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(71) Applicant: **Panasonic Intellectual Property Management Co., Ltd.**
**Osaka-shi, Osaka 540-6207 (JP)**

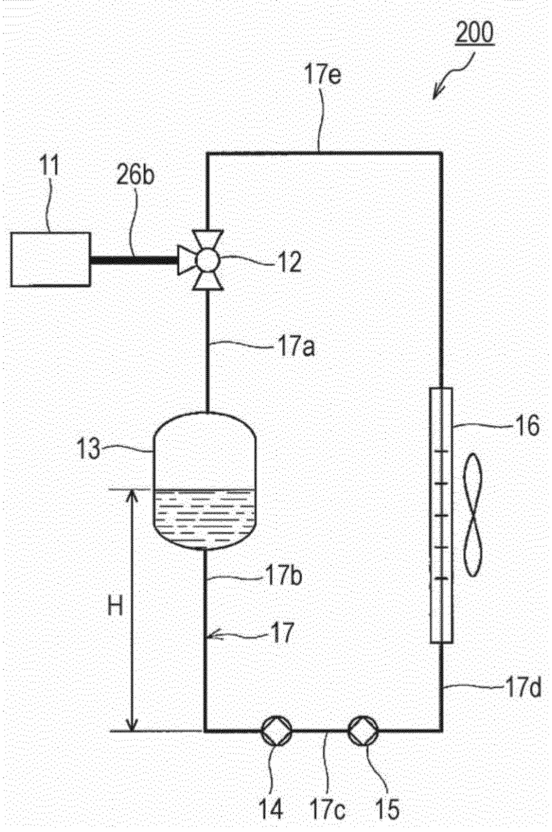
(72) Inventors:
- **KAWANO, Bunki**
  **OSAKA, 540-6207 (JP)**
- **TAMURA, Tomoichiro**
  **OSAKA, 540-6207 (JP)**

(74) Representative: **Eisenführ Speiser**
**Patentanwälte Rechtsanwälte PartGmbB**
**Postfach 31 02 60**
**80102 München (DE)**

(54) **HEAT EXCHANGE APPARATUS AND HEAT PUMP APPARATUS**

(57) A heat exchange apparatus according to the present disclosure includes a refrigerant supply source, an ejector, an extractor, a first pump, a second pump, a cooler, and a liquid passage. The first pump is a dynamic pump and disposed on the liquid passage between the extractor and the cooler. The second pump is a positive displacement pump and disposed on the liquid passage between an outlet of the first pump and an inlet of refrigerant liquid of the ejector.

FIG. 1

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## Description

BACKGROUND

1. Technical Field

**[0001]** The present disclosure relates to a heat exchange apparatus and a heat pump apparatus.

2. Description of the Related Art

**[0002]** Conventional heat exchange apparatus has been used for refrigeration cycle apparatus applied to equipment such as an air conditioner, a refrigerator freezer, and a water heater. Japanese Patent No. 4454456 describes a refrigeration cycle apparatus using water as a refrigerant having an extremely small load on the global environment. FIG. 6 illustrates a refrigeration cycle apparatus described in Japanese Patent No. 4454456.

**[0003]** As illustrated in FIG. 6, a refrigeration cycle apparatus 100 includes an evaporator 110, a condenser 120, a connection pipe 130, and a connection pipe 150. An upper portion of the evaporator 110 is connected to an upper portion of the condenser 120 by the connection pipe 130. The connection pipe 130 is provided with a compressor 140. A lower portion of the evaporator 110 is connected to a lower portion of the condenser 120 by the connection pipe 150. The evaporator 110 is connected to an evaporator-side liquid passage 160. The evaporator-side liquid passage 160 is provided with a load 180 and a cold water pump 220. The condenser 120 is connected to a condenser-side liquid passage 170. The condenser-side liquid passage 170 is provided with a cooling tower 210 and a coolant pump 230.

SUMMARY

**[0004]** In one general aspect, the techniques disclosed here feature a heat exchange apparatus including: a refrigerant supply source that supplies a refrigerant vapor, the refrigerant vapor being a refrigerant in a vapor phase; a cooler that cools a refrigerant liquid and that supplies the cooled refrigerant liquid, the refrigerant liquid being the refrigerant in a liquid phase; an ejector that produces a refrigerant mixed flow using the refrigerant vapor supplied from the refrigerant supply source and the cooled refrigerant liquid supplied from the cooler; an extractor that receives the refrigerant mixed flow from the ejector and extracts the refrigerant liquid from the refrigerant mixed flow; a liquid passage that constitutes a loop on which the extractor, the cooler and the ejector are disposed in this order and that circulates the refrigerant liquid flowing therein; a first pump that is a dynamic pump, that is disposed on the liquid passage between the an outlet of the extractor and an inlet of the cooler, and that pumps the liquid refrigerant from the extractor to the cooler; and a second pump that is a positive displacement pump and that is disposed on the liquid passage between an outlet of the first pump and an inlet of the ejector.

**[0005]** With the technique described above, a height from the first pump (dynamic pump) to the extractor can be reduced so that the size of the heat exchange apparatus can be reduced. Thus, performance of the heat exchange apparatus can be reduced with a suppressed increase in the size of the heat exchange apparatus.

**[0006]** Additional benefits and advantages of the disclosed embodiments will become apparent from the specification and drawings. The benefits and/or advantages may be individually obtained by the various embodiments and features of the specification and drawings, which need not all be provided in order to obtain one or more of such benefits and/or advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

**[0007]**

FIG. 1 illustrates a configuration of a heat exchange apparatus according to a first embodiment;
FIG. 2 is a sectional view of an ejector;
FIG. 3 illustrates a configuration of a heat exchange apparatus according to a second embodiment;
FIG. 4 illustrates a configuration of a heat exchange apparatus according to a third embodiment;
FIG. 5 illustrates a configuration of a heat exchange apparatus according to a fourth embodiment; and
FIG. 6 illustrates a configuration of a conventional refrigeration cycle apparatus.

DETAILED DESCRIPTION

(Underlying Knowledge Forming Basis of the Present Disclosure)

**[0008]** With an increased awareness of environments such as global warming, further enhancement of performance has been required for a heat exchange apparatus or a heat pump apparatus. However, a technique for enhancing performance of the heat exchange apparatus or the heat pump apparatus often causes an increase in size of a system.

**[0009]** To enhance performance of a heat exchange apparatus or a heat pump apparatus, a technique for efficiency increasing the pressure of refrigerant is needed. In view of this, inventors of the present invention have developed a technique of replacing a condenser with a condensation ejector and an extractor, as a technique for efficiency increasing the pressure of refrigerant. The extractor extracts only refrigerant liquid from a refrigerant flow in two phases discharged from the condensation ejector. The pressure of refrigerant discharged from the compressor is efficiently increased with the condensation ejector so that the refrigerant is condensed, thereby reducing work on the compressor. Accordingly, a coefficient of performance (COP) of a system can be enhanced.

**[0010]** However, the inventors found that a system employing the above-described technique requires a pump discharge pressure ten times as high as that of a conventional system. That is, to enhance the COP of a system, a pressure increase efficiency obtained by a pump and an ejector needs to exceed a pressure increase efficiency of a compressor. However, to increase the pump discharge pressure while maintaining a high pump efficiency, the head required for suppressing cavitation of the pump (required net positive suction head: NPSHr) significantly increases. If the required pump discharge pressure decuples, the required net positive suction head also decuples. This NPSHr needs to be obtained with a height (water-level head) from the inlet of the pump to an internal liquid level of the extractor. In the conventional refrigeration cycle apparatus described in Japanese Patent No. 4454456, for example, a water-level head of 1 m is obtained. In the conventional refrigeration cycle apparatus described in Japanese Patent No. 4454456, in a case where the condenser 120 is replaced with an ejector and an extractor, a water-level head of 10 m is required. This causes an increase in size of the system.

**[0011]** As described above, the inventors of the present invention found difficulty, as a new problem, in obtaining both maintenance of a high pump efficiency and prevention of a system size increase in fabricating a heat exchange apparatus in which a condenser is replaced with a condensation ejector and an extractor and a refrigerant vapor from a refrigerant supply source is efficiently increased in pressure and condensed by pump power. Based on the finding of the new problem, the inventors have reached the following aspects of the invention.

**[0012]** In a first aspect of the present disclosure, a heat exchange apparatus includes:

a refrigerant supply source that supplies a refrigerant vapor, the refrigerant vapor being a refrigerant in a vapor phase;
a cooler that cools a refrigerant liquid and that supplies the cooled refrigerant liquid, the refrigerant liquid being the refrigerant in a liquid phase;
an ejector that produces a refrigerant mixed flow using the refrigerant vapor supplied from the refrigerant supply source and the cooled refrigerant liquid supplied from the cooler;
an extractor that receives the refrigerant mixed flow from the ejector and extracts the refrigerant liquid from the refrigerant mixed flow;
a liquid passage that constitutes a loop on which the extractor, the cooler and the ejector are disposed in this order and that circulates the refrigerant liquid flowing therein;
a first pump that is a dynamic pump, that is disposed on the liquid passage between the an outlet of the extractor and an inlet of the cooler, and that pumps the liquid refrigerant from the extractor to the cooler; and
a second pump that is a positive displacement pump and that is disposed on the liquid passage between an outlet of the first pump and an inlet of the ejector.

**[0013]** In the first aspect, a width of pressure increase (a pump up width or range) by the first pump can be set at a width corresponding to the NPSHr of the second pump. Since the NPSHr of the second pump is sufficiently smaller than a required pressure of the ejector, the width of pressure increase required for the first pump is small, and the NPSHr of the first pump is also small. Thus, the use of a dynamic pump as the first pump can efficiently increase the pressure with a small NPSHr. In addition, the second pump sucks refrigerant liquid whose pressure has been increased in a width corresponding to the NPSHr of the second pump, and thus, the risk of performance degradation due to cavitation in the second pump can be reduced. Accordingly, the pressure of an efficient positive displacement pump as the second pump can efficiently increase the pressure of refrigerant liquid to a required pressure of the ejector. Thus, in this configuration, the height from the first pump to the extractor is reduced so that the size of the heat exchange apparatus can be reduced and the pressure of refrigerant liquid can be efficiently increased to a required pressure of the ejector.

**[0014]** In a second aspect of the present disclosure, the heat exchange apparatus in the first aspect may further include: a third pump that is a dynamic pump and that is disposed on the liquid passage between the outlet of the first pump and an inlet of the second pump. In the second aspect, the width of pressure increase by the first pump can be further reduced so that the NPSHr of the first pump can be further reduced and the size of the heat exchange apparatus can be further reduced.

**[0015]** In a third aspect of the present disclosure, the second pump of the heat exchange apparatus of the first or second aspect may be disposed on the liquid passage between the outlet of the first pump and an inlet of the cooler.

**[0016]** In a fourth aspect of the present disclosure, the first pump of the heat exchange apparatus in one of the first to third aspects may be located at a lowest level in a vertical direction on the liquid passage.

**[0017]** In a fifth aspect of the present disclosure, the first pump and the second pump of the heat exchange apparatus in one of the first to fourth aspects may be located at an identical level in a vertical direction.

**[0018]** In a sixth aspect of the present disclosure, in the heat exchange apparatus in one of the first to fifth aspects, the first pump may have a required net positive suction head smaller than a required net positive suction head of the second pump, and the first pump may have a width of pressure increase larger than the required net positive suction head of the second pump.

**[0019]** In a seventh aspect of the present disclosure, the second pump of the heat exchange apparatus in one of the first to sixth aspects may have a pump efficiency higher than a pump efficiency of the first pump. The phrase of "the second pump has a pump efficiency higher than a pump efficiency of the first pump" means that the maximum efficiency of the second pump is higher than the maximum efficiency of the first pump.

**[0020]** In an eighth aspect of the present disclosure, a saturation vapor pressure at a temperature of 20°C±15°C of the refrigerant of the heat exchange apparatus in one of the first to seventh aspects may be lower than an atmospheric pressure.

**[0021]** A heat pump apparatus in a ninth aspect of the present disclosure includes the heat exchange apparatus according to any one of the first to eighth aspects, and the refrigerant supply source is a compressor that compresses a refrigerant vapor input to the refrigerant supply source and that outputs the compressed refrigerant vapor to the ejector. In the ninth aspect, advantages as those of the first aspect can be obtained.

**[0022]** In a tenth aspect of the present disclosure, the heat pump apparatus in the ninth aspect may further include an evaporator that generates the refrigerant vapor to be supplied to the compressor; and a liquid back passage that connects the extractor and the evaporator and that flows a refrigerant liquid that has an amount equal to the refrigerant that was output from the evaporator and that was supplied to the extractor via the compressor and the ejector. With the configuration in which the amount of the refrigerant liquid in the evaporator and the amount of the refrigerant liquid in the extractor are balanced by the liquid back passage, the heat pump apparatus can be stably operated.

**[0023]** Embodiments of the present disclosure will be described hereinafter with reference to the drawings. The present disclosure is not limited to the following embodiments.

(First Embodiment)

**[0024]** As illustrated in FIG. 1, a heat exchange apparatus 200 according to a first embodiment includes a refrigerant supply source 11, an ejector 12, an extractor 13, a first pump 14, a second pump 15, a cooler 16, and a first liquid passage 17. The first liquid passage 17 constitutes a loop and includes pipes 17a to 17e. On the loop constituted by the first liquid passage 17, the ejector 12, the extractor 13, the first pump 14, the second pump 15, and the cooler 16 are connected to one another in this order by the pipes 17a to 17e.

**[0025]** The refrigerant supply source 11 is not specifically limited as long as the refrigerant supply source 11 can supply a refrigerant vapor (a refrigerant in a gas phase) to the ejector 12. The refrigerant supply source 11 is, for example, a compressor that is a component of a heat pump apparatus. The refrigerant supply source 11 may be an evaporator that vaporizes a refrigerant (e.g., water) by using exhaust heat from factories and outputs the vaporized refrigerant as a refrigerant vapor.

**[0026]** As illustrated in FIG. 2, the ejector 12 includes a first nozzle 23, a second nozzle 25, a mixing portion 27, and a diffuser portion 28. The first nozzle 23 is connected to the cooler 16 by the pipe 17e. The refrigerant liquid (refrigerant in a liquid phase) flowed from the cooler 16 is supplied as a motive flow to the first nozzle 23 through the pipe 17e. The second nozzle 25 is connected to the refrigerant supply source 11 by the pipe 26b (vapor passage). The temperature of liquid refrigerant ejected from the first nozzle 23 is reduced by the cooler 16. The refrigerant liquid ejected from the first nozzle 23 with acceleration and the expanded refrigerant vapor ejected from the second nozzle 25 with acceleration are mixed in the mixing portion 27. Then, there occur first condensation due to a temperature difference between the refrigerant liquid and the refrigerant vapor and second condensation due to a pressure increase based on energy transportation between the refrigerant liquid and the refrigerant vapor and momentum transportation between the refrigerant liquid and the refrigerant vapor. The refrigerant vapor supplied from the refrigerant supply source 11 is continuously sucked into the second nozzle 25 through the pipe 26b. Through the two condensation stages, a refrigerant mixed flow having a small quality (dryness fraction) is generated. The diffuser portion 28 restores a static pressure by decelerating the refrigerant mixed flow. In the ejector 12 having such a configuration, the temperature and pressure of refrigerant increase.

**[0027]** The ejector 12 includes a needle pipe 29 and a servo actuator 30. The needle pipe 29 and the servo actuator 30 are flow controllers for controlling the flow rate of refrigerant liquid as a motive flow. The cross section of the orifice of the first nozzle 23 at a tip thereof can be changed by using the needle pipe 29. The servo actuator 30 can adjust the location of the needle pipe 29. With this configuration, the flow rate of the refrigerant liquid flowing in the first nozzle 23 can be controlled.

**[0028]** The extractor 13 receives the refrigerant mixed flow from the ejector 12, extracts refrigerant liquid from the refrigerant mixed flow, and stores the refrigerant liquid. That is, the extractor 13 separates the refrigerant liquid and the refrigerant vapor from each other. The extractor 13 basically extracts only the refrigerant liquid. The extractor 13 is, for example, a pressure-resistant container having heat insulating properties. The configuration of the extractor 13 is not specifically limited as long as the extractor 13 can extract refrigerant liquid.

**[0029]** The first liquid passage 17 is a passage through which refrigerant liquid flowed from the extractor 13 returns to the extractor 13 via the cooler 16 and the ejector 12. The first passage 17 constitutes a loop. On the first passage 17, the extractor 13, the cooler 16, and the ejector 12 are arranged in this order. The refrigerant liquid circulates in the first passage 17.

**[0030]** The first pump 14 is disposed on the first liquid passage 17 between the extractor 13 and the cooler 16 (specifically between an outlet of the extractor 13 and an inlet of the cooler 16). The first pump 14 pumps the refrigerant liquid received from the extractor 13 to the cooler

16.

**[0031]** In the first embodiment, the first pump 14 is a dynamic pump. The dynamic pump is a pump that gives a speed to received fluid (refrigerant liquid), increases the pressure thereof by performing static pressure recovery on the given speed, and sends the fluid. Examples of the dynamic pump include a centrifugal pump, a diagonal pump, and an axial flow pump. The first pump 14 is disposed at a location at which a height H from an inlet of the first pump 14 to the liquid level of refrigerant liquid in the extractor 13 is larger than the NPSHr of the first pump 14.

**[0032]** The second pump 15 is disposed on the first liquid passage 17 between an outlet of the first pump 14 to a liquid inlet (inlet of refrigerant liquid, inlet of a motive flow) of the ejector 12. In the first embodiment, the second pump 15 is disposed on the first liquid passage 17 between the outlet of the first pump 14 and the inlet of the cooler 16. In a case where the second pump 15 is disposed at such a location, a pressure loss in a section between the outlet of the first pump 14 and an inlet of the second pump 15 can be minimized. Consequently, the possibility of cavitation in the second pump 15 further decreases. In addition, the possibility that the second pump 15 sucks a refrigerant in a gas phase in a period of transition such as a start time also decreases. Alternatively, the second pump 15 may be disposed on the first liquid passage 17 between an outlet of the cooler 16 and the liquid inlet of the ejector 12. That is, the second pump 15 may be disposed downstream of the cooler 16.

**[0033]** In the first embodiment, the second pump 15 is a positive displacement pump. The positive displacement pump is a pump that increases the pressure of received fluid (refrigerant liquid) by changing the volume thereof and sends the fluid. Examples of the positive displacement pump include a piston pump, a plunger pump, a gear pump, a roots pump, a vane pump, and a rotary pump.

**[0034]** In the first embodiment, the first pump 14 is located at a lowest level in a vertical direction in the first liquid passage 17. The positional relationship between the first pump 14 and the second pump 15 in the vertical direction is not specifically limited. However, the second pump 15 and the first pump 14 are preferably disposed at an identical level in the vertical direction.

**[0035]** In the first embodiment, in the first pump 14, the pressure of refrigerant liquid is increased to a pressure at which the second pump 15 does not cause cavitation. A most important performance required for the first pump 14 is unlikeliness of cavitation with a small NPSHr. That is, a dynamic pump is more preferably used as the first pump 14 than a positive displacement pump is. The dynamic pump has difficulty in increasing the pressure of refrigerant liquid to a high pressure but is not likely to cause cavitation with a small NPSHr. On the other hand, most important performances for the second pump 15 are high efficiency and capability of increasing the pressure of refrigerant liquid to a high pressure. That is, a positive displacement pump is more preferably used as the second pump 15 than a dynamic pump is. The NPSHr of the first pump 14 is smaller than the NPSHr of the second pump 15. The ratio of (NPSHr of first pump 14)/(NPSHr of second pump 15) is about 0.1, for example.

**[0036]** The cooler 16 is constituted by a known heat exchanger such as a fin-and-tube heat exchanger, a shell-and-tube heat exchanger, and a cooling tower.

**[0037]** An operation of the heat exchange apparatus 200 will now be described.

**[0038]** First, the ejector 12 receives a refrigerant vapor discharged from the refrigerant supply source 11 and a refrigerant liquid supplied from the cooler 16 and generates a refrigerant mixed flow. The refrigerant mixed flow generated by the ejector 12 is input to the extractor 13. The extractor 13 extracts refrigerant liquid and stores the refrigerant liquid therein. The refrigerant liquid stored in the extractor 13 is supplied to the ejector 12 via the first pump 14, the second pump 15, and the cooler 16. To reduce a loss of an effective head by a pressure loss of the pipe, the first pump 14 is disposed on the first liquid passage 17 between the outlet of the extractor 13 and the inlet of the cooler 16. The refrigerant liquid stored in the extractor 13 is first sucked into the first pump 14 and is then increased in pressure in the first pump 14. The pressure of the refrigerant liquid that has been increased by the first pump 14 is further increased by the second pump 15 disposed on the first liquid passage 17 between the outlet of the first pump 14 and the liquid inlet of the ejector 12. The second pump 15 may be disposed on the first liquid passage 17 between the outlet of the cooler 16 and the liquid inlet of the ejector 12.

**[0039]** In the first embodiment, the pressure of the refrigerant liquid extracted by the extractor 13 is increased by the first pump 14 and then is further increased by the second pump 15. The width of the pressure increase by the first pump 14 can be set at a width corresponding to the NPSHr of the second pump 15. Since the NPSHr of the second pump 15 is sufficiently smaller than a required pressure of the ejector 12, a required width of pressure increase by the first pump 14 is small, and the NPSHr of the first pump 14 is also small. Thus, the use of the dynamic pump as the first pump 14 can efficiently increase the pressure with a small NPSHr. In addition, since the second pump 15 sucks refrigerant liquid whose pressure has been increased in a width corresponding to the NPSHr of the second pump 15, the risk of performance degradation due to cavitation in the second pump 15 can be reduced. Thus, the use of an efficient positive displacement pump as the second pump 15 can efficiently increase refrigerant liquid to a required pressure of the ejector 12. Accordingly, in the first embodiment, the height from the first pump 14 to the extractor 13 is reduced so that the size of the heat exchange apparatus 200 can be reduced and the pressure of refrigerant liquid can be efficiently increased to a required pressure of the ejector 12.

(Second Embodiment)

**[0040]** As illustrated in FIG. 3, a heat exchange apparatus 300 according to a second embodiment additionally includes a third pump 18 in addition to the configuration of the heat exchange apparatus 200 described with reference to FIG. 1. In the second embodiment, a first liquid passage 17 constitutes a loop and includes pipes 17a to 17f. On the loop constituted by the first liquid passage 17, the ejector 12, the extractor 13, the first pump 14, the third pump 18, the cooler 16, and the second pump 15 are connected to one another in this order by the pipes 17a to 17f.

**[0041]** The third pump 18 is disposed on the first liquid passage 17 between the first pump 14 and the second pump 15. Specifically, the third pump 18 is disposed on the first liquid passage 17 between the outlet of the first pump 14 and the inlet of the second pump 15. More specifically, the third pump 18 is disposed on the first liquid passage 17 between the outlet of the first pump 14 and the inlet of the cooler 16. The third pump 18 is a dynamic pump. One or more pumps may be additionally provided on the first liquid passage 17 between the first pump 14 and the second pump 15. That is, on the first liquid passage 17 between the outlet of the first pump 14 and the inlet of the second pump 15, a plurality of pumps including the third pump 18 to an N-th pump (where N is an integer of four or more) may be disposed in this order in a flow direction of refrigerant liquid. These pumps can be dynamic pumps.

**[0042]** In the heat exchange apparatus 300, the second pump 15 is disposed between the outlet of the cooler 16 and the liquid inlet of the ejector 12. The second pump 15 may be disposed between the outlet of the N-th pump and the inlet of the cooler 16. That is, the third pump 18 and the additional pumps can be disposed between the outlet of the first pump 14 and the inlet of the second pump 15, independently of the location of the cooler 16.

**[0043]** In the second embodiment, the plurality of dynamic pumps are disposed on the first liquid passage 17. Such multiple stages of dynamic pumps individually provide speeds to fluid (refrigerant liquid) passing through the pumps. Thus, the efficiency of the entire multi-stage dynamic pumps can be significantly increased, as compared to a case where a single dynamic pump is provided. The total NPSHr of the dynamic pumps is smaller than the NPSHr of the second pump 15. The ratio of (total NPSHr of dynamic pumps)/(NPSHr of second pump 15) is less than or equal to 0.1, for example.

**[0044]** In the second embodiment, the width of the pressure increase by the first pump 14 can be further reduced so that the NPSHr of the first pump 14 can be further reduced, resulting in further size reduction of the heat exchange apparatus 300.

(Variations)

**[0045]** The heat exchange apparatus 200 illustrated in FIG. 1 and the heat exchange apparatus 300 illustrated in FIG. 3 may be charged domestic with a refrigerant whose saturation vapor pressure is negative (lower than atmospheric pressure in an absolute pressure) at an ordinary temperature (Japanese Industrial Standards: 20°C±15°C/ JIS Z8703). Examples of such a refrigerant include a refrigerant including water alcohol, or ether as a main component. In an operation of the heat exchange apparatus 200 or 300, the internal pressure of the heat exchange apparatus 200 or 300 is lower than the atmospheric pressure. The pressure at the outlet of the refrigerant supply source 11 is in the range from 5 to 15 kPaA, for example. To prevent freezing, for example, the refrigerant may be a refrigerant containing water as a main component and includes 10 to 40%, in terms of mass %, of ethylene glycol, Nybrine (registered trademark), or mineral salts, for example. The "main component" herein refers to a component occupying the largest proportion in mass ratio. In a case where the heat exchange apparatus 200 or 300 is charged with such a refrigerant, the size of the system tends to increase, as compared to a case where an apparatus is charged with a refrigerant whose pressure saturation vapor pressure at an ordinary temperature is positive. Thus, the technique disclosed herein is significantly effective for a system using a refrigerant whose saturation vapor pressure at an ordinary temperature is negative.

(Third Embodiment)

**[0046]** FIG. 4 illustrates a configuration of a heat pump apparatus according to a third embodiment. A heat pump apparatus 400 (refrigeration cycle apparatus) according to the third embodiment includes a first heat exchange unit 40, a second heat exchange unit 42, a compressor 31, and a vapor passage 26. The first heat exchange unit 40 and the second heat exchange unit 42 form a heat-dissipation side circuit and a heat-absorption side circuit, respectively. Refrigerant vapor generated by the second heat exchange unit 42 is supplied to the first heat exchange unit 40 via the compressor 31 and the vapor passage 26.

**[0047]** The compressor 31, a downstream portion 26b of the vapor passage 26, and the first heat exchange unit 40 correspond to the heat exchange apparatus 200 described with reference to FIG. 1. That is, the heat pump apparatus 400 includes the heat exchange apparatus 200. The compressor 31 corresponds to the refrigerant supply source 11, compresses received refrigerant vapor, and outputs the compressed refrigerant vapor to the ejector 12. Thus, the heat pump apparatus 400 can obtain advantages similar to those of the first embodiment.

**[0048]** Description similar to that of the heat exchange apparatus 200 in the first embodiment is applicable to the first heat exchange unit 40.

**[0049]** The second heat exchange unit 42 includes an evaporator 19, a pump 20 (evaporator-side pump), and a heat exchanger 21. The evaporator 19 stores refrigerant liquid and vaporizes the refrigerant liquid, thereby generating a refrigerant vapor to be compressed in the compressor 31. The evaporator 19, the pump 20, and the heat exchanger 21 are connected to one another by pipes 22a to 22c to constitute a loop. The evaporator 19 is constituted by, for example, a pressure-resistant container having heat insulating properties. The pipes 22a to 22c constitute a second liquid passage 22 in which refrigerant liquid stored in the evaporator 19 circulates via the heat exchanger 21. The pump 20 is provided on the second liquid passage 22 between a liquid outlet of the evaporator 19 and an inlet of the heat exchanger 21. The pump 20 increases the pressure of the refrigerant liquid stored in the evaporator 19 and pumps the refrigerant liquid to the heat exchanger 21. The discharge pressure of the pump 20 is lower than the atmospheric pressure. The pump 20 is disposed at a location at which a height He from an inlet of the pump 20 to the liquid level of refrigerant liquid in the evaporator 19 is larger than a required head (NPSHr).

**[0050]** The heat exchanger 21 is constituted by a known heat exchanger such as a fin-and-tube heat exchanger or a shell-and-tube heat exchanger.

**[0051]** In the third embodiment, the evaporator 19 is a heat exchanger that directly vaporizes, therein, refrigerant liquid heated by circulating in the second liquid passage 22. The refrigerant liquid stored in the evaporator 19 is in direct contact with refrigerant liquid circulating in the second liquid passage 22. That is, part of the refrigerant liquid in the evaporator 19 is heated by the heat exchanger 21 and is used as a heat source for heating refrigerant liquid in a saturation state. An upstream end of the pipe 22a is preferably connected to a lower portion of the evaporator 19. A downstream end of the pipe 22c is preferably connected to an intermediate portion of the evaporator 19. The second heat exchange unit 42 may be configured in such a manner that refrigerant liquid stored in the evaporator 19 is not mixed with other refrigerant liquid circulating in the second liquid passage 22. For example, in a case where the evaporator 19 has a heat exchange configuration similar to that of a shell-and-tube heat exchanger, refrigerant liquid stored in the evaporator 19 can be heated and evaporated by a heating medium circulating in the second liquid passage 22. In the heat exchanger 21, a heating medium for heating the refrigerant liquid stored in the evaporator 19 flows.

**[0052]** The vapor passage 26 includes an upstream portion 26a and the downstream portion 26b. On the vapor passage 26, the compressor 31 is disposed. An upper portion of the evaporator 19 is connected to an inlet of the compressor 31 through the upstream portion 26a of the vapor passage 26. An outlet of the compressor 31 is connected to a second nozzle 25 of the ejector 12 through the downstream portion 26b of the vapor passage 26. The compressor 31 is a centrifugal compressor or a positive-displacement compressor. On the vapor passage 26, a plurality of compressors may be provided. The compressor 31 sucks a refrigerant vapor from the evaporator 19 of the second heat exchange unit 42 through the upstream portion 26a and compresses the refrigerant vapor. The compressed refrigerant vapor is supplied to the ejector 12 through the downstream portion 26b.

**[0053]** In the third embodiment, the temperature and pressure of refrigerant are increased in the ejector 12. Since work on the compressor 31 can be reduced, the compression ratio of the compressor 31 can be significantly reduced and the efficiency of the heat pump apparatus 400 can be increased to a level equal or higher than that in a conventional technique. In addition, the size of the heat pump apparatus 400 can be reduced.

**[0054]** The heat pump apparatus 400 further includes a liquid back passage 32 (required-return pipe) for returning refrigerant from the first heat exchange unit 40 to the second heat exchange unit 42. In the third embodiment, the extractor 13 and the evaporator 19 are connected to each other by the liquid back passage 32 so that refrigerant stored in the extractor 13 can be transferred to the evaporator 19. Typically, a lower portion of the extractor 13 and a lower portion of the evaporator 19 are connected to each other by the liquid back passage 32. The refrigerant liquid returns from the extractor 13 to the evaporator 19 through the liquid back passage 32. The liquid back passage 32 may be provided with an expansion mechanism such as a capillary or an expansion valve.

**[0055]** The liquid back passage 32 is disposed in such a manner that the liquid back passage 32 connects the extractor 13 and the evaporator 19 to each other, refrigerant liquid having an amount equal to an amount (mass flow rate) of a refrigerant vapor transferred from the evaporator 19 to the extractor 13 by the compressor 31 returns from the extractor 13 to the evaporator 19. When the amount of refrigerant liquid in the evaporator 19 and the amount of refrigerant liquid in the extractor 13 are balanced by the liquid back passage 32, the heat pump apparatus 400 can be stably operated. In a case where the amount of the refrigerant liquid stored in the evaporator 19 and the extractor 13 is sufficiently larger than the amount of refrigerant vapor transferred by an operation of the heat pump apparatus 400, the liquid back passage 32 may be omitted.

**[0056]** The liquid back passage 32 may be branched off at any location on the first heat exchange unit 40. For example, the liquid back passage 32 may be branched off at the pipe 17a connecting the ejector 12 and the extractor 13 to each other, or may be branched off at an upper portion of the extractor 13. The first heat exchange unit 40 may be configured to discharge redundant refrigerant when necessary. The second heat exchange unit 42 may be configured to add refrigerant when necessary.

**[0057]** In a manner similar to that of the heat exchange apparatus 200, the heat pump apparatus 400 can use a refrigerant whose saturation vapor pressure at an ordinary temperature is negative.

(Fourth Embodiment)

**[0058]** FIG. 5 illustrates a configuration of a heat pump apparatus according to a fourth embodiment. A heat pump apparatus 500 (refrigeration cycle apparatus) according to the fifth embodiment includes a first heat exchange unit 41, a second heat exchange unit 42, a compressor 31, and a vapor passage 26. The first heat exchange unit 41 and the second heat exchange unit 42 constitute a heat-dissipation side circuit and a heat-absorption side circuit, respectively. A refrigerant vapor generated in the second heat exchange unit 42 is supplied to the first heat exchange unit 41 via the compressor 31 and the vapor passage 26.

**[0059]** The compressor 31, a downstream portion 26b of the vapor passage 26, and the first heat exchange unit 41 correspond to the heat exchange apparatus 300 described with reference to FIG. 3. That is, the heat pump apparatus 500 includes a heat exchange apparatus 300. The compressor 31 corresponds to a refrigerant supply source 11, compresses received refrigerant vapor, and outputs the compressed refrigerant vapor to the ejector 12. Thus, in the heat pump apparatus 500, advantages similar to those described in the second embodiment can be obtained.

**[0060]** Description similar to that of the heat exchange apparatus 300 in the second embodiment is applicable to the first heat exchange unit 41. Detailed description of the second heat exchange unit 42 is similar to that in the third embodiment.

**[0061]** In a manner similar to the heat exchange apparatus 300, the heat pump apparatus 500 can use a refrigerant whose saturation vapor pressure at an ordinary temperature is negative.

**[0062]** As described above, a heat exchange apparatus and a heat pump apparatus described herein includes a first pump 14 (dynamic pump) and a second pump 15 (positive displacement pump). The width of pressure increase by the first pump 14 is set equal to the width of pressure increase corresponding to the NPSHr of the second pump 15. Since the NPSHr of the second pump 15 is sufficiently smaller than a required pressure of the ejector 12, a required width of pressure increase by the first pump 14 is also small, and the NPSHr of the first pump 14 is small. Thus, the height from the first pump 14 to the extractor 13 can be reduced. That is, the height of the heat exchange apparatus or the heat pump apparatus can be reduced so that the size of the entire system can be reduced.

**[0063]** The technique described herein can provide a small-size efficient heat pump apparatus. Specifically, air-conditioning can be performed by using a heat pump apparatus 400 or 500 even in a building with a small installation space. In addition to air-conditioning, hot water at higher temperatures can be supplied in application of the heat pump apparatus 400 or 500 to hot water supply.

**[0064]** A heat exchange apparatus and a heat pump apparatus disclosed herein are applicable to a hot water heating apparatus using vapor, air conditioners such as a domestic air-conditioner and a business-use air-conditioner, and a water heater, for example.

## Claims

**1.** A heat exchange apparatus comprising:

a refrigerant supply source that supplies a refrigerant vapor, the refrigerant vapor being a refrigerant in a vapor phase;
a cooler that cools a refrigerant liquid and that supplies the cooled refrigerant liquid, the refrigerant liquid being the refrigerant in a liquid phase;
an ejector that produces a refrigerant mixed flow using the refrigerant vapor supplied from the refrigerant supply source and the cooled refrigerant liquid supplied from the cooler;
an extractor that receives the refrigerant mixed flow from the ejector and extracts the refrigerant liquid from the refrigerant mixed flow;
a liquid passage that constitutes a loop on which the extractor, the cooler and the ejector are disposed in this order and that circulates the refrigerant liquid flowing therein;
a first pump that is a dynamic pump, that is disposed on the liquid passage between the an outlet of the extractor and an inlet of the cooler, and that pumps the liquid refrigerant from the extractor to the cooler; and
a second pump that is a positive displacement pump and that is disposed on the liquid passage between an outlet of the first pump and an inlet of the ejector.

**2.** The heat exchange apparatus according to claim 1, further comprising:

a third pump that is a dynamic pump and that is disposed on the liquid passage between the outlet of the first pump and inlet of the second pump.

**3.** The heat exchange apparatus according to claim 1 or 2, wherein
the second pump is disposed on the liquid passage between the outlet of the first pump and an inlet of the cooler.

**4.** The heat exchange apparatus according to any one of claims 1 to 3, wherein
the first pump is located at a lowest level in a vertical direction on the liquid passage.

**5.** The heat exchange apparatus according to any one of claims 1 to 4, wherein the first pump and the second pump are located at an identical level in a vertical direction.

**6.** The heat exchange apparatus according to any one of claims 1 to 5, wherein
the first pump has a required net positive suction head smaller than a required net positive suction head of the second pump, and
the first pump has a width of pressure increase larger than the required net positive suction head of the second pump.

**7.** The heat exchange apparatus according to any one of claims 1 to 6, wherein
the second pump has a pump efficiency higher than a pump efficiency of the first pump.

**8.** The heat exchange apparatus according to any one of claims 1 to 7, wherein
a saturation vapor pressure at a temperature of 20°C±15°C of the refrigerant is lower than an atmospheric pressure.

**9.** A heat pump apparatus comprising:

the heat exchange apparatus according to any one of claims 1 to 8, wherein
the refrigerant supply source is a compressor that compresses a refrigerant vapor input to the refrigerant supply source and that outputs the compressed refrigerant vapor to the ejector.

**10.** The heat pump apparatus according to claim 9, further comprising:

an evaporator that generates the refrigerant vapor to be supplied to the compressor; and
a liquid back passage that connects the extractor and the evaporator and that flows a refrigerant liquid that has an amount equal to the refrigerant that was output from the evaporator and that was supplied to the extractor via the compressor and the ejector.

FIG. 1

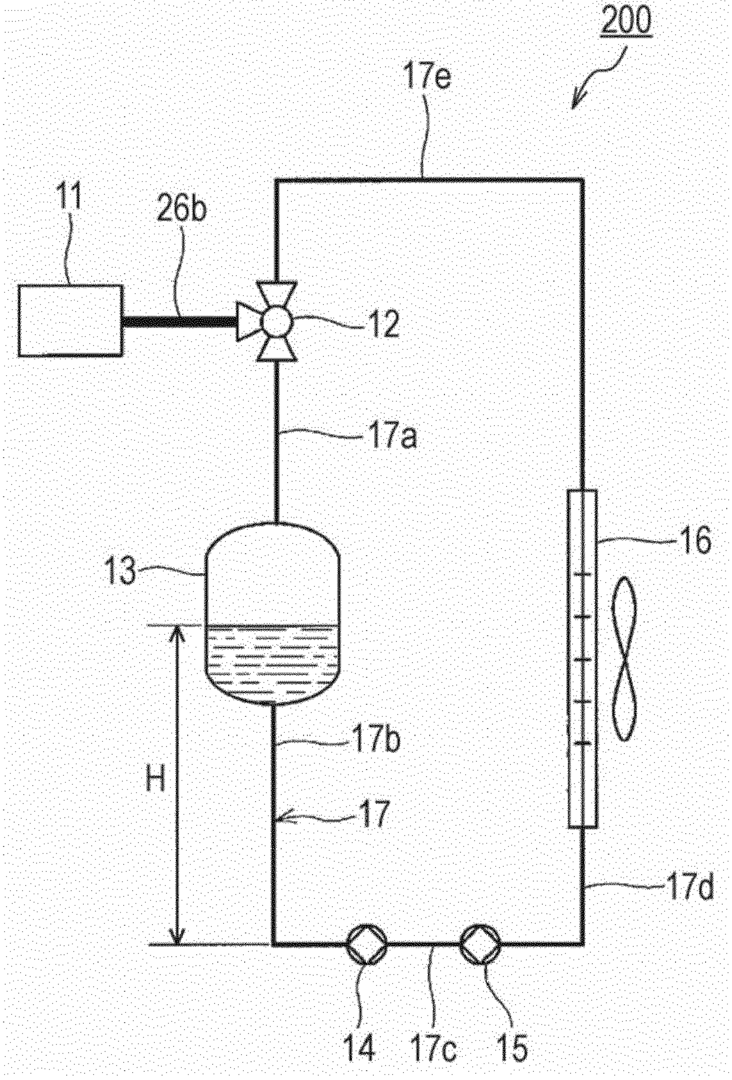


FIG. 2

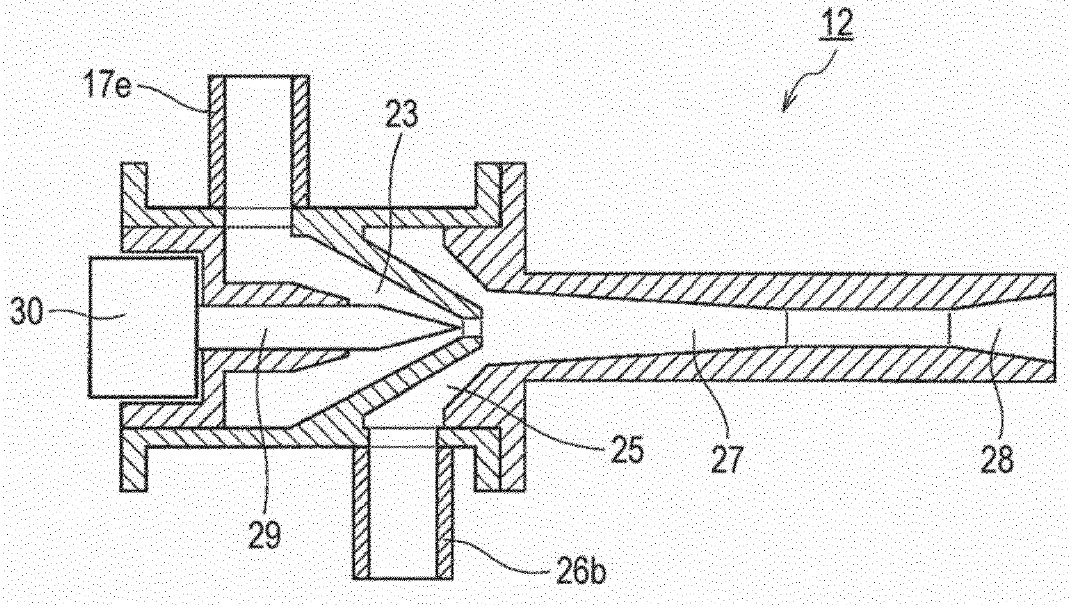


FIG. 3

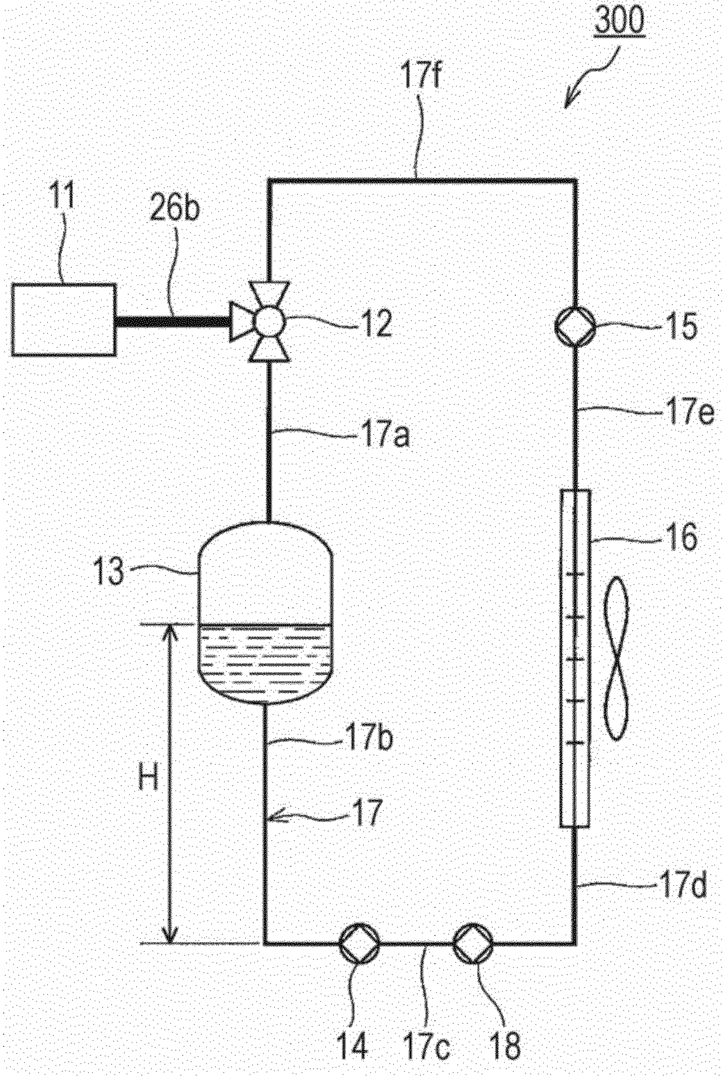


FIG. 4

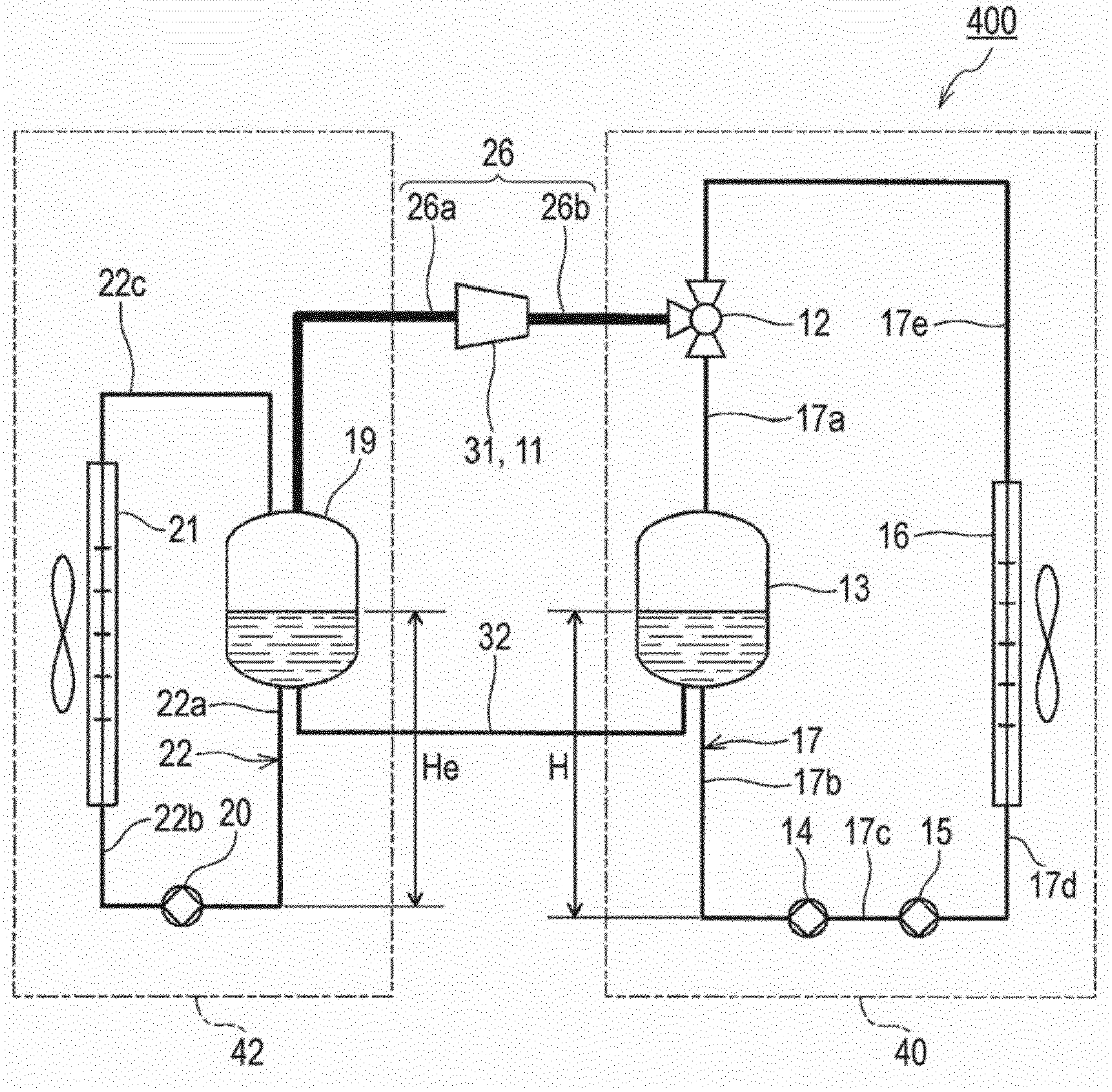
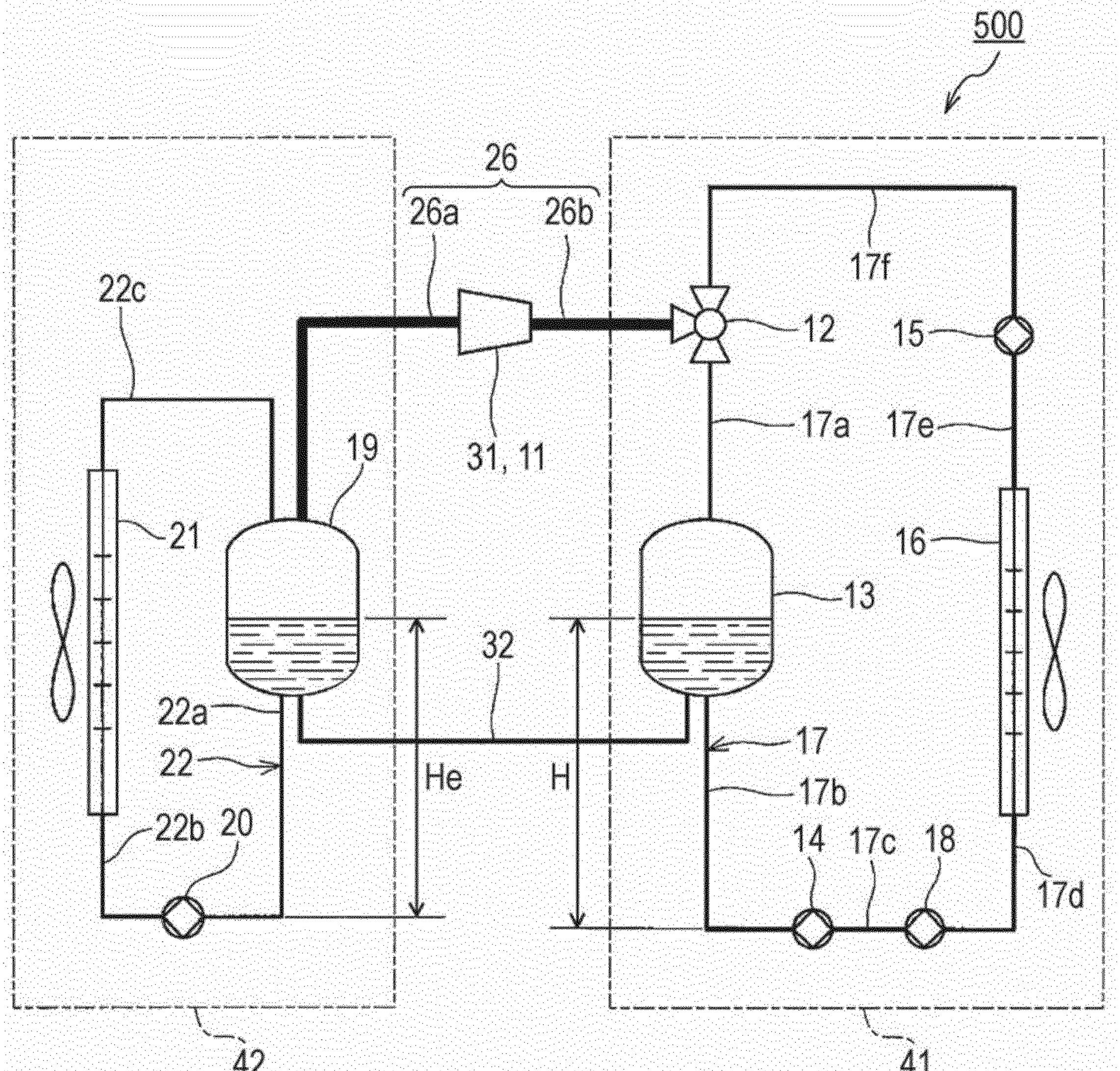

400
26
26a
26b
22c
12
17e
17a
19
31, 11
21
16
13
32
22a
17
22
He
H
17b
22b
20
14
17c
15
17d
42
40

FIG. 5


500
26
26a
26b
22c
12
15
17f
31, 11
19
17a
17e
21
16
13
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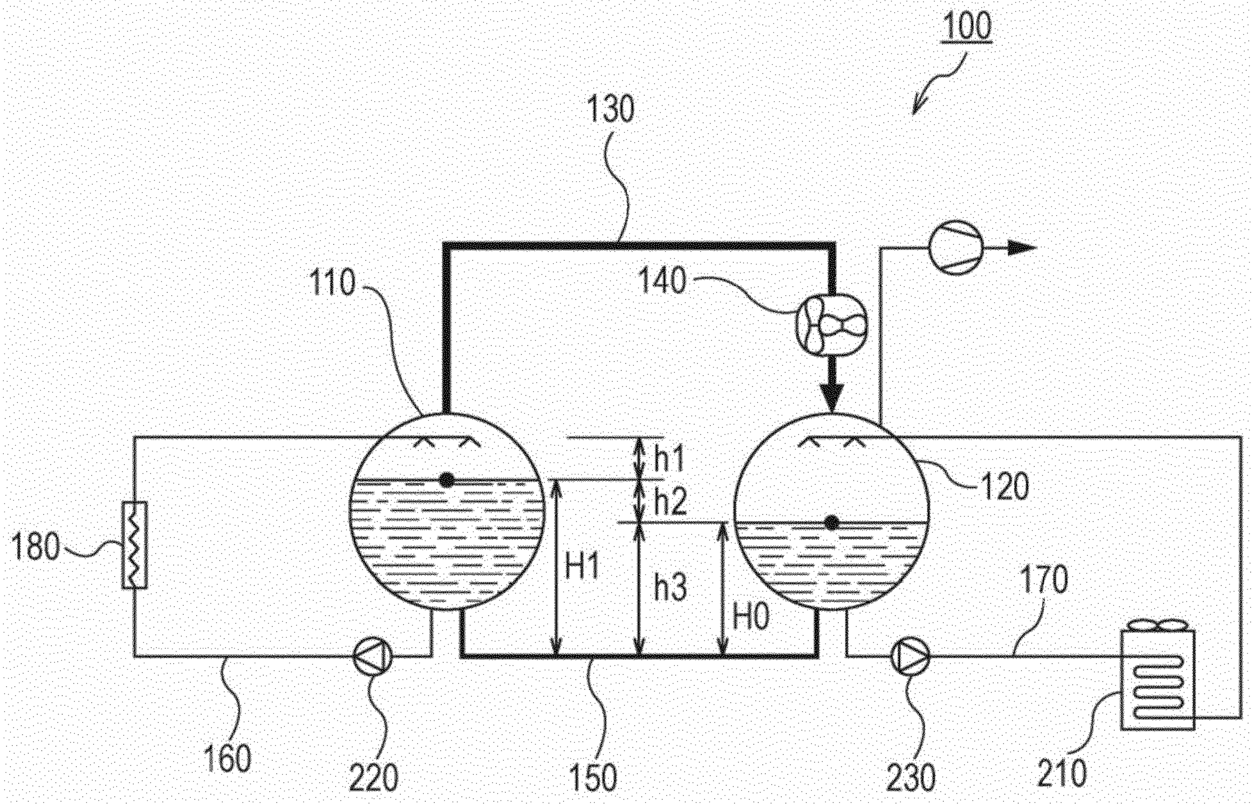
17
22
He
H
17b
22b
20
14
17c
18
17d
42
41

FIG. 6



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Application Number
EP 16 16 4946

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| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
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| | | | F25B |

The present search report has been drawn up for all claims

2

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 8 November 2016 | Lucic, Anita |

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EPO FORM 1503 03.82 (P04C01)

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