooling systems and is not directly related to the production of liquefied methane. Producing liquid methane using this method is complex and economically very demanding.

[0008] US11243026 B2 discloses a device for liquefying methane and filling a transport tank. The device for liquefying methane comprises a liquefaction system, a system for filtration and filling the transport tank. The liquefaction system comprises the first heat exchanger, a compressor, the second heat exchanger, a liquefaction exchanger and a pump, the outlet of which is connected to a storage tank intended to store the liquefied methane. A transport tank is connected to the outlet of the storage tank via the filtration and filling system. The gaseous methane vaporized in the tanks is returned via a reinjection system before the inlet of the first heat exchanger.

[0009] During the liquefaction, the gaseous methane enters the device at a temperature close to -100 °C. The gaseous methane then enters the heat exchanger, where it is heated to a temperature of approximately 20 °C and then enters the compressor, where it is compressed to a pressure of 15 bar. The temperature of the compressor outlet is approximately 80 °C because it is cooled. The methane leaving the compressor has therefore a pressure of 15 bar and a temperature at the compressor outlet of 80 °C. The methane is afterwards cooled to a temperature of 20 °C in the second heat exchanger. The methane then passes again through the first heat exchanger, where its temperature is reduced to -90 ° C. At this stage, the methane is still in gaseous state. It is liquefied in a liquefaction exchanger, where it is cooled to a saturation temperature close to - 114 °C, which corresponds to a saturation pressure of 15 bar. The liquefied methane is then stored in the storage tank at a pressure of 15 bar and a temperature of -114 °C. From the storage tank, the liquid methane is then transferred to a transport tank, in which its pressure is lower than 8 bar. The disadvantage of this device is mainly its high energy consumption.

[0010] A device for liquefying methane is also disclosed in EP 3045849. For methane liquefaction, the Joule-Thompson method is used. This method consists of significantly increasing the pressure of methane and further throttling in Joule-Thompson valves without the supply of cold from an external source. However, this method is highly energy intensive and therefore inefficient. It can therefore be used for high liquid methane productivity and for high pressure methane sources. The document describes the use of gaseous heat recovery flow, but since only two recovery heat exchangers are used, it is difficult to thermodynamically balance the flow due to the large temperature differences in the main stream. The consequence is insufficient heat recovery and reduced efficiency of heat exchangers. Furthermore, it is not clear from the document whether the described system can operate at partial flows, because if the actual methane flow differs from the calculated flow, it is difficult to balance the system energetically.

[0011] Patent application EP 4123251 describes production of LNG from methane-containing gas. To separate the components of the mixture, distillation columns are used, wherein the pressure of the gas entering the system is 20 to 80 bar. The solution does not relate to liquefaction of pure methane.

[0012] Similarly, US 9863697 B2 discloses an integrated cooling system for methane for liquefying natural gas to produce LNG. The natural gas stream is liquefied by indirect heat, with a gaseous methane or natural gas refrigerant circulating in a gaseous expander cycle, to produce the first LNG stream. The first LNG stream is expanded, and the resulting vapor and liquid phases are separated to produce the first gas stream and the second LNG stream. The second LNG stream is expanded, with the resulting vapor and liquid phases being separated to produce the second gas stream and the third LNG stream, all or a portion of which forms the resulting LNG product. The solution is very energy intensive and does not serve to liquefy pure methane.

[0013] The method and device for liquefying methane gas (LMG) from various gas sources disclosed in US 10240863 are also energy intensive. The system includes gas feed, gas purification from unsuitable impurities, nitrogen removal and methane condensation using cryogenic cooling. The solution serves to reduce methane loss when nitrogen is vented to the atmosphere and is energy intensive.

[0014] The objective of the invention is to provide a device for methane liquefaction and to propose a method/system for methane liquefaction with the lowest possible energy requirements while eliminating the loss of gaseous methane during the liquefaction process.

Summary of the invention

[0015] The objective of the invention is achieved by a device for methane liquefaction comprising a cooling module to the outlet of which is associated a condensing and separating module provided with a liquid methane outlet according to the invention, whose principle consists in that the cooling module comprises at least one heat recovery exchanger and a condenser coupled to a cooling device, wherein the downstream condensing and separating module comprises a condensing cooling device and at least one recovery heat exchanger which is followed by a methane gas/liquid phase separator, upstream of which is included a throttling device, the methane gas/liquid phase separator being provided with an outlet of gas phase of methane to which are associated return pipelines passing through the heat recovery exchangers up to the end return pipeline. Using two-stage refrigeration followed by methane condensation results in efficient heat transfer with a lower temperature difference in the condensing device. The consequence of using two-stage refrigeration, each cooling device operates at its own temperature level and thus achieves optimal efficiency.

[0016] In a preferred embodiment, at the inlet of the gaseous methane to the cooling module is arranged a warm heat recovery exchanger, to which the first cooler coupled to the first cooling device is connected, wherein the outlet of the first cooler is connected to the inlet of a cold heat recovery exchanger, the outlet of which is connected to the inlet of a condensing and separating module, in the inlet of which is arranged a condenser, which is coupled with a condensing cooling device, wherein the condenser outlet is connected via a condensing heat recovery exchanger and a throttling device to the inlet of the methane gas/liquid phase separator, which is provided with an outlet of liquid methane and an outlet of methane gas phase to which the first return pipeline of methane gas is connected. The first methane gas return pipeline is connected via the condensing heat recovery exchanger to the second return pipeline which is connected via a cold heat recovery exchanger to the third return pipeline which is connected via a warm heat recovery exchanger to the end return pipeline. In the heat recovery exchangers, the methane advancing through the device is cooled in the main stream, thus consuming the cold generated by the methane liquefaction and saving energy.

[0017] Preferably, at least two condensing and separating modules are associated with the cooling module and are connected to the cooling module outlet, which is formed by the outlet of the cold heat recovery exchanger. A larger number of condensing and separating modules allows to increase the productivity of the device.

[0018] Additional condensing and separating modules are essentially the same and include the first return pipeline connecting the outlet of the methane gas phase from the respective methane gas/liquid phase separator to the respective condensing heat recovery exchanger, whereby the outlets of all the condensing heat recovery exchangers are connected to the outlet of the cooling module formed by the outlet of the cold heat recovery exchanger.

[0019] For compressing methane fed into the liquefaction device by the main stream, arranged upstream of the cooling module are a main compressor and an inlet cooler, which ensure the necessary pressure and temperature of the incoming methane.

[0020] To utilize the gaseous methane returning from the methane gas/liquid phase separator via the return pipelines and gradually transferring the cold to the main methane stream in the recovery exchangers, the end return pipeline is connected to the main gaseous methane stream via an additional compressor and an additional cooler and opens into the main stream upstream of the cooling module or upstream of the inlet to the main compressor. Thus, there is no loss of the device capacity and the amount of purified methane entering the device is equal to the amount of liquid methane generated.

[0021] In order to achieve optimal liquefaction efficiency, it is advantageous if the cooling devices used are formed by closed-cycle air cooling machines.

Brief description of drawings

[0022] Exemplary embodiments of the invention will be described with reference to the accompanying drawings, wherein Fig. 1 shows a diagram of a methane liquefaction device for a 3 tonnes per day output, Fig. 2 is a diagram of a methane liquefaction device for a 3 to 5 tonnes per day output, Fig. 3 is a diagram of the methane liquefaction device for a capacity of 5 to 10 tonnes per day, Fig. 4 is a diagram of the methane liquefaction device according to Fig. 1 with an upstream main compressor and an air cooler without returning methane vapour to the main stream, Fig. 5 is a diagram of the methane liquefaction device according to Fig. 1 with the upstream main compressor and the air cooler with returning methane via an additional compressor to the main stream and Fig. 6 shows a diagram for the methane liquefaction device according to Fig. 1 with the upstream main compressor and the air cooler with returning methane via the additional compressor to the main stream before the main compressor.

[0023] The connection variants according to the invention are not limited to the drawings shown but may be varied and supplemented with the circuit elements used depending on the amount of liquid methane production, the input conditions and known standard equipment not described in more detail in this patent application and is commonly known to the skilled person.

Examples of embodiment

[0024] The device according to the invention is intended to liquefy medium-pressure methane with low capacity and external cold source.

[0025] The source of methane for the liquefaction system can be any known source, such as natural fossil gas, associated petroleum gas (APG), biogas and others.

[0026] The exit pressure from biogas production systems is usually 2 bar, with a methane content of up to 50 %. After primary purification, biomethane with a methane content of 97-98 % is obtained, and after further purification, 100% methane is obtained at a pressure of 12 to 14 bar.

[0027] The liquefied methane is stored in storage tanks under a pressure of 2 to 4 bar. For the liquefaction of methane, the applicant has chosen a pressure value of 22 bar, at which the liquefaction temperature is about 105 °C, and so the pressure must be increased to 22 bar before entering the device.

[0028] To compress methane to the required pressure, any known compressor of any type (turbocompressor, piston, screw, scroll compressor, etc.), single-stage or multi-stage, with or without intercooling, can be used; the main thing is to ensure the required pressure and performance.

[0029] In an exemplary embodiment according to the invention of Fig. 1, the device for methane liquefaction comprises a cooling module **A** and a condensing and separating module **B.** The device is intended to produce 3 tonnes of liquefied methane (LMG) per day. Methane in gaseous state produced in any known device for its production and purified by any of the known methods is fed at a pressure of 22 bar to the cooling module **A** of the device, specifically to the inlet of a warm heat recovery exchanger **1**, in which the methane is cooled to a temperature lower than atmospheric. To the outlet of the warm heat recovery exchanger **1** is connected the inlet of the first cooler **2,** which is for cooling coupled to the first cooling device **8,** which is, in the illustrated embodiment, formed by a closed-cycle air cooling machine MIRAI LNG 30 with a water cooler **10** serving to cool water supplied to the air cooling machine MIRAI. The water cooler **10** consists of a dry cooler or a freon chiller, or any other suitable type of cooler. The cooling process of the methane in the first cooler **2** is caused by heat transfer between the warm methane and the cold nitrogen from the first cooling device. In the first cooler **2,** the methane is cooled by the cooling device 8 from atmospheric temperature to a temperature of -75 to -80 °C. To the outlet of the first cooler **2** is connected the inlet of a cold heat recovery exchanger **3,** in which methane is further cooled by about 2 to 5 °C. The outlet of the cold heat recovery exchanger **3** is also the outlet from the cooling module **A** of the device and is connected to the inlet of the condensing and separating module **B**, which is identical to the inlet of the condenser **4,** which is coupled to the condensing cooling device **9,** which, in the illustrated embodiment, is formed by MIRAI LNG closed-cycle air cooling machine equipped with a water cooler **11** serving to cool the water supplied to the MIRAI air cooling machine. The condensation of methane in the condenser **4** occurs as a result of the heat transfer from the very cold nitrogen from the condensing cooling device **9** to the warmer methane, which is consequently cooled to the condensing temperature and is converted into a liquid state. The MIRAI LNG closed-cycle air cooling machines use nitrogen as the working fluid without changing the phase state.

[0030] At the outlet of the condenser **4,** methane is in the liquid phase wherein the outlet of the condenser **4** is connected to the inlet of the condensing heat recovery exchanger **5** serving to subcool the condensed methane by 2 to 5 °C, to prevent its evaporation. A throttling device **6** is connected to the outlet of the condensing heat recovery exchanger **5** to reduce the methane pressure from the condensing pressure to a pressure close to a storage pressure in the LMG tanks, i.e. 2 to 6 bar. The schematically represented throttling device **6** may comprise any known pressure reducing device or group of devices. Since condensation occurs at a mean pressure of 22 bar, the expansion in the throttling device **6** produces a mixture containing up to 30 % methane gas phase. Connected to the outlet of the throttling device **6** is the inlet **701** of the separator **7** used to separate the methane gas phase from the methane liquid phase, for the discharge of which the separator **7** is provided with an outlet **702** of the LMG, from which the liquid methane is discharged for storage. Any known gas/liquid phase separator can be used as the separator.

[0031] The separator **7** is in the upper part provided with an outlet **703** of methane gas phase, to which is connected the first return pipeline **R1**, which is connected to the recovery inlet **503** of the condensing heat recovery exchanger **5.** To the recovery outlet **504** of the condensing heat recovery exchanger **5** is connected the second return pipeline **R2**, which is connected to the recovery inlet **303** of the cold heat recovery exchanger **3.** The third return pipeline **R3** is connected to the recovery outlet **304** of the cold heat exchanger **3.** The third return pipeline **R3** is connected to the recovery inlet **103** of the warm heat recovery exchanger **1**, to the recovery outlet **104** of which is connected an end return pipeline **R4**, which is connected to a known methane production or purification device (not shown), or is connected to the methane main stream, as will be described below.

[0032] In the flow chart and other diagrams, closing control devices, measuring devices, etc., are not shown, so that the drawing is not confusing, but the main principle of the invention is shown. The mentioned missing elements are standardly known to the skilled person and serve to preserve information about the operation of the system which does not affect the overall principle of the invention.

[0033] The drawings schematically show heat exchangers, which can be of any type, and the skilled person will select them so that they meet the required parameters of heat transfer and the operation of the entire device according to the invention.

[0034] The function of the device according to Fig. 1 is as follows:
Methane in gaseous form is fed to the cooling module **A** of the device, in which it is cooled to a temperature of -75 °C to -80 °C and fed to the condensing and separating module **B** of the device. After the gas methane is fed to the condenser **4,** the methane is liquefied using the cold supplied from the cooling device **9** consisting of a MIRAI LNG 90 closed-cycle air cooling machine and is introduced via the condensation heat recovery exchanger **5** and the throttling device **6** to the separator **7,** in which the gas phase of methane is separated from the liquid phase (LMG).

[0035] The methane gas phase is fed from the separator **7** via the first return pipeline **R1** to the condensing heat recovery exchanger **5,** where it transfers some of its cold to the liquid methane that passes through the condensing heat recovery exchanger **5,** cooling the liquid methane by 2 to 5 °C. From the condensing heat recovery exchanger **5,** the methane gas phase is led via the second return pipeline **R2** to the cold heat recovery exchanger **3,** where it transfers part of its cold to the gaseous methane passing through the heat recovery exchanger **3** and cools the gaseous methane by 5 to 10 °C. From the cold recovery heat exchanger **3,** the methane gas phase is led via the third return pipeline **R3** to the warm heat recovery exchanger **1,** where it transfers another part of its cold to the gaseous methane and cools the gaseous methane to a temperature below atmospheric temperature, namely, for example, to 25 to 30 °C below atmospheric temperature. From the heat recovery exchanger **1**, the methane gas phase is led via the end return pipeline **R4** to a known unillustrated device for methane production or purification, or to the main methane stream by connecting the end return pipeline **R4** upstream or downstream of the main compressor **12,** as will be described hereinafter.

[0036] To produce a larger amount of liquefied methane (LMG) a day, variants of the device which are shown in Fig. 2 and Fig. 3 have been developed.

[0037] The device shown in Fig. 2 is intended to produce 3 to 5 tonnes of liquefied methane (LMG) per day. This variant of the device for methane liquefaction comprises the same cooling module **A** as the device according to Fig. 1. However, two condensing and separating modules **B-1**, **B-2** of the device are connected to the outlet of the cooling module **A** of the device, that is, to the outlet of the cool heat recovery exchanger **3**, from which gaseous methane emerges at a temperature of -75 to -80 °C.

[0038] The first condensing and separating module **B-1** is formed in the same way as in the embodiment according to Fig. 1 and comprises a condenser **4-1** of the first condensing and separating module **B-1**, hereinafter referred to as the first condenser **4-1**, which is connected to the outlet of the cooling module **A.** The first condenser **4-1** is coupled to the condensing cooling device **9-1** of the first condensing and separating module **B-1**, which is in the illustrated exemplary embodiment formed by MIRAI LNG 90 air cooling machine with a closed cycle provided with a water cooler **11-1** used to cool the water supplied to the air cooling machine. In the first condenser **4-1**, the methane is liquefied. The outlet of the first condenser **4-1** is connected to the inlet of the condensing heat recovery exchanger **5-1** of the first condensing and separating module **B-1**, hereinafter referred to as the first condensing heat recovery exchanger **5-1,** in which the liquid methane is cooled by 2 to 5 °C to prevent its evaporation. The first throttling device **6-1** of the first condensing and separating module **B-1**, hereinafter referred to as the first throttling device **6-1,** is connected to the outlet of the first condensing heat recovery exchanger **5-1.** In the first throttling device **6-1,** the methane pressure is reduced to 2 - 6 bar. The outlet of the first throttling device **6-1** is connected to the inlet of the separator **7-1** of the first condensing and separating module **B-1**, hereinafter referred to as the first separator **7-1,** in which the methane gas phase is separated from the methane liquid phase, which is discharged from the first separator **7-1** through the LMG outlet situated in the lower part thereof.

[0039] In the upper part, the first separator **7-1** is provided with the outlet of gaseous methane, to which is connected the first return pipeline **R1-1** of the first condensing and separating module **B-1**, the outlet of which opens into the inlet of the first condensing heat recovery exchanger **5-1,** serving to subcool the condensed methane. To the outlet of the first condensing heat recovery exchanger **5-1** is connected the second return pipeline **R2-1** of the first condensing and separating module **B-1**, the outlet of which opens into the cold recovery exchanger **3,** which is part of the cooling module **A** and in which the return pipelines **R3** and **R4** are arranged in the same way as in the embodiment according to Fig. 1.

[0040] Between the cooling module **A** and the first condensing and separating module **B-1**, the pipeline with cooled methane having a temperature of -75 to - 80 °C is divided into two branches, the first of which leads to the first condensing and separating module **B-1** and the second branch of the pipeline with cooled methane leads to the second condensing and separating module **B-2** and the cooled methane is introduced to the condenser **4-2** of the second condensing and separating module **B-2**, hereinafter referred to as the second condenser **4-2,** in which it is liquefied due to cooling by the condensing cooling device **9-2** of the second condensing and separating module. The condensing cooling device **9-2** is connected to the second condenser **4-2** and is formed in the illustrated embodiment by MIRAI LNG 90 closed-cycle air cooling machine, which is provided with a water cooler **11-2.** To the outlet of the second condenser **4-2** is connected the inlet of the condensing heat exchanger **5-2** of the second condensing and separating module **B-2**, hereinafter referred to as the inlet of the second condensing heat exchanger **5-2,** in which the liquid methane is cooled by 2 to 5 °C, to prevent its evaporation. To the outlet of the second condensing heat exchanger **5-2** is connected the second throttling device **6-2** of the second condensing and separating module **B-2**, hereinafter referred to as the second throttling device **6-2,** in which the pressure of the methane is reduced to 2 to 6 bar. The outlet of the second throttling device **6-2** is connected to the inlet of the second separator **7-2** of the second condensing and separating module **B-2**, hereinafter referred to as the second separator **7-2,** in which the methane gaseous phase is separated from liquid phase. The methane liquid phase is discharged through the LMG outlet in the lower part of the second separator **7-2,** wherein in the illustrated embodiment, the LMG discharge pipelines for discharging from both separators **7-1** and **7-2** are connected into one and the liquid methane from both condensing and separating modules **B-1** and **B-2** is discharged for storage.

[0041] In the upper part, the second separator **7-2** is provided with an outlet of gaseous methane, to which is connected the first return pipeline **R1-2** of the second condensing and separating module **B-2**, the outlet of which opens into the second condensing heat recovery exchanger **5-2**, serving to subcool the liquid methane. To the outlet of the second condensing heat recovery exchanger **5-2** is connected the second return pipeline **R2-2** of the second condensing and separating module **B-2**, the outlet of which opens into the cold heat recovery exchanger **3**, which is part of the cooling module **A** and in which the return pipelines **R3** and **R4** are arranged in the same way as in the embodiment according to Fig. 1. In the illustrated embodiment, the second return pipeline **R2-2** of the second condensing and separating module **B-2** is connected to the second return pipeline **R2-1** of the first condensing and separating module **B-1** before opening into the cold heat recovery exchanger **3.**

[0042] By using the two condensing and separating modules **B-1** and **B-2**, the amount of the liquefied methane has doubled compared to the embodiment of the device according to Fig. 1.

[0043] The device shown in in Fig. 3 is intended to produce 5 to 10 tonnes of liquefied methane (LMG) per day. This variant of the device for methane liquefaction comprises the same cooling module **A** as the device according to Fig. 1 and the device according to Fig. 2. However, three condensing and separating modules **B-1**, **B-2** and **B-3** of the device are connected to the outlet of the cooling module **A** of the device, that is, to the outlet of the cold heat recovery exchanger **3,** from which emerges gaseous methane having a temperature of - 75 to -80 °C.

[0044] The first and second condensing and separating modules **B-1** and **B-2** are configured in the same way as in the embodiment of the device according to Fig. 2. From the second branch of the pipeline with methane cooled to a temperature of -75 to -80 °C led into the second condensing and separating module **B-2**, the third branch separates upstream of the second condensing and separating module **B-2** and leads to the third condensing and separating module **B-3**, where the cooled methane is introduced to the condenser **4-3** of the third condensing and separating module **B-3**, hereinafter referred to as the third condenser **B-3**. The third condenser **4-3** is connected to the third condensing cooling device **9-3,** which is in the illustrated embodiment formed by MIRAI LNG 90 closed-cycle air cooling machine, which is equipped with a water cooler **11-3.** To the outlet of the third condenser **4-3** is connected to the inlet of the condensing heat exchanger **5-3** of the third condensing and separating module **B-3**, hereinafter referred to as the third condensing heat exchanger **5-3,** in which the liquid methane is cooled by 2 to 5 °C, to prevent its evaporation. Connected to the outlet of the third condensing exchanger **5-3** is the throttling device **6-3** of the third condensing and separating module **B-3**, hereinafter referred to as the third throttling device **6-3,** in which the pressure of the liquid methane is reduced to 2 to 6 bar, which is a pressure close to the storage pressure in LMG tanks. The outlet of the third throttling device **6-3** is connected to the inlet of the separator **7-3** of the third condensing and separating module **B-3**, hereinafter referred to as the third separator **7-3,** in which the methane gas phase is separated from the liquid phase. The methane liquid phase is discharged through the outlet of LMG in the lower part of the third separator **7-3,** wherein, in the illustrated embodiment, the pipelines for the discharge of LMG from all the three separators **7-1**, **7-2** and **7-3** are connected into one and the liquid methane from all the three condensing and separating modules **B-1**, **B-2** and **B-3** is discharged for storage.

[0045] In the upper part, the third separator **7-3** is provided with a gaseous methane outlet to which is connected the first return pipeline **R1-3** of the third condensing and separating module **B-3**, the outlet of which opens into the inlet of the third condensing heat exchanger **5-3,** serving to subcool the liquid methane. To the outlet of the third condensing heat exchanger **5-3** is connected the second return pipeline **R2-3** of the third condensing and separating module **B-3**, the outlet of which opens into the cold heat recovery exchanger **3,** which is part of the cooling module **A** and in which the return pipelines **R3** and **R4** are arranged in the same way as in the embodiment according to Fig. 1 and Fig. 2. In the illustrated embodiment, the second return pipeline **R2-3** of the third condensing and separating module **B-3** is connected to the second return pipeline **R2-2** of the second condensing and separating module **B-2** and to the second return pipeline **R2-1** of the first condensing and separating module **B-1** before entering the cold heat exchanger **3.**

[0046] The use of the three condensing and separation modules **B-1**, **B-2** and **B-3** increased the amount of liquefied methane produced per day to 5 to 10 tonnes compared to the embodiment according to Fig. 2.

[0047] Due to the fact that the device according to the invention is intended to liquefy pure methane and the pressure value was chosen to be 22 bar, wherein the methane pressure after purification is 14 bar, the main compressor **20** and the inlet cooler **21** are included in the main gaseous methane stream upstream of the inlet to the device, as shown in Fig. 4. The inlet cooler **21** is used to cool the methane gas compressed by the main compressor **20** to a temperature close to atmospheric temperature, approximately by 2 to 5 °C above atmospheric temperature.

[0048] The actual methane liquefaction device is used in the diagram from Fig. 1, since it is the simplest version. Nevertheless, it will be clear to the skilled person that any of the variants shown in Figs. 1 to 3 may be used. The methane gas/liquid phase separator **7** is provided with an inlet **701** of liquid methane from the throttling device **6** and an outlet **702** of methane liquid phase (LMG) to which a liquid methane storage tank **13** is connected via a liquid methane outlet valve **12.** The liquid methane storage tank **13** is provided with known liquid methane outlet means (not shown in more detail) for connecting and filling tank trucks for delivery of liquid methane, or tanks of vehicles equipped with methane combustion engines, such as ships or trucks. The above-mentioned liquid methane outlet means are associated with means for returning the gaseous methane produced during the filling of the tanks or containers back to the liquid methane storage tank **13,** where the gaseous methane is collected in its upper part. Accordingly, the storage tank **13** is provided in its upper part with a methane gas outlet **703** and a shut-off valve **14.** In the basic variant according to Fig. 4, after opening the shut-off valve **14** the gaseous methane is discharged back to a known unillustrated device for the production or purification of methane. Similarly, the gaseous methane is discharged from the separator **7** through the end return pipeline **R4** after passing through heat recovery exchangers **5**, **3** and **1**, in which it gradually transferred its cold.

[0049] In an exemplary embodiment according to Fig. 5, it is the liquefying device according to Fig. 1 that is used again for methane liquefaction, representing the simplest variant. The methane gas/liquid phase separator **7** is in the lower part provided with the outlet **702** of methane liquid phase (LMG), which is connected to other means for storing and distributing liquid methane, as in the previous embodiment according to Fig. 4. Similarly, means are provided for the return of gaseous methane generated during the filling of tanks or reservoirs back to the liquid methane storage tank **13.** The liquid methane storage tank **13** is provided in the upper part with an outlet **703** of gaseous methane and a shut-off valve **14,** to which a gaseous methane discharge pipeline is connected, into which the end return pipeline **R4** opens, through which gaseous methane is discharged from the separator **7** after passing through the recovery exchangers **5, 3** and **1,** in which it gradually transferred its cold. Connected to the outlet of the discharge pipeline is the inlet of the additional compressor **30,** the outlet of which is connected to the inlet of the additional cooler **31**, from the outlet of which the gaseous methane is fed into the main stream of the gaseous methane before the cooling module **A.** The pressure of the methane gas at the inlet to the additional compressor **30** is 1 to 3 bar and in the additional compressor **30** it is compressed to 22 bar of the operating pressure for liquefaction, i.e., to the same pressure as the main stream of the methane gas after leaving the main compressor **20.** Also, the temperature of the methane gas after leaving the additional cooler **31** is the same, or nearly the same, as the temperature of the main stream of the methane gas after leaving the inlet cooler **21**, i.e., close to atmospheric temperature.

[0050] In an exemplary embodiment according to Fig. 6, it is the liquefying device according to Fig. 1 that is used again for methane liquefaction. The means for storing and distributing liquid methane are formed in the same way as in the embodiment according to Figs. 4 and 5. The means for collecting and removing gaseous methane from the liquid methane storage tank **13** are designed in the same way as in the embodiment according to Fig. 5, including the connection of the discharge pipeline with the end return pipeline **R4** and the connection of the additional compressor **30** and the additional cooler **31**. The difference is that the outlet of the gaseous methane from the additional cooler **31** is fed into the main stream of gaseous methane before the main compressor **20.** The additional compressor **30** in this embodiment compresses the gaseous methane fed from the storage tank **13** of the liquid methane and the gaseous methane fed via the end return pipeline **R4** only to a pressure corresponding to the pressure of the gaseous methane in the main stream before the main compressor **20.**

[0051] The methane gas phase returned from the methane gas/liquid phase separator **7** is used in the recovery exchangers **5, 3** and **1** to sequentially transfer the cold to the liquid methane in the condensing recovery exchanger **5** and to the methane gas in the cold recovery exchanger **3** and subsequently in the warm recovery exchanger **1.** The methane gas phase returned from the liquid methane storage tank **13** is, after being combined with the methane gas phase returned from the methane gas/liquid phase separator **7,** in the embodiment according to Figures 5 and 6, introduced back into the main methane gas stream, which results in complete condensation of the entire inlet methane gas stream in the operating mode of the device according to the invention.

Industrial applicability

[0052] The device according to the invention is intended to liquefy methane using external sources of cold, preferably MIRAI air cooling machines. Since the cold obtained in the cooling machines is returned to the circulation in the device according to the invention by means of heat recovery exchangers, an energy saving is achieved which is approximately equal to the value of the recuperative flow rate. In addition, the pure methane gas generated when the liquid methane is depressurized to storage pressure is returned to the liquefaction cycle, which represents a further energy saving.

List of references

[0053]

A cooling module
1 warm heat recovery exchanger
103 recovery inlet of the warm heat recovery exchanger
104 recovery outlet of the warm heat recovery exchanger
2 first cooler
8 first cooling device
10 water cooler of the first cooling device
3 cold heat recovery exchanger
303 recovery inlet of the cold heat recovery exchanger
304 recovery outlet of the cold heat recovery exchanger
B condensing and separating module
4 condenser
9 condensing cooling device
11 water cooler of the condensing cooling device
5 condensing heat recovery exchanger
503 recovery inlet of the condensing heat recovery exchanger
504 recovery outlet of the condensing heat recovery exchanger 6 throttling device
7 methane gas/liquid phase separator
701 inlet of the separator
702 outlet of the methane liquid phase from the separator
703 outlet of the methane gas phase from the separator
R1 first return pipeline
R2 second return pipeline
R3 third return pipeline
R4 end return pipeline
B-1 first condensing and separating module
4-1 condenser of the first condensing and separating module
9-1 condensing cooling device of the first condensing and separating module
11-1 water cooler of the condensing cooling device
5-1 condensing heat recovery exchanger of the first condensing and separating module
6-1 throttling device of the first condensing and separating module
7-1 separator of the first condensing and separating module
R1-1 first return pipeline of the first condensing and separating module
R2-1 second return pipeline of the first condensing and separating module
B-2 second condensing and separating module

4-2 condenser of the second condensing and separating module
9-2 condensing cooling device of the second condensing and separating module
11-2 water cooler of the condensing cooling device
5-2 condensing heat recovery exchanger of the second condensing and separating module
6-2 throttling device of the second condensing and separating module
7-2 separator of the second condensing and separating module
R1-1 first return pipeline of the second condensing and separating module
R2-1 second return pipeline of the second condensing and separating module
B-3 third condensing and separating module
4-3 condenser of the third condensing and separating module
9-3 condensing cooling device of the third condensing and separating module
11-3 water cooler
5-3 condensing heat recovery exchanger of the third condensing and separating module
6-3 throttling device of the third condensing and separating module
7-3 separator of the third condensing and separating module
R1-3 first return pipeline of the third condensing and separating module
R2-3 second return pipeline of the third condensing and separating module
12 outlet valve of liquid methane
13 storage tank of liquid methane
14 shut-off valve of the methane gas phase in the storage tank of liquid methane
15 connecting valve
20 main compressor
21 inlet cooler
30 additional compressor
31 additional cooler

Claims

1. A device for methane liquefaction comprising a cooling module (A) which is provided with an inlet of gaseous methane, to the outlet of the cooling module (A) being associated a condensing and separating module (B) provided with an outlet (702) of liquid methane, **characterized in that** the cooling module (A) comprises at least one heat recovery exchanger (1, 3) and a cooler (2) coupled to a cooling device (8), wherein the downstream condensing and separating module (B) comprises a condensing cooling device (9) and at least one heat recovery exchanger (5), which is connected to a methane gas/liquid phase separator (7), upstream of which a throttling device (6) is included, wherein the methane gas/liquid phase separator (7) is provided with an outlet (703) of methane gas phase, to which are associated return pipelines (R1, R2, R3), passing through the heat recovery exchangers (1, 3, 5) to an end return pipeline (R4).

2. The device for methane liquefaction according to claim 1, **characterized in that** at the inlet of gaseous methane to the cooling module (A) is arranged a warm heat recovery exchanger (1), to which is connected the first cooler (2) coupled to the first cooling device (8), wherein the outlet pf the first cooler (2) is connected to the inlet of the cold recovery exchanger (3), the outlet of which is connected to the inlet of the condensing and separating module (B), at the inlet of which is arranged a condenser (4), which is coupled to the condensing cooling device (9), wherein the outlet of the condenser (4) is via the condensing recovery exchanger (5) and the throttling device (6) connected to the inlet (701) of the methane gas/liquid phase separator (7), which is provided with an outlet (702) of methane liquid phase and the outlet (703) of methane gas phase, to which is connected the first return pipeline (R1) of methane gas, which is via the condensing recovery exchanger (5) connected to the second return pipeline (R2), which is via the cold heat recovery exchanger (3) connected to the third return pipeline (R3), which is connected via the warm heat recovery exchanger (1) to the end return pipeline (R4).

3. The device according to claim 2, **characterized in that** the cooling module (A) is associated with at least two condensing and separating modules (B1, B2, B3), which are connected to the outlet of the cold heat recovery exchanger (3) of the cooling module (A).

4. The device according to claim 3, **characterized in that** each condensing and separating module (B1, B2, B3) comprises the first return pipeline (R1-1, R1-2, R1-3) connecting the outlet (703) of the methane gas phase of the respective methane gas/liquid phase separator (7-1, 7-2, 7-3) to the respective condensing heat recovery exchanger (5-1, 5-2, 5-3), wherein the outlets of each of the heat recovery condensing exchangers (5-1, 5-2, 5-3) are connected to the outlet of the cold heat recovery exchanger (3) of the cooling module (A).

5. The device according to any of the preceding claims 1-4, **characterized in that** a main compressor (20) and an inlet cooler (21) are arranged upstream of the cooling module (A), wherein the main stream of the methane gas entering the liquefaction device passes through the main compressor (20) and the inlet cooler (21).

6. The device according to claim 5, **characterized in that** the end return pipeline (R4) is led through the auxiliary compressor (30) and the auxiliary cooler (31) to the main stream of the methane gas before the cooling module (A).

7. The device according to claim 5. **characterized in that** the end return pipeline (R4) is led through the auxiliary compressor (30) and the auxiliary cooler (31) to the inlet of the main compressor (20).

8. The device according to any of the preceding claims 1-7, **characterized in that** the cooling devices (8, 9) are formed by closed-cycle air cooling machines.

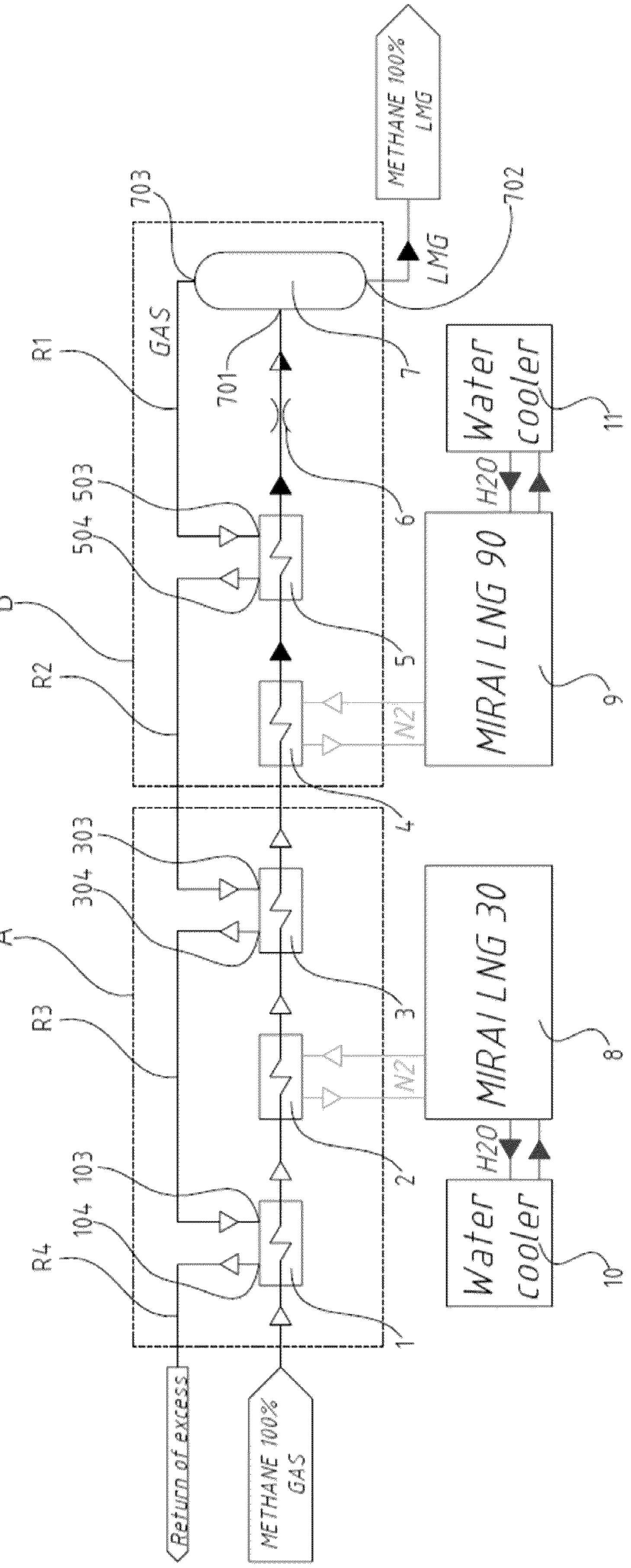
METHANE 100%
LMG
703
702
LMG
GAS
R1
701
7
Water
cooler
11
H2O
504 503
6
MIRAI LNG 90
B
R2
5
N2
9
4
304 303
A
R3
3
MIRAI LNG 30
N2
2
8
104 103
R4
H2O
Water
cooler
10
1
Return of excess
METHANE 100%
GAS

Fig. 1

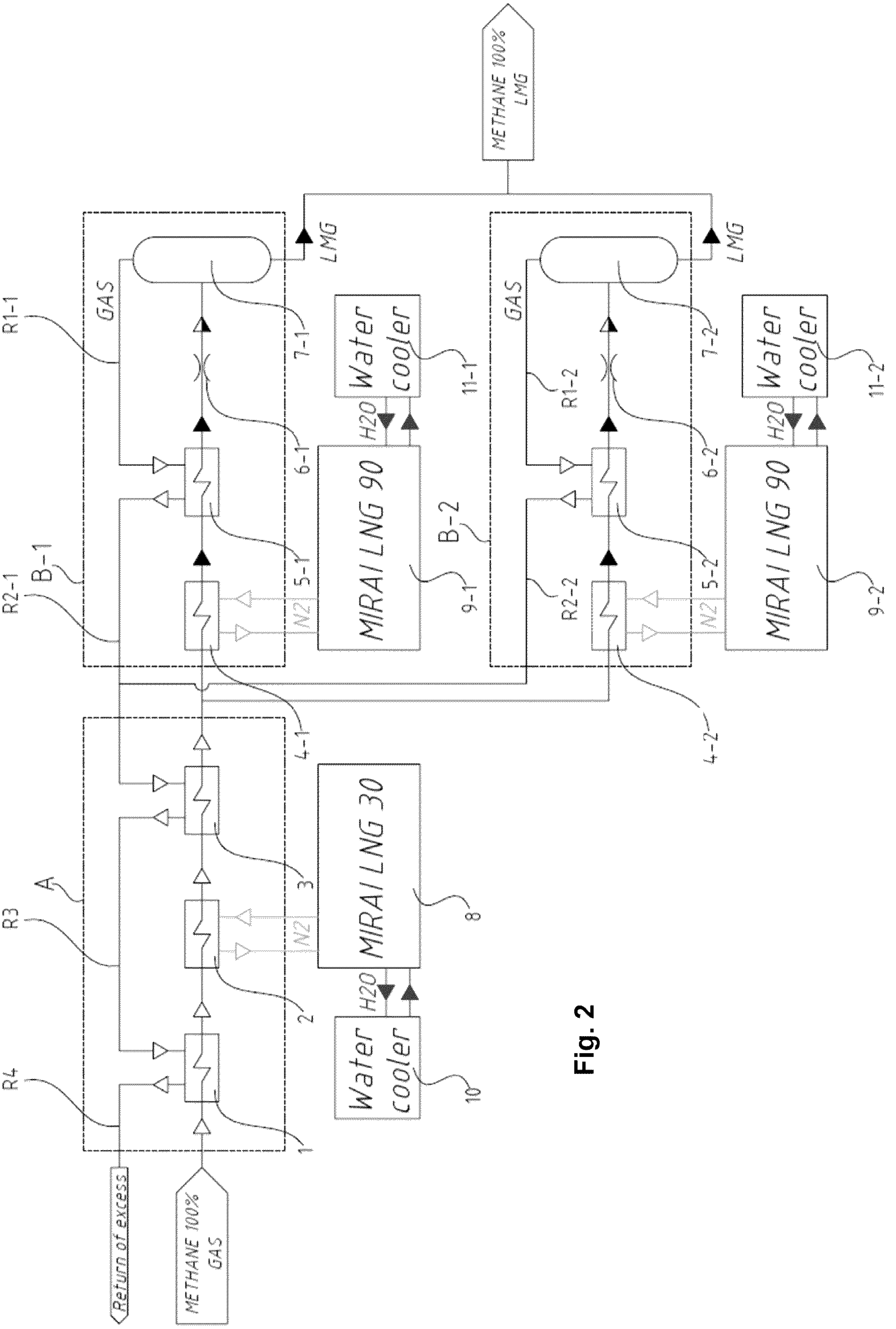
METHANE 100%
LMG
R1-1
GAS
LMG
7-1
Water
cooler
11-1
H2O
6-1
MIRAI LNG 90
B-1
R2-1
5-1
9-1
N2
B-2
R1-2
GAS
LMG
7-2
Water
cooler
11-2
H2O
6-2
MIRAI LNG 90
R2-2
5-2
9-2
N2
4-1
4-2
R3
A
R4
MIRAI LNG 30
N2
H2O
Water
cooler
3
2
1
8
10
Return of excess
METHANE 100%
GAS

Fig. 2

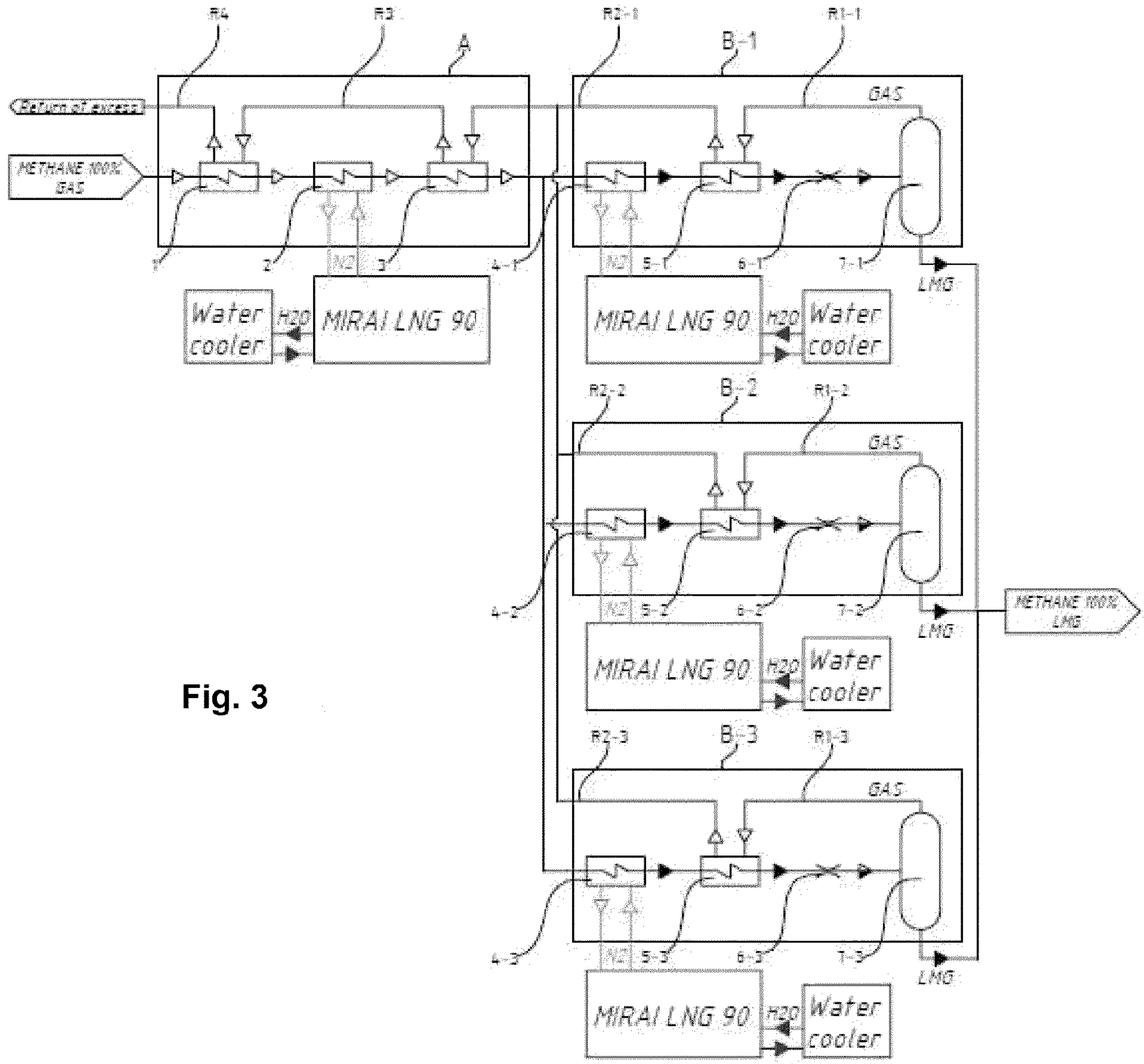
R4
R3
A
R2-1
B-1
R1-1
Return of excess
METHANE 100% GAS
GAS
1
2
N2
3
4-1
5-1
6-1
7-1
LNG
Water cooler
H2O
MIRAI LNG 90
MIRAI LNG 90
H2O
Water cooler
R2-2
B-2
R1-2
GAS
N2
4-2
5-2
6-2
7-2
LNG
METHANE 100% LNG
MIRAI LNG 90
H2O
Water cooler
R2-3
B-3
R1-3
GAS
4-3
N2
5-3
6-3
7-3
LNG
MIRAI LNG 90
H2O
Water cooler

Fig. 3

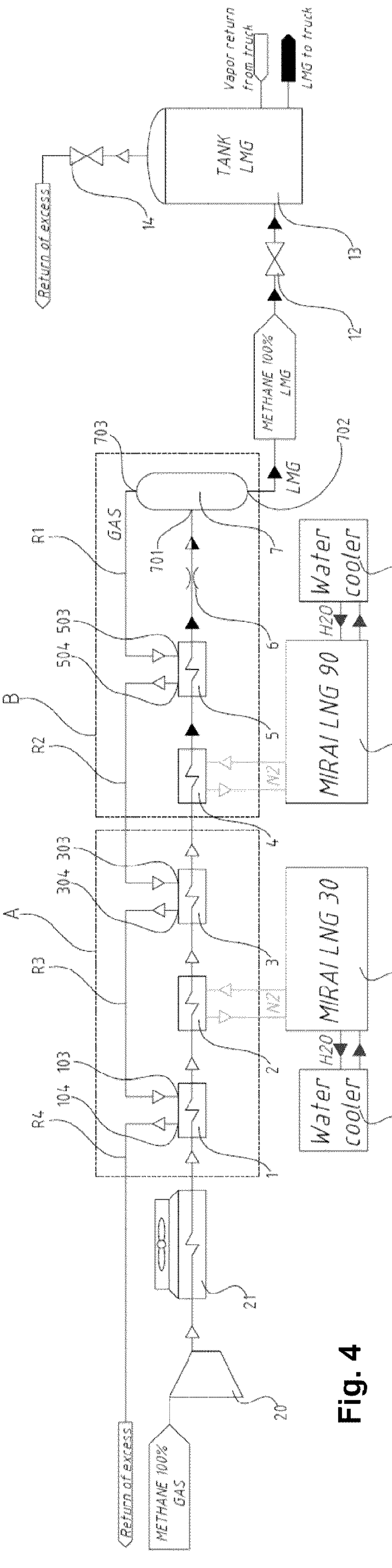
Vapor return from truck
LMG to truck
TANK LMG
Return of excess
METHANE 100% LMG
LMG
GAS
Water cooler
H2O
MIRAI LNG 90
MIRAI LNG 30
N2
METHANE 100% GAS
Return of excess
A
B
R1
R2
R3
R4

Fig. 4

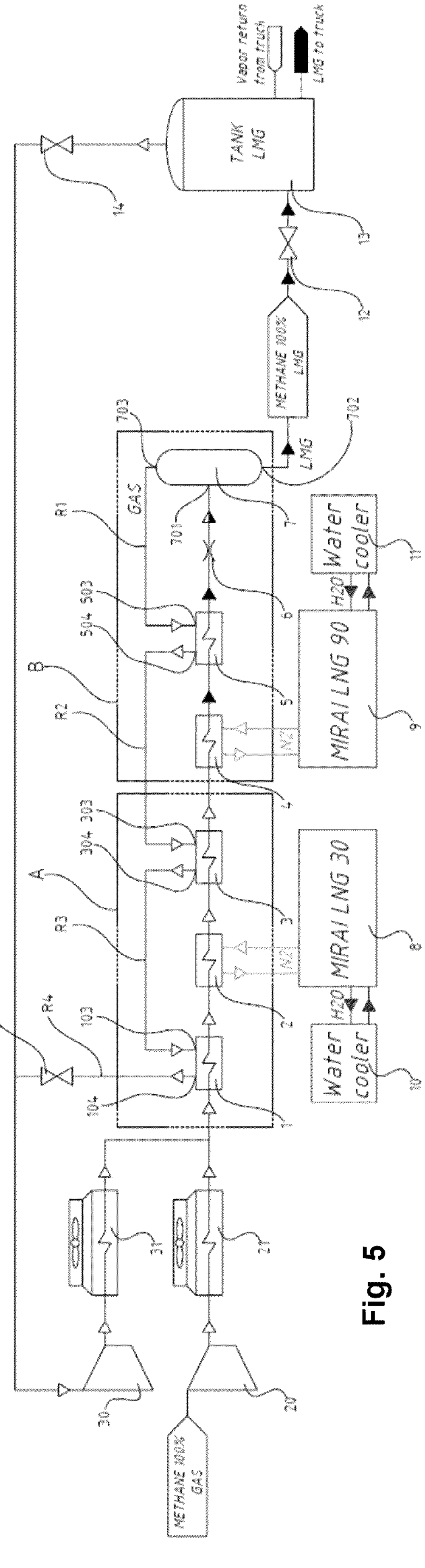
METHANE 100% GAS
20
30
21
31
1
104
103
R4
15
R3
A
2
N2
3
304
303
H2O
Water cooler
10
MIRAI LNG 30
8
4
R2
B
504
503
5
N2
MIRAI LNG 90
9
H2O
Water cooler
11
6
R1
GAS
701
7
703
702
LMG
METHANE 100% LMG
12
13
TANK LMG
14
Vapor return from truck
LMG to truck

Fig. 5

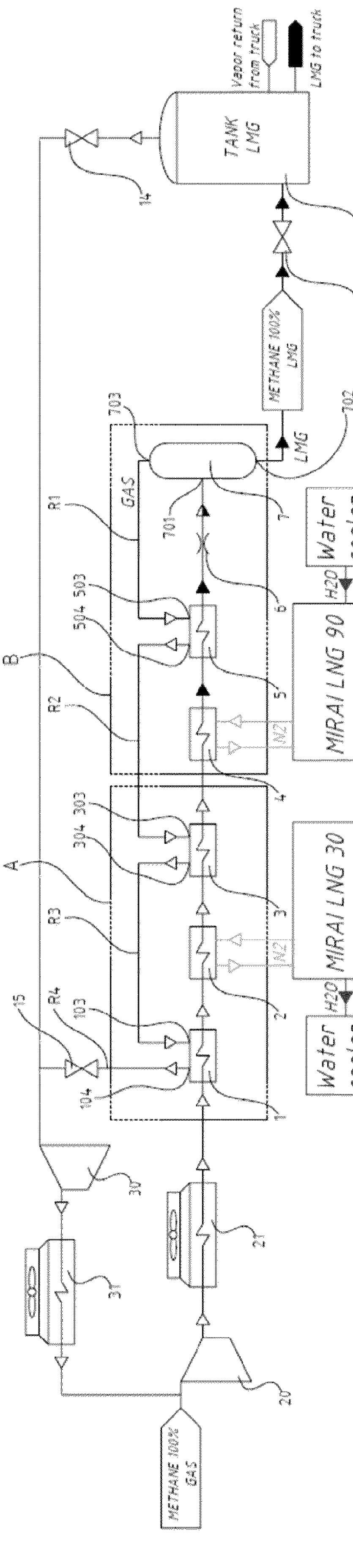
Vapor return from truck
LMG to truck
TANK LMG
METHANE 100% LMG
LMG
GAS
Water cooler
MIRAI LNG 90
MIRAI LNG 30
H2O
N2
METHANE 100% GAS
A
B
R1
R2
R3
R4
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
20
21
30
31
103
104
303
304
503
504
701
702
703

Fig. 6

REFERENCES CITED IN THE DESCRIPTION

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