DESCRIPTION

REFRIGERATION APPARATUS AND TEMPERATURE REGULATION SYSTEM

Technical Field

[0001]

An embodiment of the present invention relates to a multiple-type refrigeration apparatus comprising a plurality of refrigeration circuits, and a temperature regulation system.

Background Art

[0002]

A binary refrigeration apparatus (cascade refrigeration apparatus), which is an example of the multiple-type refrigeration apparatus, comprises a high-temperature-side refrigeration circuit and a low-temperature-side refrigeration circuit, wherein an evaporator of the high-temperature-side refrigeration apparatus and a condenser of the low-temperature-side refrigeration circuit constitute a cascade condenser capable of exchanging heat with each other. In the cascade condenser, a high-temperature-side refrigerant, which has been condensed and expanded in the high-temperature-side refrigeration circuit, condenses a low-temperature-side refrigerant, which has been compressed in the low-temperature-side refrigeration circuit. The condensed low-temperature-side refrigerant is provided with a large degree of supercooling, and is then expanded to have a lower temperature. Thus, the binary refrigeration apparatus can cool a temperature of an object whose temperature is to be controlled (temperature control target) down to an extremely low

temperature range (JP 6727422 B).

Disclosure of The Invention

[0003]

Because of its two refrigeration circuits, the binary refrigeration apparatus usually has a larger size than a unitary refrigeration apparatus. The binary refrigeration apparatus has to use a compressor with a high flow rate and a high compression ratio, in order to obtain a high refrigeration capacity. This further increases the size, in addition to component cost and energy consumption.

[0004]

The present inventor has considered to obtain a desired refrigeration capacity by supplementarily cooling a low-temperature-side refrigerant having a high temperature and a high pressure, which has flowed out from the compressor of the low-temperature-side refrigeration circuit, by means of a cooler using water (water cooler herebelow) , while reducing the overall size and energy consumption of the apparatus. The use of water cooler can also reduce an impact given by the apparatus to the environment.

[0005]

However, when a refrigerant is evaporated at a cryogenic temperature such as -70°C or lower in the low-temperature-side refrigeration circuit, or when a high refrigeration capacity output is desired, an evaporator of the high-temperature-side refrigeration circuit has needs to have a large refrigeration capacity. In other words, the low-temperature-side refrigeration circuit must have a large condensation load. In this case, a water cooler does not contribute significantly to a desired

condensation load. Thus, when a cryogenic temperature or a high refrigeration capacity is required, a high-temperature-side refrigeration circuit having a large output or a large size is finally needed. Thus, it is difficult to effectively reduce an apparatus size and energy consumption, even by using the water cooler.

[0006]

In addition, a temperature of the water used in the water cooler vary depending on the season. Thus, it is necessary to adjust the refrigeration capacity required for the high-temperature-side refrigeration circuit depending on the temperature variation of the water used in the water cooler. The adjustment range of the refrigeration capacity in such a case should be as small as possible for a steady-state operation, in order to obtain control stability.

[0007]

The present inventor has also found that refrigerant circulation rates set for the high-temperature-side refrigeration circuit and the low-temperature-side refrigeration circuit have large impact on a stable output of a desired refrigeration capacity when the water cooler is used, reduction in energy consumption, reasonable setting of compressor capacity, and the apparatus size.

[0008]

The present inventor has conducted intensive research in consideration of the above problems and findings to find conditions under which a multiple-type refrigeration apparatus can stably and reliably have a desired refrigeration capacity with the use of a water cooler, while reducing increase in size, energy consumption and environmental impact.

[0009]

The object of the present invention is to provide a

refrigeration apparatus and a temperature regulation system capable of stably providing a desired refrigeration capacity, while reducing increase in size, energy consumption and environmental impact.

[0010]

A refrigeration apparatus according to one embodiment of the present invention comprises a high-temperature-side refrigeration circuit and a low-temperature-side refrigeration circuit, an evaporator of the high-temperature-side refrigeration circuit and a condenser of the low-temperature-side refrigeration circuit constituting a cascade condenser,

wherein the refrigeration apparatus comprises a water cooler that cools a low-temperature-side refrigerant circulated by the low-temperature-side refrigeration circuit, between a compressor and a condenser in the low-temperature-side refrigeration circuit, and

wherein the refrigeration apparatus performs an operation in such a manner that the following relationships are satisfied, $0.25 \times (CL+PA) \leq CW \leq 0.4 \times (CL+PA)$, and $0.6 \times (CL+PA) \leq CH \leq 0.75 \times (CL+PA)$, and $0.5 \times PA \leq CW$, and $F1 \leq F2$, wherein CL (Kw) represents a refrigeration capacity of an evaporator of the low-temperature-side refrigeration circuit, PA (Kw) represents compression power of a compressor of the low-temperature-side refrigeration circuit, CW (Kw) represents a cooling capacity of the water cooler, CH (Kw) represents a refrigeration capacity of an evaporator of the high-temperature-side refrigeration circuit, F1 (Kg/hour) represents a refrigerant circulation rate of the high-temperature-side refrigeration circuit, and F2 (Kg/hour) represents a refrigerant circulation rate of the low-temperature-side refrigeration circuit.

[0011]

The refrigeration apparatus according to the one embodiment may perform an operation in such a manner that a relationship of $0.5 \times F2 < F1 \leq 0.7 \times F2$ is satisfied.

[0012]

The refrigeration apparatus according to the one embodiment may perform an operation in such a manner that the refrigerant circulation rate F1 of the high-temperature-side refrigeration circuit is between 470 Kg/hour or more and 600 Kg/hour or less, and that the refrigerant circulation rate F2 of the low-temperature-side refrigeration circuit is between 880 or more Kg/hour and 920 Kg/hour or less.

[0013]

The water cooler may cool the low-temperature-side refrigerant by means of water in a range between 5°C or more and 28°C or less.

[0014]

The water cooler may flow water from a water source to cool the low-temperature-side refrigerant, without regulating a temperature of the water.

[0015]

The refrigeration capacity CL of an evaporator of the low-temperature-side refrigeration circuit may be 30 Kw or less.

[0016]

The refrigeration capacity CL of an evaporator of the low-temperature-side refrigeration circuit may be between 20 Kw or more and 30 Kw or less.

[0017]

The refrigeration capacity CL of an evaporator of the low-temperature-side refrigeration circuit may be between twice or

more and three times or less a lower limit value of the cooling capacity CW of the water cooler.

[0018]

In addition, the refrigeration apparatus according to the one embodiment may further provided with a low-temperature-side hot gas circuit which delivers a low-temperature-side refrigerant, which has flowed out from a compressor of the low-temperature-side refrigeration circuit and has not yet passed through the water cooler and a condenser of the low-temperature-side refrigeration circuit, to a part of the low-temperature-side refrigeration circuit, which is downstream of an expansion valve and upstream of an evaporator.

[0019]

In addition, a temperature regulation system according to one embodiment comprises the aforementioned refrigeration apparatus, and a fluid flow apparatus that flows a fluid to be cooled by an evaporator of the low-temperature-side refrigeration circuit.

[0020]

The present invention can stably provide a desired refrigeration capacity while reducing increase in size, energy consumption and environmental impact.

Brief Description of The Drawings

[0021]

Fig. 1 is a view schematically showing a temperature regulation system comprising a refrigeration apparatus according to one embodiment.

Fig. 2 is a Mollier diagram for explaining an operation state of a low-temperature-side refrigeration circuit constituting the

refrigeration apparatus shown in Fig. 1.

Mode for Carrying out the Invention

[0022]

One embodiment is described in detail herebelow with reference to the attached drawings.

[0023] <Structures of Temperature Regulation System and Refrigeration Apparatus>

Fig. 1 is a view showing a temperature regulation system S comprising a refrigeration apparatus 10 according to one embodiment. The temperature regulation system S shown in Fig. 1 comprises the refrigeration apparatus 10, a water supply apparatus 100, a fluid flow apparatus 200, and a controller 300.

[0024]

The refrigeration apparatus 10 is a binary refrigeration apparatus. The refrigeration apparatus 10 comprises a high-temperature-side refrigeration circuit 20 and a low-temperature-side refrigeration circuit 30. In the refrigeration apparatus 10, a cascade condenser CC is formed between the high-temperature-side refrigeration circuit 20 and the low-temperature-side refrigeration circuit 30, in which a high-temperature-side refrigerant circulated by the high-temperature-side refrigeration circuit 20 and a low-temperature-side refrigerant circulated by the low-temperature-side refrigeration circuit 30 exchange heat.

[0025]

The high-temperature-side refrigeration circuit 20 comprises a high-temperature-side refrigerant circulation unit 25, a supercooling circuit unit 26, and a high-temperature-side hot gas circuit unit 27. In the high-temperature-side refrigerant circulation unit 25, a high-temperature-side compressor 21, a

high-temperature-side condenser 22, a high-temperature-side expansion valve 23, and a high-temperature-side evaporator 24 are connected in this order such that a high-temperature-side refrigerant circulates therethrough.

[0026]

The supercooling circuit unit 26 has a supercooling flow path 26A, a supercooling control valve 26B provided on the supercooling flow path 26A, and a supercooling heat exchanger 26C provided downstream of the supercooling control valve 26B in the supercooling flow path 26A. The supercooling flow path 26A connects a part of the high-temperature-side refrigerant circulation unit 25, which is downstream of the high-temperature-side condenser 22 and upstream of the high-temperature-side expansion valve 23, and the high-temperature-side compressor 21.

[0027]

The supercooling flow path 26A can deliver a part of the high-temperature-side refrigerant having flowed out from the high-temperature-side condenser 22, to the high-temperature-side compressor 21. By opening the supercooling control valve 26B, the high-temperature-side refrigerant flowing through the supercooling flow path 26A is expanded to have a lower temperature. The high-temperature-side refrigerant is then delivered to the supercooling heat exchanger 26C.

[0028]

The supercooling heat exchanger 26C cools the high-temperature-side refrigerant, which flows from the high-temperature-side condenser 22 toward the high-temperature-side expansion valve 23, by means of the high-temperature-side refrigerant which has flowed out from the supercooling control

valve 26B. Thus, a degree of supercooling can be given to the high-temperature-side refrigerant flowing from the high-temperature-side condenser 22 toward the high-temperature-side expansion valve 23.

[0029]

The high-temperature-side hot gas circuit 27 has a high-temperature-side hot gas flow path 27A and a high-temperature-side hot gas control valve 27B provided on the high-temperature-side hot gas flow path 27A. The high-temperature-side hot gas flow path 27B connects a part of the high-temperature-side refrigerant circulation unit 25, which is downstream of the high-temperature-side compressor 21 and upstream of the high-temperature-side condenser 22, and a part of the high-temperature-side refrigerant circulation unit 25, which is downstream of the high-temperature-side expansion valve 23 and upstream of the high-temperature-side evaporator 24.

[0030]

The high-temperature-side hot gas flow path 27A can deliver the high-temperature-side refrigerant having flowed out from the high-temperature-side compressor 21, to a part which is downstream of the high-temperature-side expansion valve 23 and upstream of the high-temperature-side evaporator 24. By opening the high-temperature-side hot gas control valve 27B, the high-temperature-side refrigerant flowing through the high-temperature-side hot gas flow path 27A and the high-temperature-side refrigerant having flowed out from the high-temperature-side expansion valve 23 can be mixed.

[0031]

The high-temperature-side refrigeration circuit 30 comprises a low-temperature-side refrigerant circulation unit 35,

a low-temperature-side hot gas circuit unit 36, and an injection circuit unit 37. In the low-temperature-side refrigerant circulation unit 35, a low-temperature-side compressor 31, a low-temperature-side condenser 32, a low-temperature-side expansion valve 33, and a low-temperature-side evaporator 34 are connected in this order such that a low-temperature-side refrigerant circulates therethrough.

[0032]

The low-temperature-side hot gas circuit 36 has a low-temperature-side hot gas flow path 36A, and a low-temperature-side hot gas control valve 36B provided on the low-temperature-side hot gas flow path 36A. The low-temperature-side hot gas flow path 26A connects a part of the low-temperature-side refrigerant circulation unit 35, which is downstream of the low-temperature-side compressor 31 and upstream of the low-temperature-side condenser 32, and a part of the low-temperature-side refrigerant circulation unit 35, which is downstream of the low-temperature-side expansion valve 33 and upstream of the low-temperature-side evaporator 34.

[0033]

The low-temperature-side hot gas flow path 36A can deliver the low-temperature-side refrigerant, which has flowed out from the low-temperature-side compressor 31, to a part which is downstream of the low-temperature-side expansion valve 33 and upstream of the low-temperature-side evaporator 23. By opening the low-temperature-side hot gas control valve 36B, the low-temperature-side refrigerant flowing through the low-temperature-side hot gas flow path 36A and the low-temperature-side refrigerant having flowed out from the low-temperature-side expansion valve 33 can be mixed.

[0034]

The injection circuit unit 37 has an injection flow path 37A, and an injection control valve 37B provided on the injection flow path 37A. The injection flow path 37A connects a part of the low-temperature-side refrigerant circulation unit 35, which is downstream of the low-temperature-side condenser 32 and upstream of the low-temperature-side expansion valve 33, and a part of the low-temperature-side refrigerant circulation unit 35, which is downstream of the low-temperature-side evaporator 34 and upstream of the low-temperature-side compressor 31.

[0035]

The injection flow path 37A can deliver the low-temperature-side refrigerant having flowed out from the low-temperature-side condenser 32, to a part which is downstream of the low-temperature-side evaporator 34 and upstream of low-temperature-side compressor 31. By opening the injection control valve 37A, the low-temperature-side refrigerant flowing through the injection flow path 37A and the low-temperature-side refrigerant having flowed out from the low-temperature-side evaporator 34 can be mixed.

[0036]

The aforementioned cascade condenser CC is constituted by the high-temperature-side evaporator 24 of the high-temperature-side refrigeration circuit 20 and the low-temperature-side condenser 32 of the low-temperature-side refrigeration circuit 30. In the cascade condenser CC, the high-temperature-side refrigerant, which has been expanded by the high-temperature-side expansion valve 23 to have a low temperature and a low pressure, and the low-temperature-side refrigerant, which has flowed out from the low-temperature-side

compressor 31, exchange heat. This allows the low-temperature-side refrigerant flowing out from the cascade condenser CC to be condensed. Then, the condensed low-temperature-side refrigerant is expanded in the low-temperature-side expansion valve 33 to have a low temperature and a low pressure, and thereafter flows into the low-temperature-side evaporator 34. Types of the high-temperature-side refrigerant and the low-temperature-side refrigerant are not particularly limited. For example, the high-temperature-side refrigerant may be R449A, and the low-temperature-side refrigerant may be R508B.

[0037]

The low-temperature-side refrigeration circuit 30 also comprises a water cooler 38. The water cooler 38 is a heat exchanger and receives therein water and the low-temperature-side refrigerant. The water cooler 38 cools, by means of the water flowing therein, the low-temperature-side refrigerant before it flows into the cascade condenser CC (low-temperature-side condenser 32). Namely, in the refrigeration apparatus 10, the low-temperature-side refrigerant having flowed out from the low-temperature-side compressor 31 is first cooled by the water cooler 38, and is then cooled by the cascade condenser CC. Thus, a large degree of supercooling is given to the low-temperature-side refrigerant. The low-temperature-side hot gas flow path 36A is configured to deliver the low-temperature-side refrigerant, which has flowed out from the low-temperature-side compressor 31 and has not yet passed through the water cooler 38 and the low-temperature-side condenser 32 (cascade condenser CC), to a part which is downstream of the low-temperature-side expansion valve 33 and upstream of the low-temperature-side

evaporator 34.

[0038]

The water used by the water cooler 38 is supplied from a water supply apparatus 100. The water supply apparatus 100 is connected to a water source 101 to deliver water in the water source 101 to the water cooler 38 and the high-temperature-side condenser 22. The water supply apparatus 100 has a water pump 102. By driving the water pump 102, the water is delivered to the water cooler 38 and the high-temperature-side condenser 22.

[0039]

The water source 101 may be, for example, a tap water supply, a factory water supply, a well, or a tank holding water. The water supply apparatus 100 in this embodiment does not have a device for regulating a temperature of the water, in consideration of energy saving. Namely, the water cooler 38 flows the water, without regulating a temperature of the water from the water source 101, to cool the low-temperature-side refrigerant. However, a water temperature regulator may be used.

[0040]

When the water source 101 is a tap water supply, a factory water supply, a well, or a tank holding water, a temperature of the water supplied by the water supply apparatus 100 may vary in many regions in a range between 5°C or more and 28°C or less, depending on the season. The water supply apparatus 100 may flow the water at a flow rate in a range between 10L/min or more and 25L/min or less. In this case, less power of the water pump 102 is needed, so that energy can be saved. In the case of the above flow rate range, a cooing capacity (Kw) of the water supply

apparatus 100 may vary in a range approximately between 10 Kw or more and 16 Kw or less due to seasonal factors.

[0041]

The illustrated water supply apparatus 100 has a first supply path 103A and a second supply path 103B which are bifurcated from the common water source 101. The water from the first supply path 103A is supplied to the water cooler 38, and the water from the second supply path 103B is supplied to the low-temperature-side condenser 22. A constant flow valve 104 is provided downstream of a water outlet of the water cooler 38. This controls a flow rate of the water flowing into the water cooler 38 to a predetermined value. A structure capable of adjusting a water flow rate by means of a valve may be employed.

[0042]

The fluid flow apparatus 200 flows a fluid which is cooled by the low-temperature-side refrigerant in the low-temperature-side evaporator 34 of the low-temperature-side refrigeration circuit 30. A fluid to be flowed may be brine, etc., but is not limited to any particular fluid.

[0043]

The fluid flow apparatus 200 has a circulation flow path 201 connected to the low-temperature-side evaporator 34, a three-way valve 202 which constitutes a part of the circulation flow path 201, a bypass flow path 203, and a circulation pump 204. The low-temperature-side evaporator 34 has a part through which the low-temperature-side refrigerant passes (low-temperature-side refrigerant passing part), and a part through which the fluid passes (fluid passing part). The circulation flow path 201 has an upstream flow path 201U connected to one opening of the fluid passing part of the low-temperature-side

evaporator 34, and a downstream flow path 201D connected to the other opening of the fluid passing part of the low-temperature-side evaporator 34.

[0044]

The three-way valve 202 has three ports. A part between two ports out of the three ports forms a part of the downstream flow path 201D. The bypass flow path 203 is connected to the remaining port of the three-way valve 202. The bypass flow path 203 connects the three-way valve 202 and the upstream flow path 201U. The circulation pump 204 is provided on the upstream flow path 201U. By driving the circulation pump 204, the fluid flows.

[0045]

In the fluid flow apparatus 200, the fluid which flows in response to the driving of the circulation pump 204 is cooled by the low-temperature-side refrigerant in the low-temperature-side evaporator 34, and the fluid having flowed out from the low-temperature-side evaporator 34 is delivered through the downstream flow path 201D to a not-shown temperature control target. Then, the fluid having passed through the temperature control target returns to the low-temperature-side evaporator 34 through the upstream flow path 201U. The three-way valve 202 can adjust a flow rate of the fluid, which returns to the low-temperature-side evaporator 34, and a flow rate of the fluid, which does not return to the low-temperature-side evaporator 34 but is bypassed to a part downstream of the low-temperature-side evaporator 34. This can adjust a mixture ratio of the fluid, which has been cooled in the low-temperature-side evaporator 34, and the fluid, which does not return to the low-temperature-side evaporator 34 but is bypassed to a part downstream of the low-

temperature-side evaporator 34. Thus, a temperature of the fluid to be delivered to the temperature control target can be quickly adjusted.

[0046]

The controller 300 controls the components of the refrigeration apparatus 10 and the components of the fluid flow apparatus 200. Specifically, the controller 300 can control a circulation rate (kg/hour) of the high-temperature-side refrigerant by controlling a driving state (rotating speed) of the high-temperature-side compressor 21. In addition, the controller 300 can control the opening/closing of the high-temperature-side hot gas control valve 27B, and an opening degree thereof. In addition, the control 300 can control a circulation rate (kg/hour) of the low-temperature-side refrigerant by controlling a driving sate (rotating speed) of the low-temperature-side compressor 31. In addition, the controller 300 can control the opening/closing of the low-temperature-side hot gas control valve 36B, and an opening degree thereof. In addition, the controller 300 can control the opening/closing of the injection control valve 37B, and an opening degree thereof.

[0047]

The controller 300 may be formed of a computer comprising a CPU, a ROM, a RAM, etc., for example, and may control operations of the above respective units in accordance with a stored program. Alternatively, the controller 300 may be formed of another processor or an electric circuit such as an FPGA (Field Programmable Gate Alley), etc.

[0048] <Operating Conditions>

Next, operating conditions of the refrigeration apparatus 10 in this embodiment are described.

Namely, the refrigeration apparatus 10 in this embodiment performs an operation in such a manner that the following relationships are satisfied, "$0.25 \times (CL+PA) \leq CW \leq 0.4 \times (CL+PA)$, and $0.6 \times (CL+PA) \leq CH \leq 0.75 \times (CL+PA)$, and $0.5 \times PA \leq CW$, and $F1 \leq F2$", wherein CL (Kw) represents a refrigeration capacity of the low-temperature-side evaporator 34 of the low-temperature-side refrigeration circuit 30, PA (Kw) represents compression power of the low-temperature-side compressor 31 of the low-temperature-side refrigeration circuit 30, CW (Kw) represents a cooling capacity of the water cooler 38, CH (Kw) represents a refrigeration capacity of the high-temperature-side evaporator 24 of the high-temperature-side refrigeration circuit 20, F1 (Kg/hour) represents a refrigerant circulation rate of the high-temperature-side refrigeration circuit 20, and F2 (Kg/hour) represents a refrigerant circulation rate of the low-temperature-side refrigeration circuit 30.

[0049]

In particular, regarding the refrigerant circulation rate F1 of the high-temperature-side refrigeration circuit 20 and the refrigerant circulation rate F2 of the low-temperature-side refrigeration circuit 30, the operation is desirably performed in such a manner that the following relationship is satisfied, $0.5 \times F2 < F1 \leq 0.7 \times F2$. Specifically, when the refrigeration capacity CL of the low-temperature-side evaporator 34 of the low-temperature-side refrigeration circuit 30 is 30 Kw or less, in detail, between 20 Kw or more and 30 Kw or less, for example, the operation may be performed in such a manner that the refrigerant circulation rate F1 of the high-temperature-side refrigeration circuit 20 is between 400 Kg/hour or more and 800 Kg/hour or less, and that the refrigerant circulation rate F2 of the low-

temperature-side refrigeration circuit 30 is between 780 Kg/hour or more and 1400 Kg/hour or less.

[0050]

More specifically, when the refrigeration capacity CL of the low-temperature-side evaporator 34 is between 20 Kw or more and 24 Kw or less, for example, in the "relationship of $0.5 \times F2 < F1 \leq 0.7 \times F2$", the operation may be performed in such a manner that the refrigerant circulation rate F1 of the high-temperature-side refrigeration circuit 20 is between 470 Kg/hour or more and 600 Kg/hour or less, and that the refrigerant circulation rate F2 of the low-temperature-side refrigeration circuit 30 is between 880 Kg/hour or more and 920 Kg/hour or less. It goes without saying that these numerical conditions are mere examples, and the present invention is not limited to such conditions.

[0051]

Fig. 2 is a Mollier diagram for explaining an operation state of the low-temperature-side refrigeration circuit 30. Referring to Fig. 2, in the low-temperature-side refrigeration circuit 30, in a transition shown by an arrow from 1 to 2, the low-temperature-side compressor 31 compresses the low-temperature-side refrigerant. In a transition shown by an arrow from 2 to 3, the low-temperature-side refrigerant is cooled by the water cooler 38. In a transition shown by an arrow from 3 to 4, the low-temperature-side refrigerant is cooled by the high-temperature-side refrigerant in the cascade condenser CC. In a transition shown by the arrow from 4 to 5, the low-temperature-side refrigerant is expanded by the low-temperature-side expansion valve 33 into a gas-liquid mixture state to have a low pressure and a low temperature. In a transition shown by an arrow from 5 to 1, the low-temperature-side refrigerant and the fluid flowed

by the fluid flow apparatus 200 exchange heat.

[0052]

Fig. 2 shows ranges respectively corresponding to the refrigeration capacity CL (Kw) of the low-temperature-side evaporator 34 of the low-temperature-side refrigeration circuit 30, the compression power PA (Kw) of the low-temperature-side compressor 31 of the low-temperature-side refrigeration circuit 30, the cooling capacity CW (Kw) of the water cooler 38, the refrigeration capacity CH (Kw) of the evaporator of the high-temperature-side refrigeration circuit 20, which are used in the operating conditions.

The compression power PA is calculated as $F2 \times (h2 - h1)$, wherein F2 represents the refrigerant circulation rate of the low-temperature-side refrigerant, h1 represents a specific enthalpy at a point "1" in Fig. 2, and h2 represents a specific enthalpy at a point "2" in Fig. 2.

In the calculation of the compression power PA in this specification, the specific enthalpy h1 is obtained as follows. A type of the low-temperature-side refrigerant is determined. A pressure and a temperature of the low-temperature-side refrigerant, which has flowed out from the low-temperature-side evaporator 34 and has not yet flowed into the low-temperature-side compressor 31, are measured by a sensor. By specifying the positions of the pressure and the temperature of the measured low-temperature-side refrigerant on the Mollier diagram (p-h diagram, refrigerant property data) corresponding to the low-temperature-side refrigerant, the specific enthalpy h1 is obtained.

The specific enthalpy h2 is obtained as follows. A type of the low-temperature-side refrigerant is determined. A pressure

and a temperature of the low-temperature-side refrigerant, which has flowed out from the low-temperature-side compressor 31 and has not yet flowed into the water cooler 38, are measured by a sensor. By specifying the positions of the pressure and the temperature of the measured low-temperature-side refrigerant on the Mollier diagram (p-h diagram, refrigerant property data) corresponding to the low-temperature-side refrigerant, the specific enthalpy h2 is obtained.

[0053]

The aforementioned operating conditions are realized by the controller 300 which mainly controls a driving state (rotating speed) of the high-temperature-side compressor 21, and a driving state (rotating speed) of the low-temperature-side compressor 31. When the operation is performed in these operating conditions, the refrigeration apparatus 10 can provide a desired refrigeration capacity while reducing increase in size, energy consumption and environmental impact. This is described in detail below.

[0054]

First, in the relationships of "$0.25 \times (CL+PA) \leq CW \leq 0.4 \times (CL+PA)$, and $0.6 \times (CL+PA) \leq CH \leq 0.75 \times (CL+PA)$", a condensation load (CL+PA) required by the low-temperature-side refrigeration circuit 30 is specified by the refrigeration capacity CL of the low-temperature-side evaporator 34 plus the compression power PA of the low-temperature-side compressor 31. The above relationship specifies that a burden ratio of the cooling capacity CW (Kw) of the water cooler 38 in the condensation load (CL+PA) is between 25% or more and 40% or less. This burden ratio of the cooling capacity CW (Kw) of the water cooler 38 is an effective condition in terms of increasing

the refrigeration capacity CL of the low-temperature-side evaporator 34 as much as possible, while reducing the size of the high-temperature-side compressor 21, the overall size of the high-temperature-side refrigeration circuit 20, as well as energy consumption and environmental impact, and improving stability in temperature control.

[0055]

Namely, when the burden ratio of the cooling capacity CW (Kw) of the water cooler 38 is excessively high, e.g., 60% or more, the low-temperature-side refrigerant to be condensed cannot be sufficiently supercooled, making it difficult to increase the refrigeration capacity CL of the low-temperature-side evaporator 34. On the other hand, when the burden ratio of the cooling capacity CW (Kw) of the water cooler 38 is excessively low, e.g., 10% or less, cooling of the water cooler 38 does not function effectively, whereby a high performance high-temperature-side compressor needs to be used. From such a viewpoint, the fact that the burden ratio of the cooling capacity CW (Kw) of the water cooler 38 is between 25% or more and 40% or less is advantageous in terms of increasing the refrigeration capacity CL of the low-temperature-side evaporator 34 as much as possible, while reducing the size of the high-temperature-side compressor 21 and the overall size of the high-temperature-side refrigeration circuit 20. In addition, the cooing capacity CW of the water cooler 38 bears a relatively large range in the required condensation load without requiring compression power, which is advantageous in terms of reducing energy consumption and environmental impact.

[0056]

When the burden ratio of the cooling capacity CW (Kw) of

the water cooler 38 varies in a range between 25% or more and 40% or less, the refrigeration capacity CH of the high-temperature-side evaporator 24 of the high-temperature-side refrigeration circuit 20 varies in a range between 60% or more and 75% or less with respect to the condensation load (CL+PA). At this time, when the refrigeration capacity of 60% with respect to the condensation load (CL+PA) is assumed as a standard operating condition, a change ratio of the refrigeration capacity CH with respect to the maximum variation of the cooling capacity CW of the water cooler 38 is 25%. Thus, in a case where the burden ratio of the cooling capacity CW (Kw) of the water cooler 38 is between 25% or more and 40% or less, there is no need to largely adjust the refrigeration capacity CH of the high-temperature-side evaporator 24 of the high-temperature-side refrigeration circuit 20 even if the cooling capacity CW (Kw) of the water cooler 38 varies. In this case, since the use drive range of the high-temperature-side compressor 21 can be made narrow, the high-temperature-side compressor 21 can be operated only within a desirable operating range for stability. In addition, it is not necessary for the compressor to have excessively high performance. This is advantageous in terms of temperature control stability.

[0057]

Next, the relationship "$0.5 \times PA \leq CW$" specifies that a ratio of the cooling capacity CW (Kw) of the water cooler 38 with respect to the compression power PA (Kw) of the low-temperature-side compressor 31 is relatively large. Namely, the relationship specifies that the ratio of the cooling capacity CW (Kw) of the water cooler 38 with respect to the compression power PA (Kw) of the low-temperature-side compressor 31 is half

or more of the compression power PA (Kw) of the low-temperature-side compressor 31. Similarly to the above, this relationship means that the cooling capacity CW (Kw) of the water cooler 38 bears a relative large range in the required condensation load. In addition, an apparatus protection function can be obtained when the high-temperature-side refrigeration circuit 20 fails or stops. Namely, even if the high-temperature-side refrigeration circuit 20 fails or stops, the cooling capacity CW (Kw) of the water cooler, which is equal to "0.5 × PA" or more, has an ability to cancel out half or more of the compression power PA of the low-temperature-side compressor 31, so that the low-temperature-side refrigerant can be cooled relatively early to protect a pipe, etc. The relationship of "0.5 × PA ≤ CW" is advantageous from this viewpoint.

[0058]

The relationship of "F1 ≤ F2" means that the refrigerant circulation rate F1 (Kg/hour) of the high-temperature-side refrigeration circuit 20 is equal to or less than the refrigerant circulation rate F2 (Kg/hour) of the low-temperature-side refrigeration circuit 30. In a binary refrigeration apparatus, a refrigerant circulation rate of a high-temperature-side refrigeration circuit is usually larger than a refrigerant circulation rate of a low-temperature-side refrigeration circuit. On the other hand, in this embodiment, the refrigerant circulation rate F1 (Kg/hour) of the high-temperature-side refrigeration circuit 20 is equal to or less than the refrigerant circulation rate F2 (Kg/hour) of the low-temperature-side refrigeration circuit 30. This is advantageous in reducing size and cost of the high-temperature-side refrigeration circuit 20. In particular, the refrigeration apparatus 10, which is configured to operate in such

a manner that a relationship of $0.5 \times PA < F1 \leq 0.7 \times F2$ is satisfied, is significantly advantageous in reducing size and cost.

[0059]

For example, as described above, when the refrigeration capacity CL of the low-temperature-side evaporator 34 is between 20 Kw or more and 24 Kw or less, the refrigeration apparatus 10 may be operated in such a manner that the refrigerant circulation amount F1 of the high-temperature-side refrigeration circuit 20 is between 470 Kg/hour or more and 600 Kg/hour or less, and that the refrigerant circulation rate F2 of the low-temperature-side refrigeration circuit 30 is between 880 Kg/hour or more and 920 Kg/hour or less. The refrigerant circulation rate F1 of the high-temperature-side refrigeration circuit 20 in this numerical condition is extremely low, which is not employed in a high-temperature-side refrigeration circuit of a general binary refrigeration apparatus of between 20 Kw or more and 24 Kw or less. In this embodiment, the use of the water cooler 38 allows such an extremely small value of the circulation rate. When the relationship of $0.5 \times F2 < F1 \leq 0.7 \times F2$ is satisfied, specifically, when the refrigerant circulation rate F1 of the high-temperature-side refrigeration circuit 20 is set to be extremely low, the high-temperature-side refrigeration circuit 20 can have an effectively small size. Namely, a liquid receiver can be omitted, or a liquid receiver with only a small volume can be used. This is advantageous in reducing size and cost of the high-temperature-side refrigeration circuit 20.

The binary refrigeration apparatus is usually configured such that a high-temperature-side refrigeration circuit and a low-temperature-side refrigeration circuit are accommodated in one housing. At this time, in this embodiment, a pipe member and

so on of the water supply apparatus 100 that introduces water into the water cooler 38 may also be accommodated in the same housing. In this case, when the high-temperature-side refrigeration circuit 20 has a large size, it is difficult to arrange the pipe member and so on of the water supply apparatus 100 efficiently in terms of space. However, in this embodiment, the high-temperature-side refrigeration circuit 20 is downsized because of a reduced amount of the high-temperature-side refrigerant to be used, whereby the apparatus can easily have a small size as a whole. The refrigeration capacity CL of the low-temperature-side evaporator 34 of the low-temperature-side refrigeration circuit 30 may be between twice or more and three times or less a lower limit value of the cooling capacity CW of the water cooler 38. This provides improved operation capacity and temperature control capacity, while the water cooler 38 effectively functions. The present inventor has come to find such conditions through various simulations and experiments.

[0060]

As described above, the refrigeration apparatus 10 in this embodiment is operated in such a manner that the following relationships are satisfied, "$0.25 \times (CL+PA) \leq CW \leq 0.4 \times (CL+PA)$, and $0.6 \times (CL+PA) \leq CH \leq 0.75 \times (CL+PA)$, and $0.5 \times PA \leq CW$, and $F1 \leq F2$", wherein CL (Kw) represents a refrigeration capacity of the low-temperature-side evaporator 34 of the low-temperature-side refrigeration circuit 30, PA (Kw) represents compression power of the low-temperature-side compressor 31 of the low-temperature-side refrigeration circuit 30, CW (Kw) represents a cooling capacity of the water cooler 38, CH (Kw) represents a refrigeration capacity of the high-temperature-side evaporator 24 of the high-temperature-side

refrigeration circuit 20, F1 (Kg/hour) represents a refrigerant circulation rate of the high-temperature-side refrigeration circuit 20, and F2 (Kg/hour) represents a refrigerant circulation rate of the low-temperature-side refrigeration circuit 30. This can stably provide a desired refrigeration capacity while reducing increase in size, energy consumption and environmental impact.

[0061]

In particular, regarding the refrigerant circulation rate F1 of the high-temperature-side refrigeration circuit 20 and the refrigerant circulation rate F2 of the low-temperature-side refrigeration circuit 30, the operation is desirably performed in such a manner that the relationship of $0.5 \times F2 < F1 \leq 0.7 \times F2$ is satisfied. This is advantageous in reducing size and cost of the high-temperature-side refrigeration circuit 20. Namely, in this embodiment, a pipe member and so on of the water supply apparatus 100 that introduces water into the water cooler 38 may be accommodated in a housing where the high-temperature-side refrigeration circuit 20 and the low-temperature-side refrigeration circuit 30 are accommodated. In this case, when the high-temperature-side refrigeration circuit 20 has a large size, it is difficult to arrange the pipe member and so on of the water supply apparatus 100 efficiently in terms of space. However, in this embodiment, the high-temperature-side refrigeration circuit 20 is downsized because of a reduced amount of the high-temperature-side refrigerant to be used, whereby the apparatus can easily have a small size as a whole. In detail, the high-temperature-side refrigeration circuit 20 and the low-temperature-side refrigeration circuit 30 are connected to form the cascade condenser CC, and the water cooler 38 is located in the vicinity thereof. When the refrigerant circulation rates of the

high-temperature-side refrigeration circuit 20 and the low-temperature-side refrigeration circuit 30 satisfy the above relationship, the low-temperature-side refrigeration circuit 30 is designed to be larger than the high-temperature-side refrigeration circuit 30 in the general design. In this case, a pipe and so on of the water supply apparatus 100 can be disposed in a space where the high-temperature-side refrigeration circuit 20 is recessed with respect to the low-temperature-side refrigeration circuit 30.

[0062]

The embodiment of the present invention has been described above, but the present invention is not limited to the above embodiment. For example, although the refrigeration apparatus 10 in the above embodiment is a binary refrigeration apparatus, the present invention can be applied to a tertiary refrigeration apparatus. In this case, a refrigerant circulated by a middle-temperature-side refrigeration circuit and/or a refrigerant circulated by a low-temperature-side refrigeration circuit is cooled by the water cooler 38.

CLAIMS

1. A refrigeration apparatus comprising a high-temperature-side refrigeration circuit and a low-temperature-side refrigeration circuit, an evaporator of the high-temperature-side refrigeration circuit and a condenser of the low-temperature-side refrigeration circuit constituting a cascade condenser,

wherein the refrigeration apparatus comprises a water cooler that cools a low-temperature-side refrigerant circulated by the low-temperature-side refrigeration circuit, between a compressor and the condenser in the low-temperature-side refrigeration circuit, and

wherein the refrigeration apparatus performs an operation in such a manner that the following relationships are satisfied, $0.25 \times (CL+PA) \leq CW \leq 0.4 \times (CL+PA)$, and $0.6 \times (CL+PA) \leq CH \leq 0.75 \times (CL+PA)$, and $0.5 \times PA \leq CW$, and $F1 \leq F2$, wherein CL (Kw) represents a refrigeration capacity of an evaporator of the low-temperature-side refrigeration circuit, PA (Kw) represents compression power of the compressor of the low-temperature-side refrigeration circuit, CW (Kw) represents a cooling capacity of the water cooler, CH (Kw) represents a refrigeration capacity of the evaporator of the high-temperature-side refrigeration circuit, F1 (Kg/hour) represents a refrigerant circulation rate of the high-temperature-side refrigeration circuit, and F2 (Kg/hour) represents a refrigerant circulation rate of the low-temperature-side refrigeration circuit.

2. The refrigeration apparatus according to claim 1, wherein

the refrigeration apparatus performs an operation in such a manner that a relationship of $0.5 \times F2 < F1 \leq 0.7 \times F2$ is

satisfied.

3. The refrigeration apparatus according to claim 2, wherein

the refrigeration apparatus performs an operation in such a manner that the refrigerant circulation rate F1 of the high-temperature-side refrigeration circuit is between 470 Kg/hour or more and 600 Kg/hour or less, and that the refrigerant circulation rate F2 of the low-temperature-side refrigeration circuit is between 880 Kg/hour or more and 920 Kg/hour or less.

4. The refrigeration apparatus according to any of claims 1 to 3, wherein

the water cooler cools the low-temperature-side refrigerant by means of water in a range between 5°C or more and 28°C or less.

5. The refrigeration apparatus according to claim 1, wherein

the water cooler flows water from a water source, without regulating a temperature of the water, to cool the low-temperature-side refrigerant.

6. The refrigeration apparatus according to claim 1, wherein

the refrigeration capacity CL of the evaporator of the low-temperature-side refrigeration circuit is 30 Kw or less.

7. The refrigeration apparatus according to claim 6, wherein

the refrigeration capacity CL of the evaporator of the low-temperature-side refrigeration circuit is between 20 Kw or more and 30 Kw or less.

8. The refrigeration apparatus according to claim 1, wherein the refrigeration capacity CL of the evaporator of the low-temperature-side refrigeration circuit is between twice or more and three times or less a lower limit value of the cooling capacity CW of the water cooler.

9. The refrigeration apparatus according to claim 1, wherein the refrigeration apparatus is further provided with a low-temperature-side hot gas circuit, which delivers a low-temperature-side refrigerant, which has flowed out from the compressor of the low-temperature-side refrigeration circuit and has not yet passed through the water cooler and the condenser of the low-temperature-side refrigeration circuit, to a part of the low-temperature-side refrigeration circuit, which is downstream of an expansion valve and upstream of the evaporator.

10. A temperature regulation system comprising:
a refrigeration apparatus according to claim 1, and
a fluid flow apparatus that flows a fluid to be cooled by the evaporator of the low-temperature-side refrigeration circuit.