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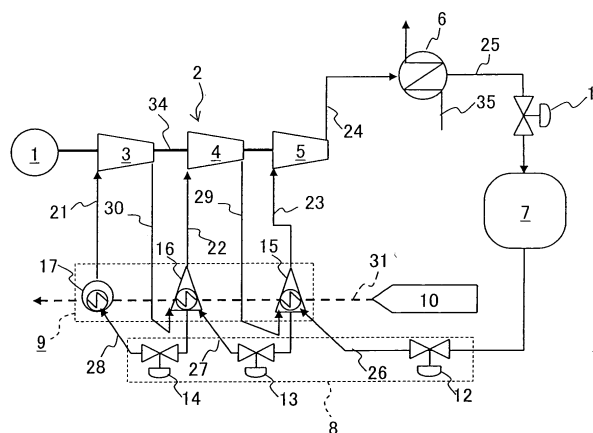
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(54) **Refrigeration cycle system, natural gas liquefaction plant, heat pump system, and method for retrofitting refrigeration cycle system**

(57) A refrigeration cycle system is provided, comprising a plurality of compressors (3,4,5) for compressing a refrigerant that is used to cool a medium (10), one of the compressors being a low pressure compressor (3), another one of the compressors being a high pressure compressor (5); a condenser (6) for cooling and condensing the refrigerant compressed by the plurality of compressors (3,4,5); a reservoir (7) for receiving the refrigerant condensed by the condenser (6); an expansion mechanism (9) for expanding and cooling the refrigerant

supplied from the reservoir (7); an evaporator (9) for evaporating the refrigerant cooled by the expansion mechanism (8) by means of the medium (10) to generate a refrigerant to be supplied to the plurality of compressors (3,4,5); and an intercooler (15,15A,61) that is provided between the low pressure compressor (3) and the high pressure compressor (5) and adapted to cool the refrigerant supplied from the low pressure compressor (3) by means of the refrigerant supplied from the expansion mechanism (8) so as to generate a refrigerant to be supplied to the high pressure compressor (5).

**FIG. 1**



## Description

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention

**[0001]** The present invention relates to a refrigeration cycle system, a natural gas liquefaction plant, a heat pump system, and a method for retrofitting the refrigeration cycle system.

## 2. Description of the Related Art

**[0002]** In order to convert a natural gas into a liquefied natural gas (LNG) which is suitable for transport, it is necessary that the natural gas be cooled to a temperature of - 150°C under the condition that the natural gas is pressurized, and be expanded to approximately atmospheric pressure to set the temperature of the natural gas to a temperature of - 162°C. The cooling of the natural gas is realized by performing a plurality of refrigeration cycles using propane, a mixed medium or the like as a refrigerant.

**[0003]** A compressor used for this type of refrigeration cycle is mainly a turbo compressor, i.e., a centrifugal compressor. Under the condition that a compressor compresses a refrigerant with the same pressure, compression work required for the compression is higher as the temperature of the refrigerant at the time when the compressor receives the refrigerant is higher. Also, the compression work required for the compression is higher as the temperature of the refrigerant at the time when each stage of a multi-stage compressor receives the refrigerant is higher. In order to reduce the compression work, studies have been carried out on a reduction in the temperature of the refrigerant at the time when each stage of the multi-stage compressor receives the refrigerant. As this type of technique, US Patent No. 5791159 discloses a compressor having a mixer for mixing a high temperature gas-phase refrigerant (that is delivered from a compression stage and in a superheated state) with a low temperature gas-phase refrigerant separately generated and reducing the temperature of the gas-phase refrigerant to be supplied to a subsequent compression stage.

## SUMMARY OF THE INVENTION

**[0004]** In the abovementioned technique, when the temperature of the low temperature gas-phase refrigerant before the mixing is set to a saturation temperature corresponding to pressure after the mixing, and when the low temperature gas-phase refrigerant is mixed with the high temperature gas-phase refrigerant in the mixer, the temperature of the refrigerant after the mixing is higher than the saturation temperature. Thus, during the entire mixing process, the temperature of the gas-phase refrigerant is maintained to be equal to or higher than the saturation temperature. In this case, the gas-phase refrigerant is not condensed, and erosion does not occur due to a liquid droplet. However, the temperature of the high temperature gas-phase refrigerant before the mixing is higher than the saturation temperature. The refrigerant obtained after the mixing is supplied to the subsequent compression stage and has a temperature higher than the saturation temperature.

**[0005]** When the temperature of the high temperature gas-phase refrigerant before the mixing is  $T_h$ ; the saturation temperature corresponding to the pressure after the mixing is  $T_{sat}$ ; and the temperature of the refrigerant after the mixing is  $T_{mix}$ , the degree of cooling of the high temperature gas-phase refrigerant is can be evaluated using an index that is a saturation percentage obtained by the following expression.

$$\text{Saturation percentage} = \frac{T_h - T_{mix}}{T_h - T_{sat}}$$

Expression 1

**[0006]** The saturation percentage of 100% indicates that the temperature of the refrigerant after the mixing reaches the saturation temperature. On the other hand, as the saturation percentage is lower, the temperature of the refrigerant is higher than the saturation temperature. In order to reduce compression work, it is desirable that the saturation percentage is close to 100%. In the abovementioned technique, the high temperature gas-phase refrigerant is mixed with the refrigerant having the saturation temperature. The saturation percentage in the technique is approximately 50% at the highest. In the technique, the compression work increases compared with compression work in the case where a

refrigerant having the saturation temperature (that is the minimum temperature for preventing the refrigerant from being liquefied) is supplied to a compressor. This reduces the efficiency of a refrigeration cycle.

**[0007]** It is, therefore, an object of the present invention to provide a refrigeration cycle system in which necessary compression work of a compressor is low, and erosion does not occur due to a liquid droplet.

**[0008]** To accomplish the object, the refrigeration cycle system for cooling a medium by means of a refrigerant includes: a plurality of compressors for compressing the refrigerant, one of the compressors being a low pressure compressor, one of the compressors being a high pressure compressor; a condenser for cooling and condensing the refrigerant compressed by the plurality of compressors; a reservoir for receiving the refrigerant condensed by the condenser; an expansion mechanism for expanding and cooling the refrigerant supplied from the reservoir; an evaporator for evaporating the refrigerant cooled by the expansion mechanism by means of the medium to generate a refrigerant to be supplied to the plurality of compressors; and an intercooler that is provided between the low pressure compressor and the high pressure compressor and adapted to cool the refrigerant supplied from the low pressure compressor by means of the refrigerant supplied from the expansion mechanism to generate a refrigerant to be supplied to the high pressure compressor.

**[0009]** According to the present invention, the temperature of a refrigerant on an intake side of the compressor can be close to a saturation temperature, it is possible to suppress occurrence of erosion due to a liquid droplet and reduce compression work of the compressor provided in the refrigeration cycle system.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0010]**

Fig. 1 is a schematic diagram showing a refrigeration cycle system according to a first embodiment of the present invention;

Fig. 2 is a schematic diagram showing a refrigeration cycle system according to a second embodiment of the present invention;

Fig. 3 is a schematic diagram showing a refrigeration cycle system according to a third embodiment of the present invention; and

Fig. 4 is a schematic diagram showing a refrigeration cycle system according to a fourth embodiment of the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

**[0011]** Embodiments of the present invention are described below with reference to the accompanying drawings.

### First Embodiment

**[0012]** Fig. 1 is a schematic diagram showing a refrigeration cycle system according to a first embodiment of the present invention.

**[0013]** The refrigeration cycle system shown in Fig. 1 is adapted to cool a medium 10 (to be cooled) by means of heat exchange with a refrigerant. The refrigeration cycle system has a power engine 1, a refrigerant compressor 2, a condenser 6, a reservoir 7, an expansion mechanism 8 and an evaporation mechanism 9. In this example, propane is used as the refrigerant. As the medium 10 to be cooled, a mixed medium including methane, ethane and propane is used. The medium 10 to be cooled is used to cool a natural gas and convert the natural gas into a liquefied natural gas (LNG) in a mixed refrigerant cycle (not shown).

**[0014]** The refrigerant compressor 2 is adapted to compress a refrigerant supplied from the evaporation mechanism 9. The refrigerant compressor 2 has a low pressure compressor 3, an intermediate pressure compressor 4 and a high pressure compressor 5. The low pressure compressor 3 is connected with a pipe 21 in which a gas-phase refrigerant flows from the evaporation mechanism 9. The intermediate pressure compressor 4 is connected with a pipe 22 in which the gas-phase refrigerant flows from the evaporation mechanism 9. The high pressure compressor 5 is connected with a pipe 23 in which the gas-phase refrigerant flows from the evaporation mechanism 9. The low pressure compressor 3 compresses the refrigerant supplied from the pipe 21. The intermediate pressure compressor 4 compresses the refrigerant supplied from the pipe 22. The high pressure compressor 5 compresses the refrigerant supplied from the pipe 23. The low pressure compressor 3, the intermediate pressure compressor 4 and the high pressure compressor 5 are connected to the power engine 1 via a rotor 34 and rotationally driven by the power engine 1. The power engine is adapted to supply, to the compressors 3 to 5, power (compression work) required for compressing the refrigerant. As the power engine 1, a motor, a gas turbine engine or the like may be used. The refrigerant compressor 2 according to the present embodiment is composed of the low pressure compressor 3, the intermediate pressure compressor 4 and

the high pressure compressor 5. The refrigerant compressor 2 may be composed of two compressors or composed of four or more compressors. Each of the compressors may be single-stage compressors or multi-stage compressors.

**[0015]** The condenser 6 is adapted to cool and condense the refrigerant compressed by the refrigerant compressor 2. The condenser 6 is connected with the high pressure compressor 5 via a pipe 24. A pipe 35 passes through the inside of the condenser 6. A cooling medium (cold source) flows in the pipe 35. The condenser 6 cools the refrigerant by means of the cooling medium. As the cooling medium flowing in the pipe 35, an atmosphere, seawater or the like may be used. When an exhaust end of the pipe 35 is connected to a heat utilization plant (not shown) for works or the like, the refrigeration cycle system according to the present embodiment can be utilized as part of a heat pump system.

**[0016]** The reservoir 7 is adapted to receive the refrigerant condensed by the condenser 6. The reservoir 7 is connected with the condenser 6 via a pipe 25. The pipe 25 has a valve 11.

**[0017]** The expansion mechanism 8 is adapted to expand and cool the refrigerant supplied from the reservoir 7. The expansion mechanism 8 has expansion valves 12, 13 and 14 in the present embodiment. The expansion valve 12 is provided with a pipe 26 that connects the reservoir 7 with a first intercooler (described later) 15. The expansion valve 13 is provided with a pipe 27 that connects the first intercooler 15 with a second intercooler (described later) 16. The expansion valve 14 is provided with a pipe 28 that connects the second intercooler 16 with an evaporator 17. The expansion valves 12, 13 and 14 expand a liquid-phase refrigerant supplied from the reservoir 7, the intercooler 15 and the intercooler 16, respectively. The expansion valves 12, 13 and 14 then convert the liquid-phase refrigerant into a gas-liquid two-phase refrigerant to reduce the temperature of the refrigerant supplied from the reservoir 7 in a stepwise manner.

**[0018]** The evaporation mechanism 9 is adapted to evaporate the refrigerant cooled by the expansion mechanism 8 and cool the medium 10 in a stepwise manner. The evaporation mechanism 9 has the first intercooler 15, the second intercooler 16 and the evaporator 17.

**[0019]** The first intercooler 15 is adapted to cool a superheated gas-phase refrigerant (compressed by the intermediate pressure compressor 4) and the medium 10 by means of a gas-liquid two-phase refrigerant cooled by the expansion valve 12 so as to generate a gas-phase refrigerant to be supplied to the high pressure compressor 5 and to cool the medium 10. The second intercooler 16 is also adapted to cool the superheated gas-phase refrigerant (compressed by the low pressure compressor 3) and the medium 10 by means of the gas-liquid two-phase refrigerant cooled by the expansion valve 13 so as to generate a gas-phase refrigerant to be supplied to the intermediate pressure compressor 4 and to cool the medium 10. The first intercooler 15 is connected with an intake side of the high pressure compressor 5 via the pipe 23. The first intercooler 15 is also connected with an output side of the intermediate pressure compressor 4 via a pipe 29. The second intercooler 16 is connected with an intake side of the intermediate pressure compressor 4 via the pipe 22. The second intercooler 16 is also connected with an output side of the low pressure compressor 3 via a pipe 30. A pipe 31 passes through the inside of the first intercooler 15 and the inside of the second intercooler 16. The medium 10 to be cooled flows in the pipe 31.

**[0020]** The heat exchange (of the superheated gas-phase refrigerant supplied from the refrigerant compressor 2 with the gas-liquid two-phase refrigerant supplied from the expansion mechanism 8) is performed in the first intercooler 15 and the second intercooler 16. However, the type of the heat exchanger is not limited. A direct contact heat exchanger, in which the gas-liquid two-phase refrigerant (or only a liquid-phase component of the gas-liquid two-phase refrigerant) is sprayed to the superheated gas-phase refrigerant, may be employed. Alternatively, indirect contact heat exchanger using a tube type heat exchanger may be performed. In the case where the direct contact heat exchange is used, the system can be manufactured with low cost. The direct contact heat exchanger is preferable in order to reduce the manufacturing cost.

**[0021]** The evaporator 17 cools the medium 10 by means of the gas-liquid two-phase refrigerant cooled by the expansion valve 14 and generates a gas-phase refrigerant to be supplied to the low pressure compressor 3. The evaporator 17 is connected with an intake side of the low pressure compressor 3 via the pipe 21. The pipe 31 passes through the inside of the evaporator 17. The medium 10 to be cooled flows in the pipe 31. The evaporator 17 evaporates the entire gas-liquid two-phase refrigerant supplied through the pipe 28.

**[0022]** Next, operations of the refrigeration cycle system according to the present embodiment during its steady operation will be described.

**[0023]** In the refrigerant cycle system having the configuration described above, the liquid-phase refrigerant (40°C, 1.5 MPa) stored in the reservoir 7 is supplied to the expansion valve 12, and then adiabatically expanded by the expansion valve 12 to a predetermined pressure value of 0.63 MPa, and then becomes in a gas-liquid mixed state (gas-liquid two-phase refrigerant) and has a saturation temperature (of 9°C) corresponding to the pressure. The refrigerant that is in the gas-liquid mixed state in the above way is introduced into the first intercooler 15 via the pipe 26.

**[0024]** The gas-liquid two-phase refrigerant introduced in the first intercooler 15 is subjected to heat exchange with the superheated gas-phase refrigerant supplied via the pipe 29. Then, a part of the liquid-phase component of the gas-liquid two-phase refrigerant is evaporated, and the gas-liquid two-phase refrigerant is cooled to a saturation temperature corresponding to pressure within the first intercooler 15. Simultaneously with the cooling of the gas-liquid two-phase refrigerant, the medium 10 (having a temperature of approximately 40°C) introduced in the first intercooler 15 via the

pipe 31 is cooled by evaporative latent heat of the liquid-phase refrigerant. The amount of the gas-phase refrigerant cooled to the saturation temperature increases due to the evaporation of the liquid-phase refrigerant and the like, compared with the amount of the gas-phase refrigerant when the gas-liquid two-phase refrigerant is introduced in the first intercooler 15. The gas-phase refrigerant cooled to the saturation temperature is supplied to the intake side of the high pressure compressor 5 via the pipe 23. In the abovementioned way, the gas-liquid refrigerant that is in a superheated state and delivered from the intermediate pressure compressor 4 is cooled to the saturation temperature by the first intercooler 15 and then supplied to the high pressure compressor 5. Therefore, compression work of the high pressure compressor 5 can be reduced. The gas-phase refrigerant supplied to the high pressure compressor 5 is compressed to pressure of 1.5 MPa by the high pressure compressor 5 and then introduced into the condenser 6 via the pipe 24.

**[0025]** The liquid-phase refrigerant that is not evaporated by the first intercooler 15 is introduced into the expansion valve 13 via the pipe 27. The liquid-phase refrigerant is adiabatically expanded by the expansion valve 13 to a predetermined pressure value of 0.25 MPa, and then becomes in a gas-liquid mixed state and has a saturation temperature (of - 19°C) corresponding to the pressure.

**[0026]** The gas-liquid two-phase refrigerant introduced in the second intercooler 16 is subjected to heat exchange with the superheated gas-phase refrigerant supplied via the pipe 30. A part of the liquid-phase component of the gas-liquid two-phase refrigerant is evaporated, and the gas-liquid two-phase refrigerant introduced in the second intercooler 16 is cooled to a saturation temperature corresponding to pressure within the second intercooler 16. Simultaneously with the cooling of the gas-liquid two-phase refrigerant, the medium 10 introduced in the second intercooler 16 via the pipe 31 is further cooled by evaporative latent heat of the liquid-phase refrigerant. The amount of the gas-phase refrigerant cooled to the saturation temperature increases due to the evaporation of the liquid-phase refrigerant and the like compared with the amount of the gas-phase refrigerant when the gas-liquid two-phase refrigerant is introduced in the second intercooler 16. The gas-phase refrigerant cooled to the saturation temperature is supplied to the intake side of the intermediate pressure compressor 4 via the pipe 22. In the abovementioned way, the gas-phase refrigerant that is in a superheated state and delivered from the low pressure compressor 3 is cooled to the saturation temperature by the second intercooler 16 and then supplied to the intermediate pressure compressor 4. Therefore, compression work of the intermediate pressure compressor 4 can be reduced. The gas-phase refrigerant supplied to the intermediate pressure compressor 4 is compressed by the intermediate pressure compressor 4, becomes in a superheated state, and is then supplied to the first intercooler 15.

**[0027]** The liquid-phase refrigerant that is not evaporated by the second intercooler 16 is introduced into the expansion valve 14 via the pipe 28. The liquid-phase refrigerant is adiabatically expanded to a predetermined pressure value of 0.1 MPa by the expansion valve 14, and then becomes in a gas-liquid mixed state and has a saturation temperature (of - 41°C) corresponding to the pressure. The gas-liquid two-phase refrigerant is introduced into the evaporator 17 via the pipe 28.

**[0028]** The gas-liquid two-phase refrigerant introduced in the evaporator 17 is heated by means of the medium 10 introduced via the pipe 31 and entirely evaporated. In this case, the medium 10 is cooled to a predetermined temperature (of - 35°C) by means of evaporative latent heat of the refrigerant. The gas-phase refrigerant evaporated by means of the medium 10 is supplied to the low pressure compressor 3 via the pipe 21. The gas-phase refrigerant supplied to the low pressure compressor 3 is compressed, becomes in a superheated state, and is then supplied to the second intercooler 16.

**[0029]** The gas-phase refrigerant supplied to the intake side (the intake side of the low pressure compressor 3) of the refrigerant compressor 2 is compressed to a predetermined pressure value of 1.5 MPa by the low pressure compressor 3, the intermediate pressure compressor 4 and the high pressure compressor 5. The refrigerant supplied to the intake side of the low pressure compressor 3 is in a saturated state corresponding to the pressure (of 1.5 MPa). The refrigerant receives more compression work as the refrigerant flows from the low pressure compressor 3 through the intermediate pressure compressor 4 to the high pressure compressor 5. The refrigerant located at the output side of the high pressure compressor 5 is in a superheated state (in a highpressure and high-temperature state). The gas-phase refrigerant that is in the superheated state in this way is supplied to the condenser 6 via the pipe 24. The gas-phase refrigerant supplied to the condenser 6 is cooled to a level equal to or similar to an atmospheric temperature by means of the cold source present in the pipe 35.

**[0030]** In the steady state, the refrigerant compressed by the refrigerant compressor 2 (low pressure compressor 3, intermediate pressure compressor 4 and high pressure compressor 5) is supplied to the reservoir 7 via the pipe 25 and temporarily stored in the reservoir 7. The refrigerant having the same amount as that of the refrigerant supplied to the reservoir 7 via the pipe 25 is supplied from the reservoir 7 to the first intercooler 15 via the pipe 26. That is, the refrigeration cycle system according to the present embodiment forms a closed loop as a whole in the steady state. Since the reservoir 7 is affected by an external temperature, the inner pressure of the reservoir 7 varies depending on the external temperature. For example, when the external temperature is 40°C, the inner pressure of the reservoir 7 is 1.5 MPa that is saturation pressure of propane at a temperature of 40°C.

**[0031]** Next, a description will be made of an effect of the refrigeration cycle system according to the present embod-

iment with reference to a comparative example.

**[0032]** As the comparative example of the refrigeration cycle system according to the present embodiment, there is a refrigeration cycle system including a compressor having a mixer for mixing a superheated gas-phase refrigerant (high-temperature gas-phase refrigerant) delivered from the last compression stage with a gas-phase medium (low-temperature gas-phase refrigerant) that is separately generated and has a temperature relatively lower than that of the superheated gas-phase refrigerant. This technique is to reduce the temperature of the refrigerant at the first compression stage and thereby reduce compression work of the compressor. In this technique, the high-temperature gas-phase refrigerant having a temperature higher than a saturation temperature is mixed with the low-temperature gas-phase refrigerant having the saturation temperature. The temperature of the mixed refrigerant is consequently higher than the saturation temperature. The mixed refrigerant saturation percentage is 50% at the highest. Therefore, the compression work is higher than that in the case where the refrigerant having the saturation temperature is supplied to the last compression stage. This results in a reduced efficiency of the refrigeration cycle in the comparative example.

**[0033]** On the other hand, the refrigeration cycle system according to the present embodiment uses the refrigerant supplied from the expansion mechanism 8 (expansion valves 12 and 13) to cool the superheated gas-phase refrigerant supplied from the low pressure compressor 3 and the intermediate pressure compressor 4. In addition, the refrigeration cycle system according to the present embodiment has the first intercooler 15 and the second intercooler 16. Each of the intercoolers 15 and 16 generates a gas-phase refrigerant. The gas-phase refrigerant generated by the second intercooler 16 has the saturation temperature and is to be supplied to the intermediate pressure compressor 4. The gas-phase refrigerant generated by the first intercooler 15 has the saturation temperature and is to be supplied to the high pressure compressor 5. In the refrigeration cycle system having this configuration, the first intercooler 15 is capable of cooling the superheated gas-phase refrigerant supplied from the intermediate pressure compressor 4 to the saturation temperature corresponding to the pressure within the first intercooler 15 and supplying the cooled refrigerant to the high pressure compressor 5. Similarly, the second intercooler 16 is capable of cooling the superheated gas-phase refrigerant supplied from the low pressure compressor 3 to the saturation temperature corresponding to the pressure within the second intercooler 16 and supplying the cooled refrigerant to the intermediate pressure compressor 4. In comparison with the comparative example in which the mixer mixes the high-temperature gas-phase refrigerant with the low-temperature gas-phase refrigerant, the temperature of the refrigerant introduced into the refrigerant compressor 2 can be close to the saturation temperature. In addition, the compression work of the refrigerant compressor 2, which is required to obtain a refrigerant having a predetermined pressure value, can be reduced. Furthermore, since the gas-phase refrigerant having the saturation temperature is introduced into the refrigerant compressor 2 in the refrigeration cycle system according to the present embodiment, erosion due to droplet condensation can be suppressed, and reliability of the refrigeration cycle system can be improved. Furthermore, since the amount of the cooled medium 10 per compression work increases by a quantity corresponding to the reduced compression work, the cost for manufacturing a liquefied natural gas can be reduced. An investment in construction of a natural gas liquefaction plant can be quickly recovered.

**[0034]** In the above example, the gas-phase refrigerant that is to be supplied from each of the intercoolers 15 and 16 to the refrigerant compressor 2 has the saturation temperature when the gas-phase refrigerant is output from each of the intercoolers 15 and 16. Specifically, it is preferable that the gas-phase refrigerant supplied from each of the intercoolers 15 and 16 to the compressors 5 and 4 has the saturation temperatures when each of the compressors 5 and 4 receives the gas-phase refrigerant. That is, it is preferable that the intercooler 16 be configured to cool the superheated gas-phase refrigerant from the compressor 3 to ensure that the gas-phase refrigerant has a temperature close to the saturation temperature when the gas-phase refrigerant is received by the compressor 4. Similarly, it is preferable that the intercooler 15 be configured to cool the superheated gas-phase refrigerant from the compressor 4 to ensure that the gas-phase refrigerant has a temperature close to the saturation temperature when the gas-phase refrigerant is received by the compressor 5.

**[0035]** In addition, the refrigerant saturation percentage obtained when the refrigerant is output from each of the intercoolers 15 and 16 needs to be set to less than 100% in some cases, in consideration of the following: the cost required to cool the refrigerant, the size of each device, occurrence of a droplet due to a heat loss in a path from each of the intercoolers 15 and 16 to the refrigerant compressor 2. When the refrigerant saturation percentages are set to less than 100%, it is preferable that the saturation percentages of the refrigerants delivered from the intercoolers 15 and 16 toward the high pressure compressor 5 and the intermediate pressure compressor 4 be set to be equal to or more than 80% from the practical perspective. When the refrigerant saturation percentages are set in the abovementioned way, the cost for manufacturing each device and the size of each device can be suppressed. In addition, when the heat loss occurs, erosion due to droplet condensation can be prevented.

**[0036]** It is preferable that the temperatures of the refrigerants delivered from the intercoolers 15 and 16 toward the high pressure compressor 5 and the intermediate pressure compressor 4 be equal to or more than the saturation temperatures in order to prevent the erosion. In this case, it is preferable that the temperatures of the refrigerants be equal to or lower than the temperature obtained by adding a temperature of 10°C to a saturation temperature corre-

sponding to pressure of the intake side of the high pressure compressor 5 in consideration of the fact that the compression work of the intermediate pressure compressor 4 and compression work of the high pressure compressor 5 are as small as possible.

## 5 Second Embodiment

**[0037]** Next, a second embodiment of the present invention will be described.

**[0038]** The feature of the second embodiment is that a first intercooler 15A and a second intercooler 16A are provided, in which the superheated gas-phase refrigerant directly contacts the gas-liquid two-phase refrigerant and is subjected to heat exchange with the gas-liquid two-phase refrigerant, and the medium 10 to be cooled indirectly contacts the gas-liquid two-phase refrigerant and is subjected to heat exchange with the gas-liquid two-phase refrigerant.

**[0039]** Fig. 2 is a schematic diagram showing a refrigeration cycle system according to the second embodiment of the present invention. It should be noted that the same parts as the parts shown in Fig. 1 are denoted by the same reference numerals and description thereof is omitted. Figs. 3 and 4 are illustrated in the same manner.

**[0040]** The refrigeration cycle system shown in Fig. 2 has an evaporation mechanism 9A. The evaporation mechanism 9A has the first intercooler 15A, the second intercooler 16A and the evaporator 17.

**[0041]** The first intercooler 15A has a spray nozzle 52 and a tube 54. The second intercooler 16A has a spray nozzle 51 and a tube 53. A lower portion of the first intercooler 15A is connected with the pipe 29, while a lower portion of the second intercooler 16A is connected with the pipe 30. A superheated gas-phase refrigerant compressed by the refrigerant compressor 2 flows in the pipes 29 and 30. An upper portion of the first intercooler 15A is connected with the pipe 23, while an upper portion of the second intercooler 16A is connected with the pipe 22. The gas-phase refrigerant in a saturated state flows in the pipes 22 and 23.

**[0042]** The spray nozzle 51 is connected to the pipe 27 to spray the gas-liquid two-phase refrigerant supplied from the expansion valve 13 (expansion mechanism 8) into the second intercooler 16A. The spray nozzle 52 is connected to the pipe 26 to spray the gas-liquid two-phase refrigerant supplied from the expansion valve 12 (expansion mechanism 8) into the first intercooler 15A. The gas-liquid two-phase refrigerant sprayed from the spray nozzle 51 directly contacts the superheated gas-phase refrigerant supplied from the pipe 30 and is subjected to heat exchange with the superheated gas-phase refrigerant and heated. The gas-liquid two-phase refrigerant sprayed from the spray nozzle 52 directly contacts the superheated gas-phase refrigerant supplied from the pipe 29 and is subjected to heat exchange with the superheated gas-phase refrigerant and heated.

**[0043]** The medium 10 to be cooled flows in the tubes 53 and 54. The tubes 53 and 54 are connected with the pipe 31. The medium 10 to be cooled flows in the pipe 31. The medium 10 flowing in the tube 53 indirectly contacts the gas-liquid two-phase refrigerant sprayed from the spray nozzle 51 and is subjected to heat exchange with the gas-liquid two-phase refrigerant and cooled. The medium 10 flowing in the tube 54 indirectly contacts the gas-liquid two-phase refrigerant sprayed from the spray nozzle 52 and is subjected to heat exchange with the gas-liquid two-phase refrigerant and cooled.

**[0044]** In the refrigeration cycle system having this configuration, the gas-liquid two-phase refrigerants sprayed from the spray nozzles 51 and 52 are subjected to heat exchange with the superheated gas-phase refrigerants supplied from the pipes 30 and 29, respectively, and part of a liquid-phase component of each gas-liquid two-phase refrigerant is evaporated. The liquid-phase refrigerants (liquid droplets) that remain in this case contact the surface of the tube 53 and the surface of the tube 54 and flow in the tubes 53 and 54 while being heated by means of the medium 10 to be cooled. A part of the liquid-phase refrigerant is evaporated. The heat amount of the medium 10 flowing in the tubes 53 and 54 is reduced by evaporative latent heat of the liquid-phase refrigerants. The medium 10 is cooled to a level close to a saturated steam temperature. The liquid-phase refrigerant that is not evaporated on each of the surfaces of the tubes 53 and 54 is accumulated on each of bottom surfaces of the first and second intercoolers 15A and 16A due to the gravity and heated by means of the superheated gas-phase refrigerant supplied from each of the pipes 29 and 30. A part of the liquid-phase refrigerant is evaporated. The liquid-phase refrigerants accumulated on the bottom surfaces of the first and second intercoolers 15A and 16A are supplied to a low pressure side of the second intercooler 16A and the evaporator 17 via the pipes 27 and 28, respectively. After the liquid-phase refrigerant passes through the expansion valves 13 and 14, the liquid-phase refrigerant is used to cool the medium 10.

**[0045]** In the refrigeration cycle system having the configuration described above, since the liquid-phase refrigerant directly contacts the gas-phase refrigerant and is subjected to heat exchange with the gas-phase refrigerant in each of the first intercooler 15A and the second intercooler 16A, the temperature of the refrigerant in each of the intercoolers 15A and 16A can be maintained to the saturation temperature. Therefore, the gas-phase refrigerants delivered from the first intercooler 15A and the second intercooler 16A through the pipes 23 and 22 are constantly in a saturated state. The gas-phase refrigerant in the saturated state can be supplied to the refrigerant compressor 2. As a result, the compression work of the refrigerant compressor 2 can be reduced. In the present embodiment, since the superheated gas-phase refrigerant directly contacts the liquid-phase refrigerant to be subjected to heat exchange with the liquid-phase refrigerant, contact resistance can be reduced, and the heat exchange efficiency can be increased, compared with the case where

the heat exchange is performed through an indirect contact of the superheated gas-phase refrigerant with the liquid-phase refrigerant. According to the present embodiment, the heat exchange of the superheated gas-phase refrigerant, the liquid-phase refrigerant and the medium 10 to be cooled can be performed in a single container. Therefore, an increase in the cost for the devices and an increase in the installation space can be suppressed.

**[0046]** In the present embodiment, in order to set the saturation percentages of the gas-phase refrigerants delivered from the intercoolers 15A and 16A to less than 100%, the position of the point at which the intercooler 15A and the pipe 29 are connected with each other and the position of the point at which the intercooler 16A and the pipe 30 are connected with each other are changed to higher positions to ensure that the positions of the points are respectively closer to the position of the point at which the intercooler 15A and the pipe 23 are connected with each other and the position of the point at which the intercooler 16A and the pipe 22 are connected with each other. This reduces the time, for which the superheated gas-phase refrigerant is in contact with the gas-liquid two-phase refrigerant, to adjust the saturation percentage.

### Third Embodiment

**[0047]** Next, a third embodiment of the present invention will be described.

**[0048]** A feature of the present embodiment is that a packing tower (intercooler) 61, an evaporator 62 and a mixer 63 are provided, and the two different heat exchangers (packing tower 61, evaporator 62) respectively cool the superheated gas-phase refrigerant and the medium 10.

**[0049]** Fig. 3 is a schematic diagram showing a refrigeration cycle system according to the third embodiment of the present invention.

**[0050]** The refrigeration cycle system shown in Fig. 3 has an expansion mechanism 8B, an evaporation mechanism 9B and the mixer 63. The expansion mechanism 8B has an expansion valve 12a, an expansion valve 12b, the expansion valve 13 and the expansion valve 14. The evaporation mechanism 9B has the packing tower (intercooler) 61, the evaporator 62, the second intercooler 16 and the evaporator 17.

**[0051]** A pipe 26a has the expansion valve 12a and is connected with the reservoir 7. A pipe 26b has the expansion valve 12b and is connected with the reservoir 7. The liquid-phase refrigerant from the reservoir 7 is supplied to and expanded by the expansion valves 12a and 12b. The liquid-phase refrigerant is then turned into a gas-liquid two-phase refrigerant and supplied to the packing tower 61 and the evaporator 62.

**[0052]** The packing tower (intercooler) 61 is adapted to perform heat exchange between the superheated gas-phase refrigerant and the gas-liquid two-phase refrigerant. The packing tower 61 has a spray nozzle 65 and a packing 66. A lower portion of the packing tower 61 is connected with the pipe 29. The superheated gas-phase refrigerant compressed by the refrigerant compressor 2 flows in the pipe 29. An upper portion of the packing tower 61 is connected with a pipe 70. The gas-phase refrigerant in the saturated state flows in the pipe 70.

**[0053]** The spray nozzle 65 is adapted to spray, into the packing tower 61, the gas-liquid two-phase refrigerant supplied from the expansion valve 12a. The spray nozzle 65 is connected with the pipe 26a. The gas-liquid two-phase refrigerant sprayed from the spray nozzle 65 directly contacts the superheated gas-phase refrigerant supplied from the pipe 29 and is subjected to heat exchange with the superheated gas-phase refrigerant and heated.

**[0054]** The packing 66 is adapted to stir the gas-liquid two-phase refrigerant and the superheated gas-phase refrigerant in the packing tower 61. The packing 66 is located in the packing tower 61 and under the spray nozzle 65. It is preferable that a structure, which is used for a chemical plant and has a large surface area per volume, be used as the packing 66 in order to increase an effective area in which the gas-phase refrigerant contacts the liquid-phase refrigerant. As the packing 66 that meets the above conditions, a regular structure, an irregular structure, a wettable honeycomb structure, a nonwettable honeycomb structure, and the like may be used. When any of the abovementioned structures is used, the system can be configured with low cost. Especially, when the wettable honeycomb structure is used and has a fine texture, the rate of the contact between the gas-phase refrigerant and the liquid-phase refrigerant is increased, and the evaporation distance of the liquid-phase refrigerant can be reduced. Therefore, the size of the packing tower 61 can be reduced.

**[0055]** As shown in Fig. 3, the packing tower 61 may have a spray nozzle 67. The spray nozzle 67 is adapted to spray a liquid-phase refrigerant accumulated on a bottom portion of the packing tower 61 to the superheated gas-phase refrigerant. The spray nozzle 67 is connected with a pipe 68. The pipe 68 is connected with the bottom portion of the packing tower 61. The pipe 68 has a pump 69. The pump 69 is operable to lift the liquid-phase refrigerant accumulated in the packing tower 61 to the spray nozzle 67. In the case where the spray nozzle 67 is provided, the spray nozzle 67 can further promote the stirring of the liquid-phase refrigerant and the superheated gas-phase refrigerant. In the case where the spray nozzle 67 is provided, the spray nozzle 67 is preferably located above the packing 66.

**[0056]** The gas-phase refrigerant cooled by the packing tower 61 flows in the pipe 70. The pipe 70 connects an output end of the packing tower 61 with the mixer 63.

**[0057]** The evaporator 62 is adapted to cool the medium 10 by means of the gas-liquid two-phase refrigerant cooled

by the expansion valve 12b and generate a gas-phase refrigerant to be supplied to the mixer 63. The evaporator 62 is connected with the reservoir 7 via the pipe 26b. The evaporator 62 is also connected with the mixer 63 and the intake side of the high pressure compressor 5 via the pipe 23. The evaporator 62 is also connected with the second intercooler 16 via the pipe 27. The pipe 31 passes through the inside of the evaporator 62. The medium 10 to be cooled flows in the pipe 31.

**[0058]** The mixer 63 is adapted to mix the gas-phase refrigerant cooled by the packing tower 61 with the gas-phase refrigerant supplied from the evaporator 62 to generate a gas-phase refrigerant to be supplied to the refrigerant compressor 2. The mixer 63 is provided with the pipe 23. The mixer 63 is connected with the output end of the packing tower 61 via the pipe 70.

**[0059]** In the refrigeration cycle system having the configuration described above, the liquid-phase refrigerant flowing in the pipe 26a is adiabatically expanded and turned into a gas-liquid two-phase refrigerant by the expansion valve 12a, and the gas-liquid two-phase refrigerant is introduced into the packing tower 61. The gas-liquid two-phase refrigerant introduced into the packing tower 61 is sprayed within the packing tower 61 by means of the spray nozzle 65. The gas-liquid two-phase refrigerant sprayed within the packing tower 61 is stirred by the packing 66. The gas-liquid two-phase refrigerant contacts the superheated gas-phase refrigerant supplied from the pipe 29 and is subjected to heat exchange with the superheated gas-phase refrigerant. In this case, since the gas-liquid two-phase refrigerant and the superheated gas-phase refrigerant are stirred by the packing 66, and are quickly mixed with each other, the evaporation distance and the evaporation time, which are required for spray cooling in the packing tower 61, are reduced. The superheated gas-phase refrigerant supplied from the intermediate pressure compressor 4 is cooled by the spraying in the packing tower 61. The temperature of the gas-phase refrigerant supplied from the intermediate pressure compressor 4 then reaches the saturation temperature. After that, the gas-phase refrigerant is supplied to the mixer 63 via the pipe 70.

**[0060]** The liquid-phase refrigerant flowing in the pipe 26b is adiabatically expanded and turned into a gas-liquid two-phase refrigerant by the expansion valve 12b. The liquid-phase refrigerant is then introduced into the evaporator 62. The gas-liquid two-phase refrigerant introduced into the evaporator 62 is subjected to heat exchange with the medium 10 present in the pipe 31. A part of the liquid-phase component of the gas-liquid two-phase refrigerant is evaporated and cooled to the saturation temperature, and the gas-phase refrigerant is cooled to the saturation temperature. The amount of the gas-phase refrigerant cooled to the saturation temperature increases due to the evaporation of the liquid-phase refrigerant, compared with the amount of the gas-phase refrigerant supplied to the evaporator 62. Then, the gas-phase refrigerant cooled to the saturation temperature is supplied to the mixer 63 via the pipe 23.

**[0061]** The gas-phase refrigerant supplied from the evaporator 62 to the mixer 63 via the pipe 23 is mixed with the gas-phase refrigerant supplied from the packing tower 61 via the pipe 70. The mixed gas-phase refrigerant is supplied to the high pressure compressor 5 via the pipe 23. Since the gas-phase refrigerant supplied to the mixer 63 via the pipe 23 and the gas-phase refrigerant supplied to the mixer 63 via the pipe 70 have the saturation temperature, the gas-phase refrigerant having the saturation temperature can be supplied to the refrigerant compressor 2.

**[0062]** In the refrigeration cycle system having the configuration described above, since the gas-phase refrigerant having the saturation temperature can be supplied to the refrigerant compressor 2, the compression work of the refrigerant compressor 2 can be reduced. In the present embodiment, since the packing 66 is used for the mixing of the superheated gas-phase refrigerant with the gas-liquid two-phase refrigerant in the packing tower 61, the evaporation distance and the evaporation time, which are required for the spraying, can be reduced. This allows the refrigerant to be sufficiently cooled to the saturation temperature and allows the size of the packing tower 61 to be reduced.

**[0063]** The packing tower 61 and the mixer 63, which are characteristic devices in the refrigeration cycle system according to the present embodiment, can be provided in an existing system. If there is an existing refrigeration cycle system having the refrigerant compressor 2, the condenser 6, the reservoir 7, the expansion mechanism 8 and the evaporation mechanism ((evaporator 62), which is adapted to evaporate the refrigerant cooled by the expansion mechanism 8 by means of the medium 10 and then supply the refrigerant to the refrigerant compressor 2), and the packing tower 61 and the mixer 63 are added to the existing refrigeration cycle system, the refrigeration cycle system according to the present embodiment can be configured.

**[0064]** Specifically, if there is an existing refrigeration cycle system having: a refrigerant compressor composed of a plurality of compressors (including a high pressure compressor and a low pressure compressor); a condenser adapted to cool and condense a refrigerant compressed by the refrigerant compressor; a reservoir adapted to receive the refrigerant condensed by the condenser; an expansion mechanism adapted to expand and cool the refrigerant supplied from the reservoir; an evaporator (evaporator 62) adapted to evaporate the refrigerant cooled by the expansion mechanism by means of a medium to be cooled and to generate a refrigerant to be supplied to the refrigerant compressor; and an evaporation pipe (pipe 23) adapted to supply the refrigerant evaporated by the evaporator to the high pressure compressor of the refrigerant compressor, an intercooler ((packing tower 61), which is adapted to cool a refrigerant compressed by the low pressure compressor of the refrigerant compressor by means of the refrigerant supplied from the expansion mechanism) and a mixer ((mixer 63), which is connected with the evaporation pipe and adapted to mix the refrigerant cooled by the intercooler with the refrigerant supplied from the evaporator so as to generate a refrigerant to be supplied

to the high pressure compressor) are added to the existing refrigeration cycle system. Then, the existing refrigeration cycle system having the intercooler and the mixer is retrofitted.

**[0065]** The retrofitting of the existing refrigeration cycle system makes it possible to reduce the time period for constructing the refrigeration cycle system, compared with the case where all equipment is assembled to construct the refrigeration cycle system. In addition, existing equipment can be used in the refrigeration cycle system.

#### Fourth Embodiment

**[0066]** Next, a fourth embodiment of the present invention will be described.

**[0067]** A feature of the fourth embodiment is that a first intercooler 74 and a second intercooler 76 are provided to cause the superheated gas-phase refrigerant and the gas-liquid two-phase refrigerant to be subjected to indirect heat exchange with each other.

**[0068]** Fig. 4 is a schematic diagram showing a refrigeration cycle system according to the fourth embodiment of the present invention.

**[0069]** The refrigeration cycle system shown in Fig. 4 has an expansion mechanism 8C and an evaporation mechanism 9C. The expansion mechanism 8C has a pipe 71 and a pipe 72. The evaporation mechanism 9C has a high pressure evaporator 73, the first intercooler 74, a medium pressure evaporator 75, and the second intercooler 76.

**[0070]** The gas-liquid two-phase refrigerant output from the expansion valve 12 flows in the pipe 71. The pipe 71 connects the pipe 26 with the first intercooler 74. The gas-liquid two-phase refrigerant delivered from the expansion valve 13 flows in the pipe 72. The pipe 72 connects the pipe 27 with the second intercooler 76.

**[0071]** The high pressure evaporator 73 is adapted to evaporate a part of the liquid-phase component of the gas-liquid two-phase refrigerant supplied from the pipe 26 by means of the medium 10 that flows in the pipe 31, and to generate a gas-phase refrigerant to be supplied to the high pressure compressor 5 and cool the medium 10. The high pressure evaporator 73 is connected with the pipe 26. The high pressure evaporator 73 is also connected with the intake side of the high pressure compressor 5 via the pipe 23. The pipe 31 passes through the inside of the high pressure evaporator 73. The medium 10 to be cooled flows in the pipe 31. A lower portion of the high pressure evaporator 73 is connected with the pipe 27. The liquid-phase refrigerant that is not evaporated by the high pressure evaporator 73 flows in the pipe 27.

**[0072]** The first intercooler 74 is adapted to cause the superheated gas-phase refrigerant supplied from the intermediate pressure compressor 4 and the gas-liquid two-phase refrigerant supplied from the pipe 71 to indirectly contact each other and to be subjected to heat exchange with each other so as to generate a gas-phase refrigerant to be supplied to the high pressure compressor 5. The first intercooler 74 is connected with the pipe 71 and a pipe 77. The gas-phase refrigerant generated by the first intercooler 74 flows in the pipe 77. The pipe 77 is connected with the pipe 23. A lower portion of the first intercooler 74 is connected with a pipe 78. The liquid-phase refrigerant that is not evaporated by the first intercooler 74 flows in the pipe 78. The pipe 78 is connected with the pipe 27. The point at which the pipe 78 is connected with the pipe 27 is located on the upstream side of the expansion valve 13. The pipe 29 passes through the inside of the first intercooler 74. The heated gas-phase refrigerant flows in the pipe 29. The pipe 29 is connected with the pipe 23.

**[0073]** The medium pressure evaporator 75 is adapted to evaporate a part of the liquid-phase component of the gas-liquid two-phase refrigerant supplied from the pipe 27 by means of the medium 10 that flows in the pipe 31, and to generate a gas-phase refrigerant to be supplied to the intermediate pressure compressor 4 and cool the medium 10. The medium pressure evaporator 75 is connected with the pipe 27. The medium pressure evaporator 75 is also connected with the intake side of the intermediate pressure compressor 4 via the pipe 22. The pipe 31 passes through the inside of the medium pressure evaporator 75. The medium 10 to be cooled flows in the pipe 31. A lower portion of the medium pressure evaporator 75 is connected with the pipe 28. The liquid-phase refrigerant that is not evaporated by the medium pressure evaporator 75 flows in the pipe 28.

**[0074]** The second intercooler 76 is adapted to cause the superheated gas-phase refrigerant supplied from the low pressure compressor 3 and the gas-liquid two-phase refrigerant supplied from the pipe 72 to indirectly contact each other and to be subjected to heat exchange with each other so as to generate a gas-phase refrigerant to be supplied to the intermediate pressure compressor 4. The second intercooler 76 is connected with the pipe 72. The second intercooler 76 is also connected with a pipe 79. The gas-phase refrigerant generated by the second intercooler 76 flows in the pipe 79. The pipe 79 is connected with the pipe 22. A lower portion of the second intercooler 76 is connected with a pipe 80. The liquid-phase refrigerant that is not evaporated by the second intercooler 76 flows in the pipe 80. The pipe 80 is connected with the pipe 28. The point at which the pipe 80 is connected with the pipe 28 is located on the upstream side of the expansion valve 14. The pipe 30 passes through the inside of the second intercooler 76. The heated gas-phase refrigerant flows in the pipe 30. The pipe 30 is connected with the pipe 22.

**[0075]** In the refrigeration cycle system having the configuration described above, the liquid-phase refrigerant supplied from the reservoir 7 is turned into a gas-liquid mixed state by the expansion valve 12 and then supplied to the high pressure evaporator 73 and the first intercooler 74 via the pipe 26 and the pipe 71.

**[0076]** The gas-liquid two-phase refrigerant supplied to the high pressure evaporator 73 indirectly contacts the medium 10 present in the pipe 31. Due to the indirect contact, a part of the liquid-phase refrigerant is evaporated. The medium 10 is then cooled by means of the evaporative latent heat. The temperature of the gas-phase component of the gas-liquid two-phase refrigerant supplied from the pipe 26 and the temperature of the refrigerant vaporized in the high pressure evaporator 73 are changed to a saturation temperature corresponding to inner pressure of the high pressure evaporator 73. Then, the refrigerants are supplied to the high pressure compressor 5 via the pipe 23. The refrigerant (liquid-phase refrigerant) that is not vaporized in the high pressure evaporator 73 is supplied to the expansion valve 13 via the pipe 27.

**[0077]** Since the gas-liquid two-phase refrigerant supplied to the first intercooler 74 indirectly contacts the superheated gas-phase refrigerant present in the pipe 29, a part of the liquid-phase component of the gas-liquid two-phase refrigerant is evaporated. The superheated gas-phase refrigerant is cooled by the evaporative latent heat to a saturation temperature corresponding to inner pressure of the first intercooler 74.

**[0078]** The temperature of the gas-phase component of the gas-liquid two-phase refrigerant supplied from the pipe 71 and the temperature of the refrigerant vaporized in the first intercooler 74 are changed to a saturation temperature corresponding to inner pressure of the first intercooler 74. The gas-phase refrigerant is then supplied to the pipe 23 via the pipe 77. The gas-phase refrigerant present in the pipe 29 is cooled to the saturation temperature corresponding to the inner pressure of the first intercooler 74 when the gas-phase refrigerant passes through the first intercooler 74. After the gas-phase refrigerant present in the pipe 29 passes through the first intercooler 74, the gas-phase refrigerant is supplied to the pipe 23. The refrigerant that is not evaporated by the first intercooler 74 is supplied to the pipe 27 via the pipe 78.

**[0079]** The gas-phase refrigerants supplied to the pipe 23 via the pipes 77 and 29 flow together with the gas-phase refrigerant delivered from the high pressure evaporator 73. The gas-phase refrigerants supplied to the pipe 23 and the gas-phase refrigerant delivered from the high pressure evaporator 73 become in the saturated state and are supplied to the high pressure compressor 5. In this way, the gas-phase refrigerants cooled to the saturation temperature corresponding to suction pressure of the high pressure compressor 5 is supplied to the high pressure compressor 5. Therefore, the compression work of the high pressure compressor 5 can be reduced.

**[0080]** The liquid-phase refrigerant supplied from the highpressure evaporator 73 and the first intercooler 74 to the pipe 27 is expanded by the expansion valve 13. A part of the liquid-phase refrigerant is vaporized, and the liquid-phase refrigerant is turned into a gas-liquid two-phase refrigerant. The refrigerant in the gas-liquid mixed state is supplied to the medium pressure evaporator 75 and the second intercooler 76 via the pipes 27 and 72.

**[0081]** Since the gas-liquid two-phase refrigerant supplied to the medium pressure evaporator 75 indirectly contacts the medium 10 present in the pipe 31, a part of the liquid-phase component of the gas-liquid two-phase refrigerant is evaporated, and the medium 10 is cooled by the evaporative latent heat. The temperature of the gas-phase component of the gas-liquid two-phase refrigerant supplied from the pipe 27 and the temperature of the refrigerant vaporized in the medium pressure evaporator 75 are changed to a saturation temperature corresponding to inner pressure of the medium pressure evaporator 75. The gas-phase component of the gas-liquid two-phase refrigerant and the refrigerant vaporized in the medium pressure evaporator 75 are supplied to the intermediate pressure compressor 4 via the pipe 22. The refrigerant (liquid-phase refrigerant) that is not evaporated by the medium pressure evaporator 75 is supplied to the expansion valve 14 via the pipe 28.

**[0082]** Since the gas-liquid two-phase refrigerant supplied to the second intercooler 76 indirectly contacts the superheated gas-phase refrigerant present in the pipe 30, a part of the liquid-phase component of the gas-liquid two-phase refrigerant is evaporated, and the superheated gas-phase refrigerant is cooled by the evaporative latent heat to a saturation temperature corresponding to inner pressure of the second intercooler 76.

**[0083]** The temperature of the gas-phase component of the gas-liquid two-phase refrigerant supplied from the pipe 72 and the temperature of the refrigerant vaporized in the second intercooler 76 are changed to the saturation temperature corresponding to the inner pressure of the second intercooler 76. Then, the gas-phase component of the gas-liquid two-phase refrigerant and the refrigerant vaporized in the second intercooler 76 are supplied to the pipe 22 via the pipe 79. The gas-phase refrigerant present in the pipe 30 is cooled by the second intercooler 76 to the saturation temperature corresponding to the inner pressure of the second intercooler 76 and supplied to the pipe 22. The refrigerant that is not evaporated by the second intercooler 76 is supplied to the pipe 28 via the pipe 80.

**[0084]** The gas-phase refrigerants supplied to the pipe 22 via the pipes 79 and 30 flow together with the gas-phase refrigerant delivered from the medium pressure evaporator 75. The gas-phase refrigerants supplied to the pipe 22 and the gas-phase refrigerant delivered from the medium pressure evaporator 75 become in a saturated state and are supplied to the intermediate pressure compressor 4. In this way, the gas-phase refrigerants cooled to the saturation temperature corresponding to suction pressure of the intermediate pressure compressor 4 is supplied to the intermediate pressure compressor 4. Therefore, the compression work of the intermediate pressure compressor 4 can be reduced.

**[0085]** In the refrigeration cycle system having the configuration described above, the gas-phase refrigerant in the saturated state can be supplied to the refrigerant compressor 2, and the compression work of the refrigerant compressor

2 can be reduced. Especially, since the first intercooler 75 and the second intercooler 76, which are adapted to perform the indirect heat exchange, are used in the present embodiment, the refrigeration cycle system according to the present embodiment can prevent a liquid droplet from being mixed with the superheated gas-phase refrigerant supplied from the pipes 29 and 30. This prevents erosion due to interference between the liquid droplet and the blades of the compressors 4 and 5. Therefore, the refrigerant compressor 2 has reliability for a long time.

**[0086]** The first intercooler 75 and the second intercooler 76, which are characteristic equipment in the present embodiment, can be used in an existing system in a similar way to the third embodiment. Thus, an effect similar to that in the third embodiment can be obtained by retrofitting the existing system. Specifically, when there is an existing refrigeration cycle system having: a refrigerant compressor composed of a plurality of compressors (including a low pressure compressor and a high pressure compressor); a condenser for cooling and condensing a refrigerant compressed by the refrigerant compressor; a reservoir for receiving the refrigerant condensed by the condenser; the expansion mechanism (expansion valves 12, 13 and 14) for expanding and cooling the refrigerant supplied from the reservoir; and the evaporator (high pressure evaporator 73, medium pressure evaporator 75 and evaporator 17) for evaporating the refrigerant cooled by the expansion mechanism by means of a medium to be cooled and generating a refrigerant to be supplied to the refrigerant compressor, the intercoolers (first intercooler 75 and second intercooler 76) are added to the existing refrigeration cycle system. The existing refrigeration cycle system is retrofitted. In this case, the intercoolers are provided between the low pressure compressor and the high pressure compressor, and adapted to cool the refrigerant supplied from the low pressure compressor by means of the refrigerant supplied from the expansion mechanism so as to generate a refrigerant to be supplied to the high pressure compressor.

**[0087]** The amounts of refrigerants extracted from the low pressure compressor 3 and the intermediate pressure compressor 4 via the pipes 30 and 29 are not described in the embodiments. The refrigeration cycle system according to each embodiment may be configured to ensure that a part or all of the refrigerants delivered from the low pressure compressor 3 and the intermediate pressure compressor 4 is or are cooled by the evaporation mechanism.

**[0088]** The refrigeration cycle system according to each embodiment of the present invention can be applied to natural gas liquefaction equipment having a refrigeration cycle system for cooling a medium by means of a refrigerant, and to a heat pump system.

## Claims

1. A refrigeration cycle system for cooling a medium (10) by means of heat exchange with a refrigerant, comprising:
  - a plurality of compressors (3, 4, 5) for compressing a refrigerant, one of the compressors being a low pressure compressor (3), another one of the compressors being a high pressure compressor (5);
  - a condenser (6) for cooling and condensing the refrigerant compressed by the plurality of compressors (3, 4, 5);
  - a reservoir (7) for receiving the refrigerant condensed by the condenser (6);
  - an expansion mechanism (8) for expanding and cooling the refrigerant supplied from the reservoir (7);
  - an evaporator (9) for evaporating the refrigerant cooled by the expansion mechanism (8) by means of heat exchange with the medium (10) and generating a refrigerant to be supplied to the plurality of compressors (3, 4, 5); and
  - an intercooler (15) that is provided between the low pressure compressor and the high pressure compressor (5) and adapted to cool the refrigerant supplied from the low pressure compressor (3) by means of heat exchange with the refrigerant supplied from the expansion mechanism (8) so as to generate a refrigerant to be supplied to the high pressure compressor (5).
2. The refrigeration cycle system according to claim 1, wherein the intercooler (15) cools the refrigerant supplied from the low pressure compressor (3) to ensure that the temperature of the refrigerant at the time when the refrigerant is supplied to the high pressure compressor (5) is close to a saturation temperature.
3. The refrigeration cycle system according to claim 1, wherein the intercooler (15) causes the refrigerant supplied from the low pressure compressor (3) and the refrigerant supplied from the expansion mechanism (8) to directly contact each other so as to cool the refrigerant supplied from the low pressure compressor (3).
4. The refrigeration cycle system according to claim 1, wherein the intercooler (15) causes the refrigerant supplied from the low pressure compressor (3) and the refrigerant supplied from the expansion mechanism (8) to indirectly contact each other so as to cool the refrigerant supplied from the

low pressure compressor (3).

5 5. The refrigeration cycle system according to claim 1, wherein the intercooler (15) cools the medium by means of heat exchange with the refrigerant supplied from the expansion mechanism (8).

10 6. The refrigeration cycle system according to claim 3, wherein the intercooler (15A) has a nozzle (52) for spraying the refrigerant supplied from the expansion mechanism (8) to the refrigerant supplied from the low pressure compressor (3).

7. The refrigeration cycle system according to claim 6, wherein the intercooler (61) further has a nozzle (67) for spraying a liquid-phase refrigerant accumulated in the intercooler (61) to the refrigerant compressed by the low pressure compressor (3).

15 8. The refrigeration cycle system according to claim 6, wherein the intercooler (61) has a packing (66) provided under the nozzle (65, 67).

20 9. The refrigeration cycle system according to claim 8, wherein the packing (66) has an wettable honeycomb structure.

10. The refrigeration cycle system according to claim 1, wherein a saturation percentage of the refrigerant delivered from the intercooler (15, 15A, 61) toward the high pressure compressor is equal to or higher than 80%.

25 11. The refrigeration cycle system according to claim 1, wherein a saturation temperature of the refrigerant cooled by the intercooler (15, 15A, 61) and supplied to the high pressure compressor (5) is equal to or lower than a temperature obtained by adding a temperature of 10°C to a saturation temperature corresponding to pressure of an intake side of the high pressure compressor (5).

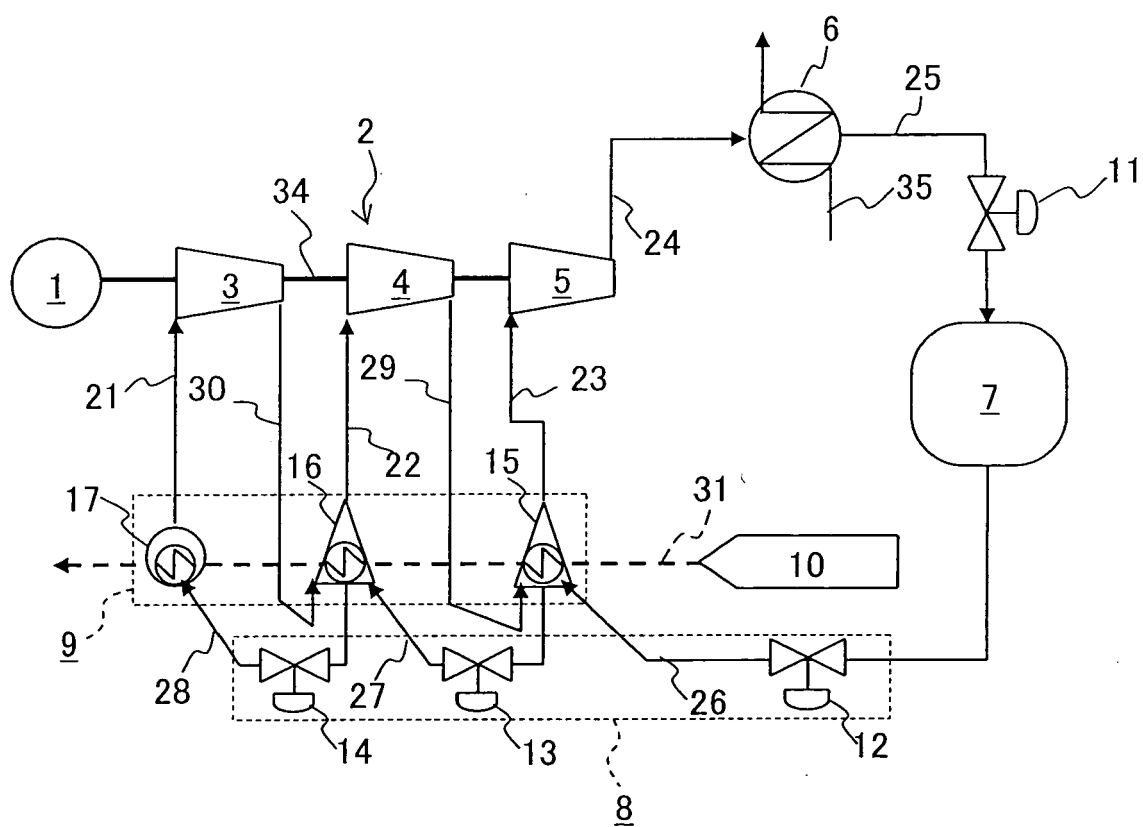
30 12. Natural gas liquefaction equipment comprising the refrigeration cycle system according to any of claims 1 to 11.

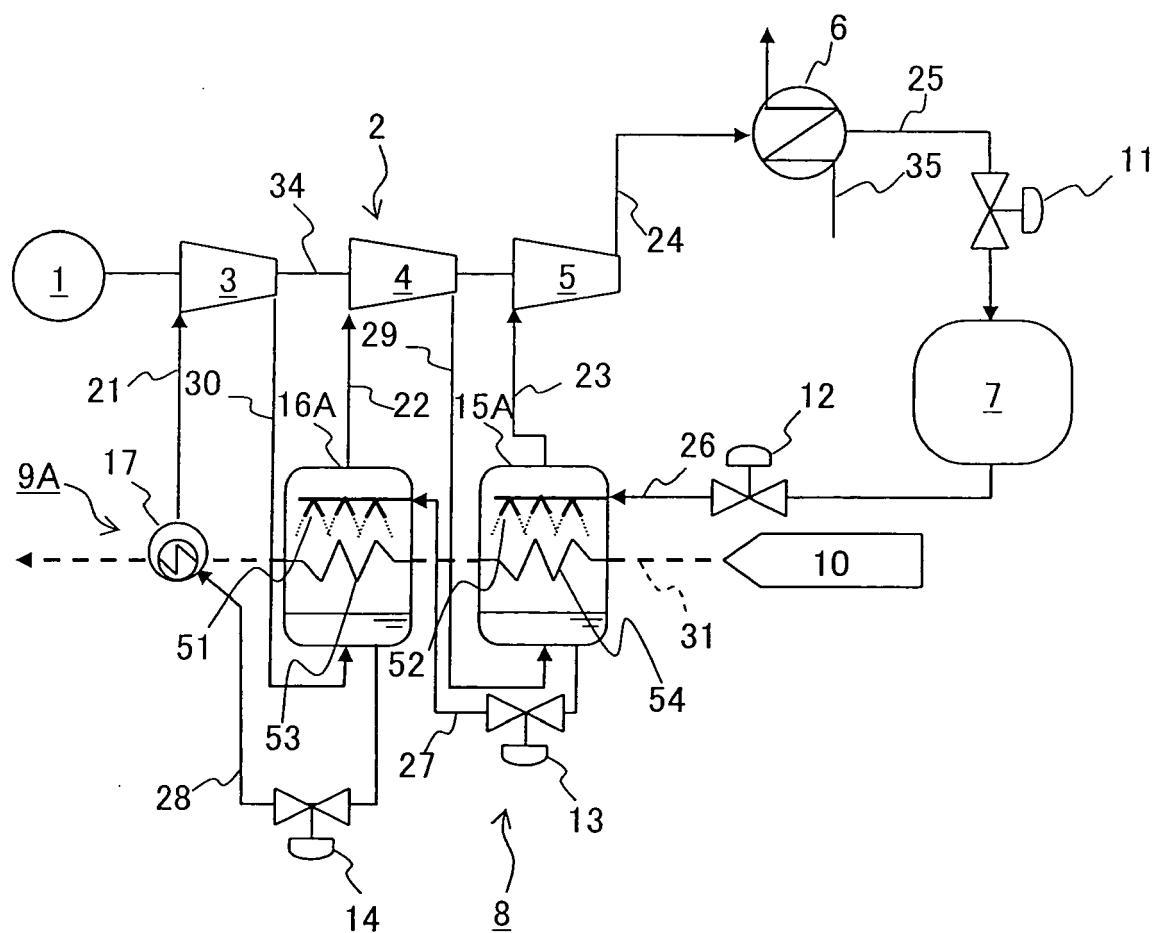
13. A heat pump system comprising the refrigeration cycle system according to any of claims 1 to 11.

35 14. A method for retrofitting a refrigeration cycle system, comprising the step of adding an intercooler (15, 15A, 61) to the refrigeration cycle system having:

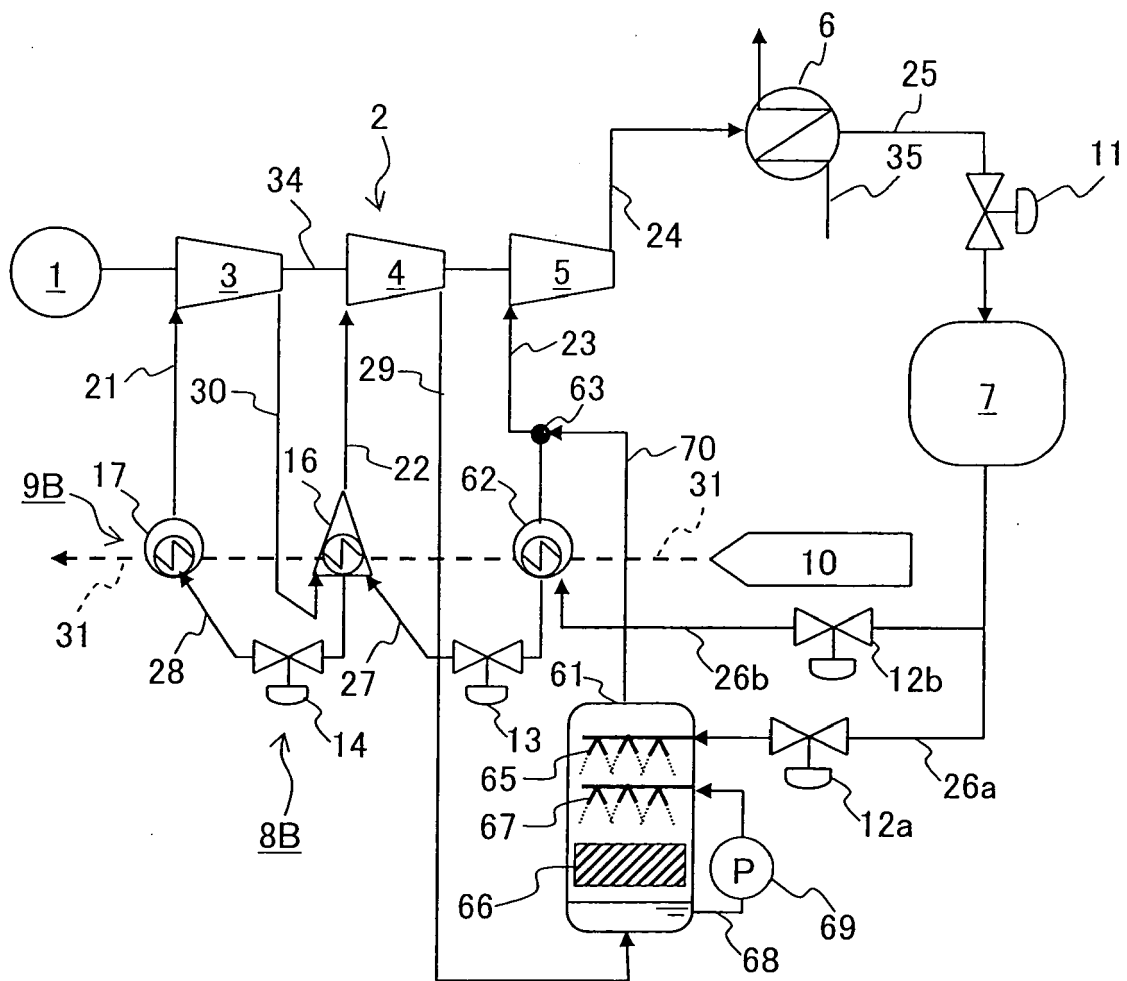
40 a plurality of compressors (3, 4, 5) for compressing a refrigerant, one of the compressors being a low pressure compressor (3), another one of the compressors being a high pressure compressor (5);  
a condenser (6) for cooling and condensing the refrigerant compressed by the plurality of compressors (3, 4, 5);  
a reservoir (7) for receiving the refrigerant condensed by the condenser (3, 4, 5);  
an expansion mechanism (8) for expanding and cooling the refrigerant supplied from the reservoir (7); and  
an evaporator (9) for evaporating the refrigerant cooled by the expansion mechanism (8) by means of a medium to be cooled to generate a refrigerant to be supplied to the plurality of compressors (3, 4, 5), wherein  
45 the intercooler (15, 15A, 61) is located between the low pressure compressor (3) and the high pressure compressor (5) and adapted to cool the refrigerant supplied from the low pressure compressor (3) by means of heat exchange with the refrigerant supplied from the expansion mechanism (8) so as to generate a refrigerant to be supplied to the high pressure compressor (5).

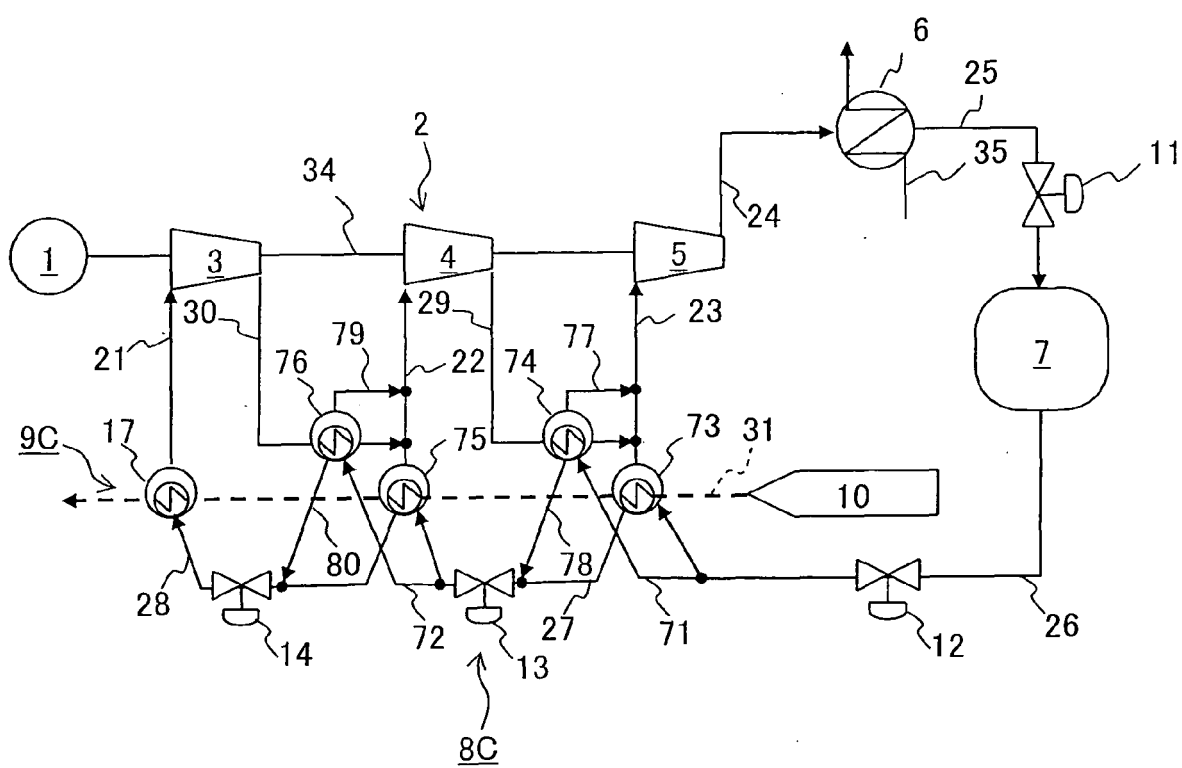
50 15. The method according to claim 14, wherein a mixer (63) is further added to the refrigeration cycle system, and provided with a pipe for supplying the refrigerant evaporated by the evaporator (9) to the plurality of compressors (3, 4, 5) and adapted to mix the refrigerant cooled by the intercooler (61) with the refrigerant supplied from the evaporator (9) so as to generate a refrigerant to be supplied to the high pressure compressor (5).

**FIG. 1**

**FIG. 2**

**FIG. 3**



**FIG. 4**

**REFERENCES CITED IN THE DESCRIPTION**

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