

REFRIGERATION APPARATUS

TECHNICAL FIELD

[0001] The present invention generally relates to the field of refrigeration apparatuses. This invention is concerned in particular with a refrigeration apparatus capable of performing operation with an optimum COP (coefficient of performance).

BACKGROUND ART

[0002] Refrigeration apparatuses, having a refrigerant circuit configured to circulate refrigerant to perform a vapor compression refrigeration cycle as disclosed in JP-A-2003-106609, have heretofore been known in the conventional technology. Some of these refrigeration apparatuses are provided with a refrigerant circuit in which a compressor, condenser, expansion valve and evaporator are connected. The opening of the expansion valve is controlled such that gas refrigerant having a predetermined degree of superheat is drawn into the compressor. This prevents the compressor from getting damaged by wet compression.

PROBLEMS THAT THE INVENTION INTENDS TO SOLVE

[0003] In the known refrigeration apparatuses, superheated, high-temperature gas refrigerant is thus drawn into the compressor, which causes a rise in discharge temperature and therefore a drop in the efficiency of the compressor. This is not an optimum situation for the refrigeration apparatuses in the light of the coefficient of performance (COP).

[0004] Normally, drawing of refrigerant in a wet state into a compressor does not make any difference to the compressor as far as it does not get damaged, but the known compressors are designed to draw excessively dried refrigerant for safety reasons.

[0005] After making researches on the relationship between the dryness fraction (wet state) of refrigerant drawn into a compressor and the coefficient of performance, the inventors have found the dryness fraction (wet state) of refrigerant that makes the coefficient of performance optimum. Accordingly, a primary object of the invention is to

enable drawing of refrigerant in a proper wet state into a compressor, which wet state provides the maximum or substantially maximum coefficient of performance, so that energy saving operation is realized.

DISCLOSURE OF THE INVENTION

[0006] The present invention provides the following aspects.

[0007] The present invention provides, as a first aspect, a refrigeration apparatus comprising a refrigerant circuit (20) for performing a refrigeration cycle which circuit includes a compressor (31). This apparatus is configured such that refrigerant in a wet state, which provides an optimum coefficient of performance (COP) for a present operating state, is drawn into the compressor (31).

[0008] In the apparatus constructed according to the first aspect, the refrigerant circulates to perform a vapor compression refrigeration cycle in the refrigerant circuit (20). And, as illustrated in Figs. 3, 4, the high pressure and low pressure of the refrigeration cycle, the compression efficiency of the compressor (31) and others, for instance, are set as operating conditions for every operating state and the dryness fraction (wet state) of the refrigerant which provides the optimum coefficient of performance (COP) for each operating state is set. Since the refrigerant having the set dryness fraction is drawn into the compressor (31), the refrigeration apparatus will perform operation with the best coefficient of performance without fail.

[0009] The present invention provides, as a second aspect, a refrigeration apparatus comprising the refrigerant circuit (20) for performing a refrigeration cycle which circuit includes the compressor (31). This apparatus is configured such that the refrigerant in a superheated state is drawn into the compressor (31) during a cooling operation mode and the refrigerant in a wet state is drawn into the compressor (31) during a heating operation mode.

[0010] In the apparatus constructed according to the second aspect, the refrigerant circulates to perform a vapor compression refrigeration cycle in the refrigerant circuit (20).

At least when operating in a normal heating operation mode, the refrigerant in a wet state, i.e., having a dryness fraction of less than 1.00 is constantly drawn into the compressor (31). Therefore, the coefficient of performance (COP) remarkably increases compared to the case where superheated refrigerant having a dryness fraction of 1.00 or more is drawn, as seen from the result of simulation shown in Figs. 3, 4. As a result, the refrigeration apparatus can perform energy saving operation. Further energy saving can be achieved by drawing the refrigerant into the compressor (31), the refrigerant having the optimum dryness fraction that is varied according to operating states so as to provide the maximum coefficient of performance.

[0011] The invention provides, as a third aspect, a refrigeration apparatus comprising the refrigerant circuit (20) for performing a refrigeration cycle which circuit includes the compressor (31). The above apparatus is configured such that a target discharge temperature for the compressor (31) is set so as to obtain the optimum coefficient of performance (COP) for a present operating state and the refrigerant in a wet state, which makes the discharge temperature of the compressor (31) equal to the target discharge temperature, is drawn into the compressor (31).

[0012] In the apparatus constructed according to the third aspect, the refrigerant circulates to perform a vapor compression refrigeration cycle in the refrigerant circuit (20). A target discharge temperature for the compressor (31) that provides the optimum coefficient of performance is set according to a given set of operating conditions which include the high pressure and low pressure of the refrigeration cycle, the compression efficiency of the compressor (31), etc. More specifically, since the discharge temperature of the compressor (31) drops with decreases in the dryness fraction of the refrigerant and rises with increases in the dryness fraction of the refrigerant, the discharge temperature of the compressor (31) is determined in accordance with the dryness fraction of the refrigerant under each set of operating conditions. It is understood from this that as shown in Figs. 3, 4, the dryness fraction (wet state) of the refrigerant that provides the optimum coefficient of

performance is determined for each set of operating conditions and the target discharge temperature for the compressor (31) that corresponds to this dryness fraction of the refrigerant is set. Therefore, operation can be performed with the optimum coefficient of performance without fail by drawing, into the compressor (31), the refrigerant having a dryness fraction that makes the discharge temperature of the compressor (31) equal to a target discharge temperature.

[0013] In the apparatuses according to the first to third aspects, since the refrigerant in a wet state is drawn into the compressor (31), the discharge temperature of the compressor (31) more significantly drops, compared to the case where refrigerant in a superheated state is drawn. Therefore, abnormal heating of the motor of the compressor (31) can be avoided and deterioration of the refrigerating machine fluid due to high temperature can be restrained. This leads to an increase in the reliability of the compressor (31).

[0014] The invention provides, as a fourth aspect, the refrigeration apparatus according to any one of the first to third aspects, wherein the refrigerant circuit (20) is provided with an expansion valve (23). This apparatus is configured such that the wet state of a suction refrigerant of the compressor (31) is controlled by adjusting the opening of the expansion valve (23).

[0015] In the apparatus constructed according to the fourth aspect, when increasing the wetness fraction of the suction refrigerant of the compressor (31), that is, when decreasing the dryness fraction of the suction refrigerant, the opening of the expansion valve (23) is increased thereby increasing the amount of refrigerant to be supplied to the evaporator. This increases the amount of refrigerant which cannot be evaporated by the evaporator so that refrigerant in a wetter state is drawn into the compressor (31). On the other hand, when decreasing the wetness fraction of the suction refrigerant of the compressor (31), that is, when increasing the dryness fraction of the suction refrigerant, the opening of the expansion valve (23) is reduced thereby reducing the amount of refrigerant to be supplied to the evaporator. This reduces the amount of refrigerant which cannot be evaporated by the

evaporator so that refrigerant in a less wet state is drawn into the compressor (31). Accordingly, the dryness fraction of the refrigerant which provides the maximum coefficient of performance is set according to operating conditions and the opening of the expansion valve (23) is adjusted according to the set dryness fraction, whereby energy saving operation which provides the maximum coefficient of performance corresponding to each set of operating conditions can be performed.

[0016] The invention provides, as a fifth aspect, the refrigeration apparatus according to any one of the first to third aspects, wherein the refrigerant circuit (20) has a gas-liquid separator (25) disposed between evaporators (22, 24) and the suction side of the compressor (31). In addition, the gas-liquid separator (25) includes a liquid injection pipe (26) having a flow rate control valve (27), for guiding liquid refrigerant from the gas-liquid separator (25) to the suction side of the compressor (31). This apparatus is further configured such that the wet state of the suction refrigerant of the compressor (31) is controlled by adjusting the flow rate control valve (27).

[0017] In the apparatus constructed according to the fifth aspect, when increasing the wetness fraction of the suction refrigerant of the compressor (31) for instance, that is, when reducing the dryness fraction of the suction refrigerant, the opening of the flow rate control valve (27) is increased thereby increasing the flow rate of the liquid refrigerant to be drawn into the compressor (31). On the other hand, when reducing the wetness fraction of the suction refrigerant of the compressor (31), that is, when increasing the dryness fraction of the suction refrigerant, the opening of the flow rate control valve (27) is reduced thereby reducing the flow rate of the liquid refrigerant to be drawn into the compressor (31). Accordingly, the dryness fraction of the refrigerant which provides the maximum coefficient of performance is set according to operating conditions and the opening of the flow rate control valve (27) is adjusted according to the set dryness fraction, whereby energy saving operation which provides the maximum coefficient of performance corresponding to each set of operating conditions can be performed.

[0018] The invention provides, as a sixth aspect, the refrigeration apparatus according to any one of the first to third aspects, wherein the refrigerant circuit (20) has an expander (33) mechanically connected to the compressor (31) through a motor (32) of the compressor (31). The refrigerant circuit (20) includes a bypass pipe (44) through which a part of the refrigerant flowing to the expander (33) flows, bypassing the expander (33), and a flow rate control valve (45) provided in the bypass pipe (44). This apparatus is configured such that the wet state of the suction refrigerant of the compressor (31) is controlled by adjusting the flow rate control valve (45).

[0019] In the apparatus constructed according to the sixth aspect, when increasing the wetness fraction of the suction refrigerant of the compressor (31) for instance, that is, when reducing the dryness fraction of the suction refrigerant, the opening of the flow rate control valve (45) is increased, that is, the amount of refrigerant that flows, bypassing the expander (33) is increased, thereby increasing the amount of refrigerant supplied to the evaporator. Thereby, the amount of refrigerant that cannot be evaporated by the evaporator increases so that refrigerant in a wetter state is drawn into the compressor (31). On the other hand, when reducing the wetness fraction of the suction refrigerant of the compressor (31), that is, when increasing the dryness fraction of the suction refrigerant, the opening of the flow rate control valve (45) is reduced, that is, the amount of refrigerant that flows, bypassing the expander (33) is reduced, thereby reducing the amount of refrigerant supplied to the evaporator. Thereby, the amount of refrigerant that cannot be evaporated by the evaporator decreases so that refrigerant in a less wet state is drawn into the compressor (31). Accordingly, the dryness fraction of the refrigerant which provides the maximum coefficient of performance is set according to operating conditions and the opening of the flow rate control valve (45) is adjusted according to the set dryness fraction, whereby energy saving operation which provides the maximum coefficient of performance corresponding to each set of operating conditions can be performed.

[0020] In the above apparatus, the energy generated when the refrigerant is expanded

by the expander (33) is converted into a rotating force which is in turn recovered as the power of the compressor (31) through the motor (32). Generally, the compressor (31) and the expander (33) used herein are of the positive displacement type and therefore the balance between the compressor (31) and the expander (33) in terms of the flow rate of the refrigerant flowing therein is lost owing to variations in the operating conditions. Even in such a case, the flow rates of the refrigerant flowing in the compressor (31) and in the expander (33) can be rebalanced by the above-described technique in which the amount of refrigerant sent to the expander (33) is controlled by adjusting the opening of the flow rate control valve (27) provided that the dryness fraction of the refrigerant drawn into the compressor (31) is optimum. This enables higher-efficiency operation.

[0021] The invention provides, as a seventh aspect, the refrigeration apparatus according to any one of the first to third aspects, wherein the refrigerant circuit (20) is configured such that the high pressure of the refrigeration cycle is higher than the critical pressure of the refrigerant.

[0022] In the apparatus constructed according to the seventh aspect, the compressor (31) compresses the refrigerant to a specified level of pressure higher than the critical pressure of the refrigerant. This means that the discharge refrigerant of the compressor (31) is in a supercritical state. Thereby, even if the refrigerant in a wet state is drawn into the compressor (31), no liquid refrigerant exists at least in the discharge section so that the so-called liquid compression can be avoided without fail.

[0023] The invention provides, as an eighth aspect, the refrigeration apparatus according to the seventh aspect, wherein the refrigerant is carbon dioxide.

[0024] The apparatus constructed according to the eighth aspect is earth-conscious, because the refrigerant is carbon dioxide (CO₂).

ADVANTAGEOUS EFFECTS OF THE INVENTION

[0025] According to the first aspect of the invention, since refrigerant in a wet state is drawn into the compressor (31), the coefficient of performance (COP) can be improved,

compared to the case where refrigerant in a superheated state is drawn. Further, the maximum energy saving can be attained in the operation by bringing the suction refrigerant of the compressor (31) into a wet state that provides the maximum coefficient of performance. In addition, since refrigerant in a wet state is drawn into the compressor (31), not only the discharge temperature of the compressor (31) can be lowered but also degradation of the refrigerating machine fluid in the compressor (31) due to high temperature can be restrained, compared to the case where refrigerant in a superheated state is drawn. In consequence, the reliability of the apparatus can be improved.

[0026] According to the second aspect of the invention, since refrigerant in a wet state is drawn into the compressor (31) during the heating operation mode, at least heating operation can be performed with the optimum coefficient of performance. According to the third aspect of the invention, since refrigerant in a wet state is drawn into the compressor (31) such that the discharge temperature of the compressor (31) becomes equal to a predetermined temperature that provides the optimum coefficient of performance, the refrigeration apparatus can perform operation with the optimum coefficient of performance without fail. Further, since the wet state of the refrigerant may be controlled according to the discharge temperature of the compressor (31), the coefficient of performance of the refrigeration cycle can be easily controlled.

[0027] According to the fourth to sixth aspects of the invention, since the wet state of the suction refrigerant of the compressor (31) is controlled by adjusting the openings of the expansion valve (23) and the flow rate control valves (27, 45), the refrigeration apparatus can perform operation with the maximum coefficient of performance over a wide range of operating conditions without fail by setting a dryness fraction of the refrigerant that provides the optimum coefficient of performance according to operating conditions.

[0028] According to the sixth aspect of the invention, even if the balance between the amount of refrigerant flowing in the expander (33) and the amount of refrigerant flowing in the compressor (31) is lost because of variations in the operating conditions, the amount of

refrigerant supplied to the expander (33) can be controlled by adjusting the opening of the flow rate control valve (45) provided that the suction refrigerant of the compressor (31) has an optimum dryness fraction, so that the amounts of refrigerant in the expander (33) and in the compressor (31) can be rebalanced. This leads to a further improvement in the efficiency.

[0029] According to the seventh aspect of the invention, since the refrigerant circuit (20) is configured to perform a supercritical cycle in which the high pressure of the refrigeration cycle is higher than the critical pressure of the refrigerant, the discharge refrigerant of the compressor (31) comes into a superheated state without fail. Accordingly, when refrigerant in a wet state is drawn into the compressor (31), the refrigerant in the discharging section of the compressor (31) is already in a superheated state and therefore, liquid compression can be prevented from occurring in the compressor (31) without fail. In consequence, a highly-reliable apparatus can be achieved.

[0030] According to the eighth aspect of the invention, since carbon dioxide is used as the refrigerant, an earth-conscious apparatus can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031]

Fig. 1 is a refrigerant circuit diagram which shows a refrigeration apparatus according to a first embodiment of the invention;

Fig. 2 is a Mollier diagram which shows the behavior of refrigerant in a refrigerant circuit during a heating operation mode;

Fig. 3 is a simulation data table which shows the relationship between the dryness fraction of the refrigerant and the coefficient of performance during the heating operation mode;

Fig. 4 is a simulation data graph which shows the relationship between the dryness fraction of the refrigerant and the coefficient of performance during the heating operation mode; and

Fig. 5 is a refrigerant circuit diagram which shows a refrigeration apparatus according to a second embodiment of the invention.

BEST EMBODIMENT MODE FOR CARRYING OUT THE INVENTION

[0032] In the following, preferred embodiments of the present invention are described in detail with reference to the accompanied drawings.

FIRST EMBODIMENT

[0033] An air conditioner (10) according to the first embodiment constitutes the refrigeration apparatus of the invention. As illustrated in Fig. 1, the air conditioner (10) is of the so-called separate type and includes an outdoor unit (11) and an indoor unit (12). Housed in the outdoor unit (11) are a compressor (31), a four way switch valve (21), an outdoor heat exchanger (24), an expansion valve (23) and a gas-liquid separator (25). Housed in the indoor unit (12) is an indoor heat exchanger (22). The outdoor unit (11) is installed outdoors whereas the indoor unit (12) is installed indoors. The outdoor unit (11) is connected to the indoor unit (12) with a pair of interunit pipelines (13, 14).

[0034] The air conditioner (10) includes a refrigerant circuit (20). The refrigerant circuit (20) is constructed in the form of a closed circuit to which a compressor (31), the indoor heat exchanger (22) and others are connected. The refrigerant circuit (20) is filled with carbon dioxide (CO₂) serving as refrigerant and configured to circulate the refrigerant, thereby performing a vapor compression refrigeration cycle.

[0035] The compressor (31) is driven by a motor (32) mechanically connected thereto and constituted, for instance, by a scroll compressor of the hermetic, high pressure dome type. This compressor (31) is designed to compress the refrigerant to a pressure level higher than the critical pressure of the refrigerant. Specifically, in the refrigerant circuit (20), the high pressure of the vapor compression refrigeration cycle becomes higher than the critical pressure of carbon dioxide. The outdoor heat exchanger (24) and the indoor heat exchanger (22) are both constituted by a fin and tube heat exchanger of the cross fin type. In the outdoor heat exchanger (24), the heat of the refrigerant circulating in the refrigerant

circuit (20) is exchanged with the heat of outdoor air. In the indoor heat exchanger (22), the heat of the refrigerant circulating in the refrigerant circuit (20) is exchanged with the heat of indoor air.

[0036] The four way switch valve (21) has four ports. In the four way switch valve (21), the first port is connected to a discharge pipe (3a) of the compressor (31); the second port is to a suction pipe (3b) of the compressor (31) through the gas-liquid separator (25); the third port is to one end of the outdoor heat exchanger (24); and the fourth port is to one end of the indoor heat exchanger (22) through the interunit pipeline (13). The other end of the indoor heat exchanger (22) is connected to the other end of the outdoor heat exchanger (24) through the interunit pipeline (14) and the expansion valve (23). The four way switch valve (21) is switchable between a first state that allows fluid communication between the first port and the third port and fluid communication between the second port and the fourth port (the state as indicated by broken line in Fig. 1) and a second state that allows fluid communication between the first port and the fourth port and fluid communication between the second port and the third port (the state as indicated by solid line in Fig. 1).

[0037] The refrigerant circuit (20) is switchable between a cooling operation mode and a heating operation mode by switching effectuated by the four way switch valve (21). Specifically, when the four way switch valve (21) has been switched to the state indicated by broken line in Fig. 1, the refrigerant circuit (20) circulates the refrigerant so as to perform cooling operation in which the refrigerant dissipates heat in the outdoor heat exchanger (24) and evaporates in the indoor heat exchanger (22). When the four way switch valve (21) has been switched to the state indicated by solid line in Fig. 1, the refrigerant circuit (20) circulates the refrigerant so as to perform heating operation in which the refrigerant dissipates heat in the indoor heat exchanger (22) and evaporates in the outdoor heat exchanger (24). That is, during the cooling operation mode, the indoor heat exchanger (22) serves as an evaporator whereas the outdoor heat exchanger (24) as a heat dissipater. During the heating operation mode, the outdoor heat exchanger (24) serves as

an evaporator the indoor heat exchanger (22) as a heat dissipater.

[0038] The gas-liquid separator (25) is provided with a liquid injection pipe (26). More concretely, the liquid injection pipe (26) is connected at one end to a liquid reservoir section of the gas-liquid separator (25) and connected at the other end to the suction pipe (3b) of the compressor (31). The liquid injection pipe (26) is configured to guide the liquid refrigerant stored in the gas-liquid separator (25) to the suction side of the compressor (31). The liquid injection pipe (26) is provided with a flow rate control valve (27) constituted by a motor-operated valve for controlling the flow rate of the liquid refrigerant flowing in the liquid injection pipe (26).

[0039] As a feature of the invention, the air conditioner (10) is configured such that, during the normal cooling operation mode, gas refrigerant in a specified superheated state is drawn into the compressor (31) and, during the normal heating operation mode, refrigerant having a specified level of dryness fraction (wet state) is drawn into the compressor (31). That is, the present invention is intended for use in normal operation mode applications and is not intended for use in special operations (e.g., defrost operation) nor conditions such as when the high pressure of a refrigeration cycle becomes abnormally high or the discharge temperature of the compressor (31) becomes abnormally high.

[0040] More concretely, in the case of the cooling operation, the opening of the expansion valve (23) is set such that the refrigerant evaporates into a gas refrigerant in a specified superheated state (e.g., a degree of superheat of 0° to 5°) in the indoor heat exchanger (22). In the case of the heating operation, the opening of the expansion valve (23) is set such that the refrigerant evaporates in the outdoor heat exchanger (24) so as to have a predetermined level of dryness fraction (e.g., 0.83 to 0.89).

[0041] This predetermined level of dryness fraction has been found by simulation and set to a value that makes the coefficient of performance of the air conditioner (10) in the heating operation mode be optimum. In this simulation, as shown in the upper table of Fig. 3 and indicated by line F in the graph of Fig. 4, the dryness fraction of the refrigerant

drawn into the compressor (31) peaks at 0.83 to 0.89. It is seen from Figs. 3, 4 that as the dryness fraction decreases or increases from the peak region, the coefficient of performance decreases and that as the dryness fraction increases after exceeding 1.00, the coefficient of performance further decreases. It is understood from the above fact that the coefficient of performance can be made closer to its optimum value by drawing the refrigerant in a wet state, i.e., having a dryness fraction of at least less than 1.00 into the compressor (31).

[0042] The above simulation was done under the conditions in which the high and low pressures of the refrigeration cycle were set to 10 MPa and 3.5 MPa respectively, the outlet temperature of the indoor heat exchanger (22) was set to 25℃, and the compression efficiency of the compressor (31) was set to 70%. In this simulation, carbon dioxide (CO₂) was used as the refrigerant. Accordingly, the dryness fraction corresponding to the optimum coefficient of performance is found while varying the value of each of the above operating conditions, whereby the optimum dryness fraction corresponding to a given set of operating conditions can be set. If the temperature of outside air changes, operating conditions are set according to the change and the dryness fraction (wet state) of the refrigerant corresponding to the set operating conditions may be set.

[0043] The air conditioner (10) is configured such that the dryness fraction of the refrigerant is controlled by controlling the evaporative power of the outdoor heat exchanger (24) by mainly adjusting the opening of the expansion valve (23). Concretely, for increasing the dryness fraction of the refrigerant, the opening of the expansion valve (23) is reduced, and for decreasing the dryness fraction of the refrigerant, the opening of the expansion valve (23) is increased. In the air conditioner (10), the dryness fraction of the refrigerant may be controlled through an adjustment of the opening of the flow rate control valve (27) of the liquid injection pipe (26). Specifically, the flow rate of the liquid refrigerant introduced from the gas-liquid separator (25) into the compressor (31) is controlled through an adjustment of the opening of the flow rate control valve (27), thereby controlling the wet state of the refrigerant.

[0044] The dryness fraction of the refrigerant drawn into the compressor (31) is determined based on the discharge temperature of the compressor (31). Specifically, the air conditioner (10) is configured such that the dryness fraction of the refrigerant is controlled by adjusting the opening of the expansion valve (23) or the flow rate control valve (27) so as to make the discharge temperature of the compressor (31) equal to a target discharge temperature. The target discharge temperature has been set to a value that allows the coefficient of performance to be optimum. That is, the discharge temperature of the compressor (31) drops as the dryness fraction of the refrigerant drawn into the compressor (31) decreases and rises as the dryness fraction of the refrigerant increases, and therefore, the discharge temperature of the compressor (31) corresponding to the dryness fraction of the refrigerant is determined for every set of operating conditions. Thus, the dryness fraction of the refrigerant that makes the coefficient of performance optimum is set for every set of operating conditions and the discharge temperature of the compressor (31) which corresponds to this dryness fraction of the refrigerant is set as a target discharge temperature. With this arrangement, even if the operating conditions vary, the target discharge temperature for the compressor (31) that corresponds to the present operating conditions can be set, so that the refrigeration apparatus can perform operation with the optimum coefficient of performance corresponding to the present operating state.

RUNNING OPERATION

[0045] The running operation of the air conditioner (10) will be described below. Herein, the operations in the normal cooling operation mode and the normal heating operation mode will be explained.

COOLING OPERATION

[0046] During the cooling operation mode, the four way switch valve (21) is switched to the state indicated by broken line in Fig. 1. If the motor (32) is activated in this condition, the refrigerant circulates in the direction indicated by dashed arrow in Fig. 1 in the refrigerant circuit (20), thereby performing a vapor compression refrigeration cycle.

It should be noted that the flow rate control valve (27) of the liquid injection pipe (26) is in a fully closed state.

[0047] The refrigerant, which has been compressed by the compressor (31), is discharged through the discharge pipe (3a). In this condition, the pressure of the refrigerant is higher than the critical pressure of the refrigerant. The discharged refrigerant flows to the outdoor heat exchanger (24) through the four way switch valve (21), exchanging heat with the heat of outdoor air for heat dissipation. The refrigerant which has dissipated heat in the outdoor heat exchanger (24) is decompressed down to a predetermined level of pressure by the expansion valve (23) and then exchanges heat with the heat of indoor air in the indoor heat exchanger (22) so that it becomes a gas refrigerant in a superheated state. At that time, indoor air is cooled. The gas refrigerant in the superheated state is drawn into the compressor (31) by the suction pipe (3b) after passing through the four way switch valve (21) and then compressed again to be discharged.

HEATING OPERATION

[0048] During the heating operation mode, the four way switch valve (21) is switched to the state indicated by solid line in Fig. 1. If the motor (32) is activated in this condition, the refrigerant circulates in the direction indicated by solid arrow in Fig. 1 in the refrigerant circuit (20), thereby performing a vapor compression refrigeration cycle. In this circulation, the state of the refrigerant changes in the cycle of A1 → B1 → C → D, as indicated by dashed line in Fig. 2. The flow rate control valve (27) of the liquid injection pipe (26) is in a fully closed state. It should be noted that the cycle of A → B → C → D in Fig. 2 is the conventional refrigeration cycle made when the degree of superheat of the suction refrigerant of the compressor (31) is zero. In the conventional refrigeration cycle, the refrigerant in the state of point B, which has been discharged from the compressor, dissipates heat in the heat dissipater so that it comes into the state of point C. Subsequently, the refrigerant is decompressed in the expansion mechanism so that it comes into the state of point C. Then, the refrigerant evaporates, in the evaporator, into a gas

refrigerant having a degree of superheat of zero (point A) which is in turn drawn into the compressor.

[0049] In the heating operation, the refrigerant decompressed by the compressor (31) is discharged from the discharge pipe (3a) (point B in Fig. 2). In this condition, the pressure of the refrigerant is higher than the critical pressure of the refrigerant. The discharge refrigerant flows to the indoor heat exchanger (22) by way of the four way switch valve (21) and then dissipates heat, exchanging heat with the heat of indoor air (point C in Fig. 2). At that time, the indoor air is heated. After the refrigerant which has dissipated heat in the indoor heat exchanger (22) is decompressed down to a predetermined level of pressure (point D) by the expansion valve (23), it evaporates, exchanging heat with the heat of outdoor air in the outdoor heat exchanger (24) (point A1 in Fig. 2). In this condition, the refrigerant which has evaporated has the predetermined level of dryness fraction (wet state) that makes the coefficient of performance optimum. The refrigerant in the wet state is drawn into the compressor (31) by the suction pipe (3b) after passing through the four way switch valve (21). This refrigerant is decompressed again, coming into the superheated state and then discharged. In this way, the heating operation is performed with the optimum coefficient of performance so that energy saving is achieved.

[0050] If the temperature of outside air or the like changes in the above condition, the values of the high pressure, low pressure etc. of the refrigeration cycle are altered to provide a new set of operating conditions and a target discharge temperature for the compressor (31) is set according to the new set of operating conditions. Thereafter, the opening of the expansion valve (23) is adjusted or alternatively, the opening of the flow rate control valve (27) of the liquid injection pipe (26) is adjusted, such that the discharge temperature of the compressor (31) becomes equal to the target discharge temperature. Thereby, the dryness fraction of the refrigerant drawn into the compressor (31) becomes optimum, whereby operation can be performed with the optimum coefficient of performance corresponding to the given set of operating conditions.

[0051] In the heating operation, since the refrigerant in a wet state is constantly drawn into the compressor (31), the discharge temperature of the compressor (31) significantly drops compared to the case where the refrigerant in a superheated state is drawn like the prior art. Thanks to this, the temperature of the motor (32) is prevented from abnormally rising and the refrigerating machine fluid within the compressor (31) is prevented from being heated to high temperature and deteriorating. This results in an improvement in the reliability of the refrigeration apparatus.

[0052] Generally, a part of the refrigerating machine fluid discharged from the compressor (31) together with the refrigerant generally flows to the evaporator and tends to stay in the evaporator because the refrigerant flowing out from the evaporator is in a perfect gaseous state. In contrast with this, in the first embodiment, the refrigerant flowing out from the outdoor heat exchanger (24) that serves as an evaporator is in a wet state, that is, a gas-liquid two-phase state, and therefore it more easily carries the refrigerating machine fluid out of the heat exchanger than a refrigerant in a gaseous state does. Since a large amount of refrigerating machine fluid is thus allowed to flow back to the compressor (31), defective lubrication of the compressor (31) can be restrained.

EFFECTS OF EMBODIMENT

[0053] As has been described earlier, according to the first embodiment, since refrigerant in a wet state is drawn into the compressor (31) during the normal heating operation mode, a more improved coefficient of performance (COP) can be achieved compared to the case where refrigerant in a superheated state is drawn. Since refrigerant in a wet state, which makes the coefficient of performance optimum in accordance with operating conditions, is drawn into the compressor (31), the refrigeration apparatus can perform operation with the optimum coefficient of performance without fail. As a result, further energy saving can be ensured.

[0054] The first embodiment can optimize the coefficient of performance in normal operation, unlike the conventional liquid injection that is employed in applications such as

defrost operation or when the discharge temperature of the compressor (31) becomes abnormally high.

[0055] Further, since the target discharge temperature of the compressor (31) that corresponds to the dryness fraction of the refrigerant that makes the coefficient of performance optimum is set and the dryness fraction (wet state) of the suction refrigerant of the compressor (31) is controlled so as to make the discharge temperature of the compressor (31) equal to the target discharge temperature, the refrigeration apparatus can perform operation with the optimum coefficient of efficiency without fail.

[0056] In addition, since the dryness fraction of the suction refrigerant of the compressor (31) is controlled through an adjustment of the opening of the expansion valve (23) or the flow rate control valve (27), the refrigeration apparatus can easily perform operation with the optimum coefficient of performance without fail.

[0057] In addition, since refrigerant in a wet state is drawn into the compressor (31), the discharge temperature of the compressor (31) significantly drops so that the motor (32) and the refrigerating machine oil can be protected. In consequence, the reliability of the refrigeration apparatus can be increased.

[0058] In addition, since the refrigerant flowing out from the outdoor heat exchanger (24) that serves as an evaporator is in a gas-liquid two-phase wet state, the refrigerating machine oil within the heat exchanger is easily removed by the refrigerant and a large amount of refrigerating machine oil is allowed to flow back to the compressor (31), so that defective lubrication of the compressor (31) can be avoided. Consequently, this makes it possible to ensure more reliable protection of compressor (31) in cooperation with the effects described earlier.

SECOND EMBODIMENT

[0059] As shown in Fig. 5, the air conditioner (10) of the second embodiment is configured such that an expander (33) mechanically connected to the compressor (31) through the motor (32) is employed in place of the expansion valve (23) used as an

expansion mechanism for the refrigeration cycle in the first embodiment.

[0060] More concretely, the compressor (31), the motor (32) and the expander (33) are housed in a casing as one unit. The compressor (31) is implemented, for example, by a positive displacement type compressor such as rotary compressor, scroll compressor etc. The expander (33) is implemented, for example, by a positive displacement type expander such as rotary expander, scroll expander etc.

[0061] Although not shown in the drawings, the expander (33) is implemented by the so-called two-stage expander provided with two cylinders, which is expanded by a first-stage cylinder and then further expanded by a second-stage cylinder. The expander (33) is designed to recover power. Specifically, the expander (33) recovers power in such a way that the energy generated in the expansion of the refrigerant in the expander (33) is utilized as a rotating power for driving the compressor (31).

[0062] The casing for housing the compressor (31) and the expander (33) has, in addition to the discharge pipe (3a) and suction pipe (3b) for the compressor (31), an inflow port (3c) through which the refrigerant flows into the first-stage cylinder of the expander (33) and an outflow port (3d) through which the refrigerant after expansion goes out from the second-stage cylinder to the outside of the casing.

[0063] The refrigerant circuit (20) includes a bridge circuit (41) disposed between the interunit pipeline (14) and the outdoor heat exchanger (24) which are provided in the outdoor unit (11). The bridge circuit (41) comprises a bridge connection of four check valves (CV1, CV2, CV3, CV4). More concretely, the bridge circuit (41) is configured such that the inflow sides of the first check valve (CV1) and the fourth check valve (CV4) are connected to the outflow port (3d) of the expander (33); the outflow sides of the second check valve (CV2) and the third check valve (CV3) are connected to the inflow port (3c) of the expander (33); the outflow side of the first check valve (CV1) and the inflow side of the second check valve (CV2) are connected to the other end of the indoor heat exchanger (22) through the interunit pipeline (14); and the inflow side of the third check valve (CV3) and

the outflow side of the fourth check valve (CV4) are connected to the other end of the outdoor heat exchanger (24).

[0064] The refrigerant circuit (20) has an injection pipe (42). The injection pipe (42) is connected, at one end, between the bridge circuit (41) and the inflow port (3c) of the expander (33) and connected, at the other end, to an intermediate port (not shown) of the first-stage and second-stage cylinders of the expander (33). The injection pipe (42) is provided with an injection valve (43). This injection valve (43) is a motor-operated valve for controlling the flow rate of the refrigerant in the injection pipe (42) and constitutes a flow rate control valve.

[0065] The refrigerant circuit (20) is provided with a bypass pipe (44). The bypass pipe (44) is connected, at one end, between the bridge circuit (41) and the inflow port (3c) of the expander (33) and connected, at the other end, between the inflow port (3c) of the expander (33) and the bridge circuit (41). The bypass pipe (44) is provided with a bypass valve (45). This bypass valve (45) is a motor-operated valve for controlling the flow rate of the refrigerant in the bypass pipe (44) and constitutes a flow rate control valve. The bypass pipe (44) is configured such that a part of the refrigerant flowing from the bridge circuit (41) to the expander (33) flows so as to bypass the expander (33) when the bypass valve (45) is in its open state.

[0066] The air conditioner (10) of the second embodiment is configured such that, like the first embodiment, gas refrigerant in a specified superheated state is drawn into the compressor (31) during the cooling operation mode and refrigerant in a specified wet state is drawn into the compressor (31) during the heating operation mode. More concretely, in the cooling operation, the opening of the injection valve (43) is set so as to make the refrigerant evaporate into a gas refrigerant in a specified superheated state (e.g., having a degree of superheat of 0° to 5°) in the indoor heat exchanger (22). On the other hand, in the heating operation, the opening of the injection valve (43) is set so as to make the refrigerant evaporate and have a predetermined dryness fraction (e.g., 0.71 to 0.77) in the

outdoor heat exchanger (24). The predetermined dryness fraction is set to a value that makes the coefficient of performance optimum, as shown in the lower table of Fig. 3 and indicated by line E in the graph of Fig. 4. This simulation was done with the following operating conditions: the high pressure and low pressure of the refrigeration cycle were set to 10 MPa and 3.5 MPa respectively, the outlet temperature of the indoor heat exchanger (22) was set to 25°C, and the compression efficiency of the compressor (31) was set to 70%.

[0067] In the air conditioner (10) of the second embodiment, the dryness fraction of the refrigerant is controlled by mainly adjusting the openings of the injection valve (43) and the bypass valve (45). Concretely, only the opening of the injection valve (43) is adjusted while the bypass valve (45) being in its fully closed state. For increasing the dryness fraction of the refrigerant for instance, the opening of the injection valve (43) is reduced. For decreasing the dryness fraction of the refrigerant, the opening of the injection valve (43) is increased. If the injection valve (43) has been fully opened and therefore the flow rate of the refrigerant in the injection pipe (42) cannot be increased any more, the opening of the bypass valve (45) will be adjusted with the injection valve (43) being in its fully open state. In the air conditioner (10), the dryness fraction of the refrigerant may be controlled by adjusting the opening of the flow rate control valve (27) of the liquid injection pipe (26) similarly to the first embodiment.

RUNNING OPERATION

[0068] The operation of the air conditioner (10) will be described below. Herein, the points differing from the running operation of the first embodiment will be explained.

COOLING OPERATION

[0069] During the cooling operation mode, the four way switch valve (21) is switched to the state indicated by broken line in Fig. 5. In this condition, if the motor (32) is activated, the refrigerant circulates in the direction indicated by dashed arrow in Fig. 5 in the refrigerant circuit (20), thereby performing a vapor compression refrigeration cycle. It should be noted that the bypass valve (45) and the flow rate control valve (27) are placed in

a fully closed state.

[0070] The refrigerant, which has dissipated heat in the outdoor heat exchanger (24), passes through the third check valve (CV3) of the bridge circuit (41). Then, a part of it flows into the first-stage cylinder of the expander (33) through the inflow port (3c) whereas the remaining part flows into the intermediate port of the expander (33) through the injection pipe (42). In the expander (33), the refrigerant expands and its internal energy is converted into the rotating force of the motor (32) which is in turn recovered as the power of the compressor (31). The refrigerant after expansion flows out from the outflow port (3d) and flows into the indoor heat exchanger (22) after passing through the first check valve (CV1) of the bridge circuit (41). In the indoor heat exchanger (22), the refrigerant evaporates, exchanging heat with the heat of indoor air so that it becomes a gas refrigerant in a superheated state.

HEATING OPERATION

[0071] During the heating operation mode, the four way switch valve (21) is switched to the state indicated by solid line in Fig. 5. If the motor (32) is activated in this condition, the refrigerant circulates in the direction indicated by solid arrow in Fig. 5 in the refrigerant circuit (20), thereby performing a vapor compression refrigeration cycle. In this circulation, the state of the refrigerant changes in the cycle of $A2 \rightarrow B2 \rightarrow C \rightarrow D2$, as indicated by solid line in Fig. 2. It should be noted that the bypass valve (45) and the flow rate control valve (27) are placed in a fully closed state.

[0072] The discharge refrigerant (indicated by point B2 in Fig. 2) of the compressor (31) dissipates heat in the indoor heat exchanger (22) (at point C in Fig. 2). After this refrigerant has passed through the second check valve (CV2) of the bridge circuit (41), a part of it flows into the first-stage cylinder of the expander (33) through the inflow port (3c) whereas the remaining part flows into the intermediate port of the expander (33) through the injection pipe (42). In the expander (33), the refrigerant expands and its internal energy is converted into the rotating force of the motor (32) which is in turn recovered as the power

of the compressor (31) (at point D2 in Fig. 2). After expansion, the refrigerant goes out from the outflow port (3d) and then flows into the outdoor heat exchanger (24) by way of the fourth check valve (CV4) of the bridge circuit (41). In this outdoor heat exchanger (24), the refrigerant evaporates, exchanging heat with the heat of outdoor air (at point A2 in Fig. 2). In this condition, the evaporated refrigerant has a predetermined dryness fraction (wet state) that makes the coefficient of performance optimum.

[0073] If outdoor air temperature changes in the condition described above, the high pressure and low pressure of the refrigeration cycle are altered to set a new set of operating conditions according to which a target discharge temperature is set for the compressor (31). Then, the opening of the injection valve (43) is adjusted such that the discharge temperature of the compressor (31) becomes equal to the target discharge temperature. When the injection valve (43) is fully opened, the opening of the bypass valve (45) is then adjusted. Alternatively, the opening of the flow rate control valve (27) of the liquid injection pipe (26) is properly adjusted. Thereby, the dryness fraction of the refrigerant drawn into the compressor (31) becomes optimum so that the refrigeration apparatus can perform with the optimum coefficient of performance in accordance with the given set of operating conditions.

[0074] In the air conditioner (10) of the second embodiment, even if the balance between the amount of refrigerant flowing in the expander (33) and the amount of refrigerant flowing in the compressor (31) is lost because of variations in the operating conditions, the amounts of refrigerant flowing in the expander (33) and in the compressor (31) can be rebalanced by introducing a part of the refrigerant from the injection pipe (42) and making the part of the refrigerant bypass the expander (33) by means of the bypass pipe (44), provided that the suction refrigerant of the compressor (31) has an optimum dryness fraction. This leads to an improvement in the rate of power recovery and, in consequence, further energy saving can be achieved. Other arrangements, functions and effects of the second embodiment do not differ from those of the first embodiment.

OTHER EMBODIMENTS

[0075] The foregoing embodiments of the present invention may be modified as follows.

[0076] For example, in the first to second embodiments, the dryness fraction of the refrigerant may be controlled by adjusting only the opening of the flow rate control valve (27) of the liquid injection pipe (26) provided in the gas-liquid separator (25).

[0077] In the first and second embodiments, the liquid injection pipe (26) of the gas-liquid separator (25) may be omitted. More specifically, the first and second embodiments may be modified such that the dryness fraction of the refrigerant is controlled by adjusting only the openings of the expansion valve (23) and the injection valve (43).

[0078] While the bypass pipe (44) and the injection pipe (42) are both provided in the second embodiment, it is possible to provide either one of them and control the dryness fraction of the refrigerant with the flow rate control valve provided for it.

[0079] While the air conditioner (10) capable of switching between the cooling operation mode and the heating operation mode has been described in the first and second embodiments, it is apparent that the invention is applicable to heating apparatuses having a heating function only.

INDUSTRIAL APPLICABILITY

[0080] As has been described above, the present invention finds useful applications in the field of refrigeration apparatuses having a refrigerant circuit for performing a vapor compression refrigeration cycle.

CLAIMS:**What is claimed is:**

1. A refrigeration apparatus comprising a refrigerant circuit (20) for performing a refrigeration cycle which circuit includes a compressor (31),
wherein:
refrigerant in a wet state, which provides an optimum coefficient of performance (COP) for a present operating state, is drawn into the compressor (31).
2. A refrigeration apparatus comprising a refrigerant circuit (20) for performing a refrigeration cycle which circuit includes a compressor (31),
wherein:
refrigerant in a superheated state is drawn into the compressor (31) during a cooling operation mode and the refrigerant in a wet state is drawn into the compressor (31) during a heating operation mode.
3. A refrigeration apparatus comprising a refrigerant circuit (20) for performing a refrigeration cycle which circuit includes a compressor (31),
wherein:
a target discharge temperature for the compressor (31) is set so as to obtain an optimum coefficient of performance (COP) for a present operating state and refrigerant in a wet state, which makes the discharge temperature of the compressor (31) equal to the target discharge temperature, is drawn into the compressor (31).
4. The refrigeration apparatus according to any one of claims 1 to 3,
wherein:
the refrigerant circuit (20) is provided with an expansion valve (23) and the wet state of suction refrigerant of the compressor (31) is controlled by adjusting the opening of the expansion valve (23).
5. The refrigeration apparatus according to any one of claim 1 to 3,

wherein:

the refrigerant circuit (20) has a gas-liquid separator (25) disposed between evaporators (22, 24) and the suction side of the compressor (31);

the gas-liquid separator (25) includes a liquid injection pipe (26) having a flow rate control valve (27), for guiding liquid refrigerant from the gas-liquid separator (25) to the suction side of the compressor (31); and

the wet state of suction refrigerant of the compressor (31) is controlled by adjusting the flow rate control valve (27).

6. The refrigeration apparatus according to any one of claims 1 to 3,

wherein:

the refrigerant circuit (20) has an expander (33) mechanically connected to the compressor (31) through a motor (32) of the compressor (31);

the refrigerant circuit (20) includes a bypass pipe (44) through which a part of the refrigerant flowing to the expander (33) flows, bypassing the expander (33), and a flow rate control valve (45) provided in the bypass pipe (44); and

the wet state of suction refrigerant of the compressor (31) is controlled by adjusting the flow rate control valve (45).

7. The refrigeration apparatus according to any one of claims 1 to 3,

wherein:

the refrigerant circuit (20) is configured such that the high pressure of the refrigeration cycle is higher than the critical pressure of the refrigerant.

8. The refrigeration apparatus according to claim 7,

wherein:

the refrigerant is carbon dioxide.