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(71) Applicant: **Tewis Smart Systems S.L.U**
46980 Paterna (Valencia) (ES)

(72) Inventor: **ATENCIA ESCUDERO, J.Javier**
46980 Paterna (Valencia) (ES)

(74) Representative: **Pons**
Glorieta Ruben Dario 4
28010 Madrid (ES)

(54) **R-744 BOOSTER REFRIGERATION CIRCUIT**

(57) Booster refrigerant circuit for increasing energy efficiency comprising a tank (8), storing liquid and vapor R-744; a first R-744 liquid line (22), connecting the tank (8) to a medium-temperature expansion valve (13) connected to a medium-temperature evaporator (15) connected to a suction line (30), which connects with a medium-temperature compressor (1); a low-temperature line (23), connected to the first R-744 liquid line (22), and comprising a low-temperature expansion valve (14) connected to a

low-temperature evaporator (16) connected to a low-temperature compressor (17) connected to the suction line (30); an adiabatic gas-cooler (4), connected to the medium-temperature compressor (1); a first back-pressure valve (7), connected to the tank (8) and to a first heat exchanger (5), connected to the adiabatic gas-cooler (4); and a R-744 vapor line (24), connecting the tank (8) with the first heat exchanger (5) and with the suction line (30).

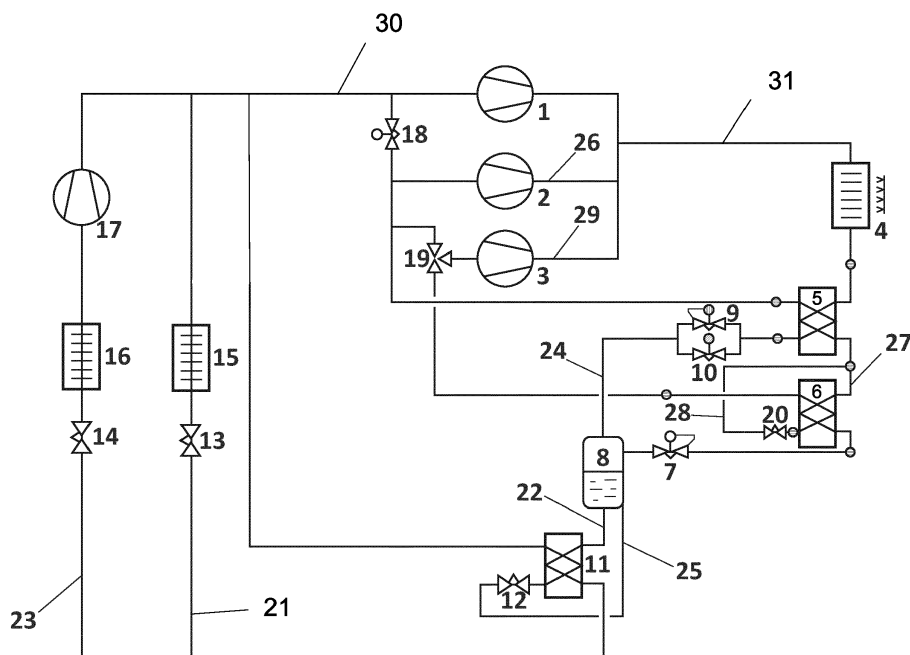


FIG. 1

Description

OBJECT OF THE INVENTION

[0001] The present invention is related to the field of refrigeration circuits, more particularly, to refrigeration circuits using CO₂ as refrigerant (R-744).

[0002] An object of the present invention is to provide a R-744 booster refrigerant circuit able to reduce the power consumption by increasing the energy efficiency.

BACKGROUND OF THE INVENTION

[0003] At present, there are different improvements introduced to the circuits with R-744 to increase their efficiency, which are mainly aimed to increase the efficiency of the facility in climates with high ambient temperatures.

[0004] The mainly problem in refrigeration circuits using R-744 is the high reduction in efficiency at medium-high ambient temperatures. This efficiency reduction is mainly despite to high power consumption of the medium-temperature compression rack (MTC).

[0005] A solution proposed consist on introducing in a circuit several ejectors (Multi-Ejector racks, MEJ). This circuit compresses part of the refrigerant of medium-temperature services (MTo) to intermediate pressure (liquid receiver pressure). For do that, the multi-ejector uses R-744 with high pressure as motive flow, which reduces its pressure through a nozzle below the medium-temperature services pressure and, consequently, increases its velocity. Thus, the motive flow suctions part of the refrigerant of the medium-temperature services and is compressed to intermediate pressure. This circuit is used with different types of ejectors, the most used is the high-pressure multi-ejector. The use of high-pressure multi-ejector reduces the refrigerant in the medium-temperature compression rack and consequently its power consumption. Additionally, the medium-temperature compression rack compresses part of the medium-temperature services refrigerant without a mechanical compressor taking the potential energy of the motive flow.

[0006] Nevertheless, this circuit needs an additional compression denoted as parallel compression rack to compress the refrigerant in vapor state generated by the multi-ejector. The vapor quality in the liquid receiver is higher and the capacity requirements in parallel compression rack is greater than the circuits without ejectors, having a similar cooling load.

[0007] The temperature at suction port of the medium-temperature compression rack is higher than the circuits without ejectors and, in consequence, the discharge temperature too, producing temperatures greater than 140°C for ambient temperatures above 35°C.

[0008] The main problem of the high-pressure multi-ejector racks is that they do not operate efficiently for ambient temperatures below 30°C in R-744 booster circuits. Also, the cost of using high-pressure multi-ejector racks is high. In addition, it has problems with the high

oil transfer rate at the parallel compression rack due to the reduced superheat in suction port. Also, the suction pressure of the parallel compression rack is fixed by a liquid receiver, storing the refrigerant, and this compressor rack does not work at its optimal operating point (maximum compressor efficiency).

[0009] A lot of solutions have been proposed to improve the efficiency of a refrigeration circuit using R-744 at medium-high ambient temperatures. Nevertheless, few improvements are used at the present time. The most used improvements to R-744 boosters are the parallel compression, mechanical subcooling and ejectors, but these circuits have several limitations. Therefore, a circuit with lower limitations using R-744 for increasing the efficiency of the refrigeration process at medium-high ambient temperatures is needed.

DESCRIPTION OF THE INVENTION

[0010] The present invention is directed to a R-744 booster refrigerant circuit able to increase the efficiency of the refrigeration process, thus, reducing the power consumption in a large variety of locations having different ambient conditions and increasing the operation temperature range.

[0011] Moreover, the R-744 booster refrigerant circuit of the invention reduces the operation cost and the complexity of the installation since is based in combining a parallel compression and a mechanical subcooling technique.

[0012] The R-744 booster refrigerant circuit of the invention comprises a tank for storing the R-744, which is in a mixed physical state, thus, storing a liquid R-744 and a vapor R-744.

[0013] The liquid R-744 is extracted from the tank by means of a first R-744 liquid line. The first R-744 liquid line is connected to a medium-temperature line and comprises a medium-temperature expansion valve, which is connected to a medium-temperature evaporator, which, in turn, is connected to a medium-temperature compressor.

[0014] A low-temperature line comprises a low-temperature expansion valve, which is connected to a low-temperature evaporator, which is connected to low-temperature compressor. The low-temperature line and the medium-temperature line are connected to the first R-744 liquid line upstream the medium-temperature and low-temperature expansion valves.

[0015] The booster refrigerant circuit also comprises a gas-cooler or an adiabatic gas-cooler. A cooling line connects the gas-cooler or adiabatic gas-cooler, intended for reducing the temperature of the R-744, to the outlet of the medium temperature compressor.

[0016] A first heat exchanger is connected to the adiabatic gas-cooler, receiving a cooled flow, and to a first back-pressure valve, intended for reducing the pressure of the cooled flow exiting the first heat exchanger. The cooled flow is returned to the tank, after it has been

passed through the first back-pressure valve.

[0017] The booster circuit could also comprise a second R-744 liquid line for circulating a second flow of liquid R-744 from the tank.

[0018] Said second R-744 liquid line connects the tank with a first expansion valve, which expands the second flow of liquid R-744, and the first expansion valve with an internal heat exchanger. In the internal heat exchanger, a heat transfer between the first and second flow of liquid R-744 is produced. The second R-744 liquid line also connects the internal heat exchanger with a suction line, upstream of the medium-temperature compressor, said suction line connecting the medium-temperature compressor with the medium-temperature line downstream the medium-temperature evaporator and with the low-temperature line downstream the low-temperature evaporator.

[0019] The vapor R-744 is extracted from the tank by means of a R-744 vapor line. The R-744 vapor line (intermediate-temperature line) is connected to the tank, to the first heat exchanger and to the suction line. Therefore, this R-744 vapor line extracts the vapor R-744 from the tank and connects with the first heat exchanger, for allowing a heat transfer process between the vapor R-744 extracted from the tank and the R-744 exiting the gas-cooler or adiabatic gas-cooler. The R-744 vapor line also connects the first heat exchanger to the suction line at inlet of the medium-temperature compressor, preferably, by means of a first motorize valve.

[0020] Preferably, a second back-pressure valve is connected to the R-744 vapor line at inlet of the first heat exchanger. The second back-pressure valve reduces the pressure of the vapor R-744 prior to be introduced into the first heat exchanger.

[0021] A second motorize valve could be also connected to the R-744 vapor line, in parallel to the second back-pressure valve. Therefore, the vapor R-744 could be flowed through the second back-pressure valve or, alternatively, the second motorize valve, wherein the pressure of the vapor R-744 is not reduced.

[0022] The R-744 refrigerant circuit could also comprise an additional compressor denoted as parallel compressor. The parallel compressor is connected by means of a first compression line, to the R-744 vapor line, at outlet of the first heat exchanger, and to the cooling line, at outlet of the medium-temperature compressor.

[0023] The parallel compressor allows to compress the vapor R-744 to a rejection temperature instead of expanding it to medium temperature using the second back-pressure valve. This feature achieves a reduction of the mass flow rate in the medium-temperature compressor and consequently reduces the power consumption on it.

[0024] Also, the compression is made at higher suction pressure and is more efficiently than using the medium-temperature compressor and, using the first heat exchanger, a slightly superheating is introduced to avoid high oil transfer rate in the parallel compressor.

[0025] The booster refrigerant circuit can comprise al-

so a high-pressure line and a low-pressure line, which allows to divide the cooled flow in a high-pressure flow and a low-pressure flow.

[0026] The high-pressure line is intended for circulating the high-pressure flow, and could be connected to the first heat exchanger or, alternatively, to the adiabatic gas-cooler.

[0027] The low-pressure line is connected to the high-pressure line for dividing the cooled flow and circulating the low-pressure flow, regardless the high-pressure line is connected to the first heat exchanger or to the adiabatic gas-cooler.

[0028] The low-pressure line could also comprise a second expansion valve for expanding the refrigerant to low-pressure flow and a second heat exchanger connected to said second expansion valve.

[0029] The second heat exchanger allows a heat transfer between the low-pressure flow exiting the second expansion valve and the high-pressure flow exiting the first heat exchanger or the adiabatic gas-cooler. When the high-pressure line is connected to the adiabatic gas-cooler the first heat exchanger is placed after the second heat exchanger, receiving from it the high-pressure flow.

[0030] Also, the low-pressure line could be connected to the R-744 vapor line at outlet of the first heat exchanger, preferably, by means of a three-way valve or a four-way valve.

[0031] Additionally, an adaptative volume compressor (AVC) could be connected to the three-way valve by means of a second compression line, which connects said adaptative volume compressor (AVC) with the first compression line at outlet of the parallel compressor or, alternatively, with the cooling line at outlet of the medium-temperature compressor.

[0032] Therefore, the three-way valve could be connected to the low-pressure line at outlet of the second heat exchanger, and manage the low-pressure flow to the R-744 vapor line or to the second compression line.

[0033] The adaptative volume compressor can be set to operate at its optimum suction pressure, by adapting said suction pressure depending on the requirements. In this case, the suction pressure is not fixed by the tank as in the case of the parallel compressor, leading the adaptative volume compressor to operate with higher efficiency.

[0034] The R-744 vapor line introduces a subcooling to high-pressure line and the R-744 in the vapor line is superheated, using the first heat exchanger. The first heat exchanger is used to reduce the R-744 temperature before the first back-pressure valve, thus, reducing the vapor quality in the tank, and to increase the temperature of the refrigerant before the compression stage.

[0035] The vapor R-744 mass flow rate expanded to medium-temperature level by the second back-pressure valve is reduced, thus, reducing the mass flow rate compressed by the medium-temperature compressor and, consequently, its power consumption and reducing an optimum rejection pressure (at outlet of the medium-tem-

perature compressor) of the booster refrigerant circuit.

[0036] By means of the second heat exchanger, the temperature after the adiabatic gas-cooler and the optimum rejection pressure are reduced, benefiting compressor, components connected at outlet of the medium-temperature compressor and lubrication oil properties.

[0037] Additionally, the subcooling introduced by said second heat exchanger reduces the vapor quality in the tank and, in consequence, the mass flow rate of vapor refrigerant which needs to be compressed, thus, reducing the compressor displacement required.

[0038] Moreover, using parallel compression and not subcooling circuit implies that, in most cases, it is needed more than one compressor in the parallel rack to adapt to the refrigeration requirements, especially for places with changes in ambient temperatures during the year above 20K. Also, it is needed a high oil transfer rate in the parallel compressor due to the reduced superheat in suction port if a heat exchanger is not introduced. The suction pressure of the parallel compressor is fixed by the tank and these compressor does not work at its optimal operating point (maximum compressor efficiency).

[0039] Similarly, using mechanical subcooling without parallel compressing leads to some problems. In this case, the circuit would be used for ambient temperatures above about 20°C, since for lower temperatures its use would not improve the efficiency of the facility, and the cost of the circuit would be higher.

[0040] The invention is also referred to a R-744 booster refrigerant system comprising the R-744 booster refrigerant circuit described, which comprises the at least one second back-pressure valve, the at least one second motorize valve, the at least one first motorize valve, the at least one medium-temperature compressor and the at least one parallel compressor.

[0041] The R-744 booster refrigerant system also comprises an ambient temperature sensor for detecting an ambient temperature and a controller configured to switch between a first operation mode and a second operation mode, based on the ambient temperature detected by the ambient temperature sensor.

[0042] The first operation mode is configured to close the at least one second back-pressure valve, open the at least one second motorize valve, close the at least one first motorize valve, activate the at least one medium-temperature compressor and activate the at least one parallel compressor.

[0043] The second operation mode is configured to open the at least one second back-pressure valve, close the at least one second motorize valve, open the at least one first motorize valve, activate the at least one medium-temperature compressor and deactivate the at least one parallel compressor. Alternatively, the controller could be further configured to switch between the first operation mode and a third operation mode based on an ambient temperature detected by the ambient temperature sensor.

[0044] In this case, the first operation mode being con-

figured to close the at least one first motorize valve, control the at least one second expansion valve so that a superheat temperature approaches a target superheat temperature, activate the at least one medium-temperature compressor and activate the at least one adaptative volume compressor.

[0045] The third operation mode is configured to open the at least one first motorize valve, close the at least one second expansion valve, activate the at least one medium-temperature compressor and deactivate the at least one adaptative volume compressor.

[0046] Also, the controller could be further configured to switch among the first operation mode, the second operation mode and the third operation mode based on an ambient temperature detected by the ambient temperature sensor.

[0047] In this case, the first operation mode is configured to close the at least one second back-pressure valve, open the at least one second motorize valve, control the at least one second expansion valve so that the superheat temperature approaches the target superheat temperature, activate the at least one parallel compressor and activate the at least one adaptative volume compressor.

[0048] The second operation mode being configured to open the at least one second back-pressure valve, close the at least one second motorize valve, control the at least one second expansion valve so that the superheat temperature approaches the target superheat temperature, deactivate the at least one parallel compressor and activate the at least one adaptative volume compressor.

[0049] The third operation mode being configured to close the at least one second back-pressure valve, close the at least one second motorize valve, close the at least one second expansion valve, deactivate the at least one parallel compressor and deactivate the at least one adaptative volume compressor.

[0050] In this case, the controller switches from the third operation mode to the second operation mode when the ambient temperature exceeds a first predetermined value and from the second operation mode to the first operation mode when the ambient temperature exceeds a second predetermined value, wherein the second predetermined value is higher than the first predetermined value.

[0051] The controller comprises a processor, such as a CPU (Central Processing Unit), a work memory used by the CPU such as a RAM (Random Access Memory), and a recording medium storing control programs and information used by the CPU such as a ROM (Read Only Memory). The controller is configured to perform information processing and signal processing by the CPU executing the control programs to control operation of the booster refrigerant system.

[0052] The booster refrigerant circuit of the invention allows to increase the operating hours of circuit that produce the subcooling and have lower is less dependence

on the ambient temperatures.

[0053] The booster refrigerant circuit of the invention using a parallel compressor and an adaptative volume compressor (AVC) has been compared to a booster circuit with multi-ejectors from the state of the art.

[0054] The COP of the booster refrigerant circuit using Adaptive Volume Compressor (AVC) and booster with multi-ejectors is similar for ambient temperatures above 30°C. However, for ambient temperatures from 10 to 30°C the energy efficiency of the booster refrigerant circuit using Adaptive Volume Compressor (AVC) is greater.

[0055] The booster refrigerant circuit using the Adaptive Volume Compressor (AVC) achieves a great reduction in annual energy consumption regarding the Multi-ejector technology, reducing the power consumption in compressor, the size of the additional compressor and compressor discharge temperatures.

[0056] All compressors, evaporators and expansion valves presented in this description could be single compressors, evaporators and expansion valves or compression racks, evaporator racks and expansion valve racks, comprising more than one compressor, evaporator or expansion valve.

[0057] The term back-pressure valve is referred to an expansion valve operating as back-pressure regulation.

DESCRIPTION OF THE DRAWINGS

[0058] To complement the description being made and in order to aid towards a better understanding of the characteristics of the invention, in accordance with a preferred example of practical embodiment thereof, a set of drawings is attached as an integral part of said description wherein, with illustrative and non-limiting character, the following has been represented:

Figure 1.- Shows a schematic view of a first embodiment of the booster refrigerant circuit of the invention.

Figure 2.- Shows a schematic view of a pressure-enthalpy diagram of the first embodiment of the booster refrigerant circuit of the invention in a first operation mode at ambient temperature of 40°C, wherein the vertical axis represents the pressure and the horizontal axis represents the enthalpy.

Figure 3.- Shows a schematic view of a pressure-enthalpy diagram of the first embodiment of the booster refrigerant circuit of the invention in a first operation mode at ambient temperature of 32°C, wherein the vertical axis represents the pressure and the horizontal axis represents the enthalpy.

Figure 4.- Shows a schematic view of a pressure-enthalpy diagram of the first embodiment of the booster refrigerant circuit of the invention in a first

operation mode at ambient temperature of 20°C, wherein the vertical axis represents the pressure and the horizontal axis represents the enthalpy.

Figure 5.- Shows a schematic view of a pressure-enthalpy diagram of the preferred embodiment of the booster refrigerant circuit of the invention in a second operation mode at 13°C, wherein the vertical axis represents the pressure and the horizontal axis represents the enthalpy.

Figure 6.- Shows a schematic view of a pressure-enthalpy diagram of the preferred embodiment of the booster refrigerant circuit of the invention in a third operation mode at ambient temperature of 10°C, wherein the vertical axis represents the pressure and the horizontal axis represents the enthalpy.

Figure 7.- Shows a schematic view of a second embodiment of the booster refrigerant circuit of the invention.

Figure 8.- Shows a schematic view of a pressure-enthalpy diagram of the second embodiment of the booster refrigerant circuit of the invention at ambient temperature of 40°C, wherein the vertical axis represents the pressure and the horizontal axis represents the enthalpy.

Figure 9.- Shows a diagram comparison between the mass flow rate of the additional compressors (different to medium and low temperature compressor) in a circuit with multi-ejectors (parallel compressors are the additional ones) and the refrigerant circuit of the invention (Comp. 1 and Comp.2 are the additional ones)

Figure 10.- Shows a diagram comparison of COP between the booster refrigerant circuit of the invention and a circuit with multi-ejectors.

Figure 11.- Shows a diagram comparison of annual energy consumption in different locations between the booster refrigerant circuit of the invention and a circuit with multi-ejectors.

PREFERRED EMBODIMENTS OF THE INVENTION

[0059] The present invention is directed to a booster refrigerant circuit able to increase the energy efficiency, particularly, when operating in changing-temperature ambients and reduce the overall power consumption.

[0060] Further advantages of the booster refrigerant are described in relation to figures, which represent particular embodiments of the invention non-limiting the scope of the invention defined by claims.

[0061] Figure 1 shows a first embodiment of the booster refrigerant circuit of the invention which comprises a

tank (8) configured to store a mixture of vapor and liquid R-744.

[0062] The liquid R-744 is transferred to an internal heat exchanger (11) by using a first R-744 liquid line (22). The internal heat exchanger (11) allows a heat transfer between a first flow of liquid R-744 and a second flow of liquid R-744, which is previously extracted from the tank (8) by means of a second R-744 liquid line (25) and expanded using a first expansion valve (12). The first flow of liquid R-744, after passing through the internal heat exchanger (11), is split for being circulated in a low-temperature line (23) and a medium-temperature line (21).

[0063] The medium-temperature line (21) comprises a medium-temperature expansion valve (13) connected to a medium-temperature evaporator (15), connected to a medium-temperature compressor (1). The low-temperature line (23), in turn, comprises a low-temperature expansion valve (14) connected to a low-temperature evaporator (16), connected to a low-temperature compressor (17). The low-temperature line (23) and the medium-temperature line (21) are connected to the first R-744 liquid line (22) upstream the medium-temperature expansion valve (13) and the low-temperature expansion valve (14).

[0064] The second flow of liquid R-744, after being passed through the internal heat exchanger (11), is connected by means of the second R-744 liquid line (25) to a suction line (30), which connects the low-temperature line (23), downstream the low-temperature compressor (17), and the medium-temperature line (21), downstream the medium-temperature evaporator (15), with inlet of the medium temperature compressor (1).

[0065] The mixture of the second flow of liquid R-744, after being passed through the internal heat exchanger (11), the R-744 exiting the medium-temperature evaporator (15) and the R-744 exiting the low-temperature compressor (17) is directed to the medium-temperature compressor (1), by using the suction line (30). Said compressed mixture is flowed to an adiabatic gas-cooler (4), for being cooled, by using a cooling line (31).

[0066] The vapor R-744 from the tank (8), in turn, is transferred by a R-744 vapor line (24) to a first heat exchanger (5), previously passing through a second back-pressure valve (9) or a second motorize valve (10), set in parallel to the first back-pressure valve (9).

[0067] Then, the R-744 in vapor state is directed to the suction line (30) at inlet of the medium-temperature compressor (1), passing through a first motorize valve (18), or to a parallel compressor (2), by using a first compression line (26), directing the compressed vapor R-744 to the outlet of the medium-temperature compressor (1).

[0068] The flow entering the adiabatic gas-cooler (4) is cooled and directed to the first heat exchanger (5) wherein a heat transfer is produced between said cooled flow exiting the adiabatic gas-cooler (4) and the vapor R-744 obtained from the tank (8).

[0069] Then, the cooled flow is divided into a high-pressure flow and a low-pressure flow, by means of a low-pressure line (28) and a high-pressure line (27). The high-

pressure flow is directed to a second heat exchanger (6), and then is flowed to the tank (8), previously passing through a back-pressure valve (7). The low-pressure flow is expanded in a second expansion valve (20) and, then, passes through the second heat exchanger (6), thus, being produced a heat transfer between the high-pressure flow and the low-pressure flow.

[0070] After being flowed through the second heat exchanger (6), the low-pressure flow is directed to a second compression line (29) for connection to an adaptative volume compressor (AVC) (3), previously passing through a three-way valve (19). The three-way valve (19) is also connected to the R-744 vapor line (24) at inlet of the parallel compressor (2). The compressed low-pressure flow is directed to the first compression line (26) at outlet of the parallel compressor (2).

[0071] The adaptative volume compressor (3) (AVC) has a lower compression ratio than the parallel compressor (2). The three-way valve (19) could be used for operating the adaptative volume compressor (3) as the parallel compressor (2), when it is more efficient or for maintenance processes.

[0072] Therefore, the compressed mixture exiting the medium-temperature compressor (1), the compressed vapor R-744 exiting the parallel compressor (2) and the compressed low-pressure flow exiting the adaptative volume compressor (3) are mixed and directed to the adiabatic gas-cooler (4), exiting the cooled flow.

[0073] The R-744 booster refrigerant circuit of the invention is intended for improving the energy efficiency in a variety of ambient temperatures. For achieving that, the R-744 booster refrigerant circuit could be operated in three different operation modes. Each operation mode is controlled by a controller. The controller includes a CPU (Central Processing Unit), a RAM (Random Access Memory) memory used by the CPU and a ROM (Read Only Memory) for storing control programs and information used by the CPU. The controller is configured to perform information processing and signal processing by the CPU executing the control programs to control operation of the booster refrigerant circuit.

[0074] A first operation mode is directed to high ambient temperatures. In this operation mode the second back-pressure valve (9) and the first motorize valve (18) are closed, the second motorize valve (10) is opened and the three-way valve (19) is configured to direct the low-pressure flow to the second compression line (29), for being compressed by the adaptative volume compressor (3), closing the way to the parallel compressor (2).

[0075] Therefore, the vapor R-744 obtained from the tank (8) passes through the second motorize valve (10), then, is directed to the first heat exchanger (5), and, then, to the parallel compressor (2). Also, the low-pressure flow exiting the second heat exchanger (6) is directed to the adaptative volume compressor (3) by using the three-way valve (19).

[0076] Figure 2 shows a representation of the enthalpy-pressure diagram of R-744, wherein the physical

state of the R-744 in the R-744 booster refrigerant circuit of the invention operating in the first operation mode is included. The R-744 stored in the tank (8) comprises liquid and vapor R-744.

[0077] The first flow of liquid R-744 is directed to the internal heat exchanger (11). The second flow of liquid R-744 is directed to the first expansion valve (12), wherein the pressure and the temperature are diminished and the enthalpy remains constant, and then to the internal heat exchanger (11).

[0078] In the internal heat exchanger (11), a heat transfer between the first flow of liquid R-744 and the expanded second flow of liquid R-744 is produced. Therefore, the temperature of the first flow of liquid R-744 is reduced and the temperature of the second flow of liquid R-744 is increased in the internal heat exchanger (11).

[0079] The first flow of liquid R-744 is divided into a low-temperature flow, flowing in the low-temperature line (23), and a medium-temperature flow, flowing in the medium-temperature line (21).

[0080] The low-temperature flow passes through the low-temperature expansion valve (14), wherein the pressure and the temperature are reduced and the enthalpy remains constant. The expanded low-temperature flow passes through the low-temperature evaporator (16), wherein the temperature and the enthalpy are increased and the pressure remains constant. Then, the low-temperature flow passes through the low-temperature compressor (17), wherein the pressure, the temperature and the enthalpy are increased.

[0081] The medium-temperature flow passes through the medium-temperature expansion valve (13), wherein the pressure and the temperature are reduced, less than in the low-temperature expansion valve (14), and the enthalpy remains constant. The expanded medium-temperature flow passes through the medium-temperature evaporator (15), wherein the temperature and the enthalpy are increased and the pressure remains constant. Then, the medium-temperature flow exiting the medium-temperature evaporator (15) is mixed with the second flow of liquid R-744 exiting the internal heat exchanger (11), and, then, with the low-temperature flow exiting the low-temperature compressor (17), said low-temperature flow reducing its temperature and enthalpy at constant pressure.

[0082] The mixture of the second flow of liquid R-744, after being passed through the internal heat exchanger (11), the R-744 exiting the medium-temperature evaporator (15) and the R-744 exiting the low-temperature compressor (17) is directed to the medium-temperature compressor (1), wherein the pressure, the temperature and the enthalpy are increased.

[0083] The vapor R-744 obtained from the tank (8) passes through the second motorize valve (10), wherein the pressure is maintained, and is directed to the first heat exchanger (5), wherein its enthalpy and temperature are increased at a constant pressure (negligible pressure losses).

[0084] Then, the vapor R-744 exiting the first heat exchanger (5) is directed to the parallel compressor (2), wherein its enthalpy, pressure and temperature are increased.

5 **[0085]** The cooled flow exiting the adiabatic gas-cooler (4) passes through the first heat exchanger (5), wherein its enthalpy and temperature are reduced at an almost constant pressure.

10 **[0086]** The cooled flow exiting the first heat exchanger (5) is divided into the high-pressure flow and the low-pressure flow. The high-pressure flow is directed to the second heat exchanger (6), wherein its enthalpy and temperature are reduced at an almost constant pressure.

15 **[0087]** The low-pressure flow is expanded in a second expansion valve (20), wherein its pressure and temperature are reduced at a constant enthalpy, and, then, passes through the second heat exchanger (6), wherein its enthalpy and temperature are increased at an almost constant pressure.

20 **[0088]** The high-pressure flow exiting the second heat exchanger (6), then, is flowed to a first back-pressure valve (7), which reduces its pressure to the storing pressure of the tank (8), and reduces its temperature maintaining constant its enthalpy.

25 **[0089]** The low-pressure flow exiting the second heat exchanger (6) passes through the three-way valve (19). Then, said low-pressure flow is directed to the adaptive volume compressor (3), wherein its enthalpy, pressure and temperature are increased.

30 **[0090]** Then, a mixture is done with R-744 exiting the medium-temperature compressor (1), which reduces its enthalpy and temperature at a constant pressure, the compressed vapor R-744 exiting the parallel compressor (2), which reduces its enthalpy and temperature at an almost constant pressure, and the compressed low-pressure flow exiting the adaptive volume compressor (3) (AVC), which increases its enthalpy and temperature at a constant pressure, and the mixture is directed to the adiabatic gas-cooler (4), wherein an evacuation of heat at an almost constant pressure is performed, reducing the enthalpy and temperature of the mixture, and exiting cooled flow.

35 **[0091]** Figures 3 and 4 shows the influence of the ambient temperature in the operation of the R-744 booster refrigerant circuit, moving down the whole diagram of performance, in the pressure axis.

40 **[0092]** A second operation mode is directed to medium ambient temperature. In this operation mode the second motorize valve (10) is closed, the second back-pressure valve (9) and the first motorize valve (18) are opened and the three-way valve (19) is configured to open the way to the adaptive volume compressor (3) and close the way to the parallel compressor (2).

45 **[0093]** Therefore, the vapor R-744 from the tank (8) passes through the second back-pressure valve (9), is directed to the first heat exchanger (5), and, then, to the medium-temperature compressor (1), by using the vapor R-744 line, passing through the first motorize valve (18).

Also, the low-pressure flow exiting the second heat exchanger (6) is directed to the adaptative volume compressor (3) by using the three-way valve (19).

[0094] Figure 5 shows a representation of the enthalpy-pressure diagram of R-744, wherein the physical state of the R-744 in the circuit operating in the second operation mode is included.

[0095] Firstly, the vapor R-744 from the tank (8) passes through the second back-pressure valve (9), instead of the second motorize valve (10), and consequently, the pressure is not maintained but is reduced at a constant enthalpy, thus reducing the temperature of said vapor R-744.

[0096] Also, the vapor R-744 exiting the first heat exchanger (5) is mixed with refrigerant flowing at inlet of the medium-temperature compressor (1). Therefore, the parallel compressor (2) is deactivated.

[0097] Also, the pressure of the low-pressure flow in the second expansion valve (20) is reduced more than in the first operation mode and the adaptative volume compressor (3) increases its compression ratio.

[0098] A third operation mode is directed to low ambient temperatures. In this operation mode the second motorize valve (10) is closed, the second back-pressure valve (9) and the first motorize valve (18) are opened and the three-way valve (19) is configured to close the way to the adaptative volume compressor (3) and the way to the parallel compressor (2), thus, not passing any flow through said three-way valve (19).

[0099] Therefore, the vapor R-744 from the tank (8) passes through the second back-pressure valve (9), is directed to the first heat exchanger (5), and, then, to the medium-temperature compressor (1), passing through the first motorize valve (18).

[0100] The R-744 booster refrigerant circuit of the invention could be simplified in order to improve the efficiency in high ambient temperatures, medium ambient temperatures and low ambient temperatures, two of them or just one. In this last case, for improving the energy efficiency just in low ambient temperatures, the second heat exchanger (6), the parallel compressor (2) and the adaptative volume compressor (3) could be removed.

[0101] Figure 6 shows a representation of the enthalpy-pressure diagram of R-744, wherein the physical state of the R-744 in the circuit operating in the third operation mode is included.

[0102] The low-pressure flow is not present; therefore, the high-pressure flow comprises the complete mass flow, which instead of passing through the second heat exchanger (6) is directed to the first back-pressure valve (7) directly and the adaptative volume compressor (3) is deactivated.

[0103] Figure 7 shows a second embodiment of the R-744 booster refrigerant circuit of the invention. In this embodiment, the first heat exchanger (5) and the second heat exchanger (6) are interchanged in position.

[0104] Therefore, the flow exiting the adiabatic gas-cooler (4) is divided into a high-pressure flow and a low-

pressure flow. The high-pressure flow is directed to the second heat exchanger (6). The low-pressure flow, in turn, is expanded in the second expansion valve (20), producing a two-phases state having a lower temperature than the high-pressure flow, and then passes through the second heat exchanger (6), thus, being produced a heat transfer between the high-pressure flow and the low-pressure flow.

[0105] The high-pressure flow exiting the second heat exchanger (6) is directed to the first heat exchanger (5), and then is flowed to the tank (8), previously passing through the first back-pressure valve (7).

[0106] The vapor R-744, as in the previous case, is transferred to the first heat exchanger (5), previously passing through the second back-pressure valve (9) or, alternatively, through the second motorize valve (10) set in parallel to the second back-pressure valve (9). Then, the vapor R-744 is directed to a parallel compressor (2), and the compressed vapor R-744 is directed to the adiabatic gas-cooler (4).

[0107] Thus, in the first heat exchanger (5) a heat transfer is produced between the high-pressure flow exiting the second heat exchanger (6) and the vapor R-744 obtained from the tank (8), in a saturated vapor state.

[0108] Figure 8 shows a representation of the enthalpy-pressure diagram of R-744, wherein the physical state of the R-744 in the second embodiment of the circuit operating in the first operation mode is included.

[0109] The heat transfer process of the first heat exchanger (5) and the second heat exchanger (6) are interchanged. As a consequence, the temperature at inlet of the parallel compressor (2) is reduced, since the heat transfer in the first heat exchanger (5) is performed just with the high-pressure flow instead of the complete flow exiting from the adiabatic gas-cooler (4), as in the first embodiment.

[0110] The figure 9 shows a diagram comparison of the aggregated mass flow rate flowing in the additional compressor between the R-744 booster refrigerant circuit of the invention and a circuit with multi-ejectors with parallel compression.

[0111] The aggregated mass flow rate of the R-744 booster refrigerant circuit of the invention is intermediate to the circuit with multi-ejectors with parallel compression, being more different both on increasing the ambient temperature.

[0112] The figure 10 shows a diagram comparison of COP between the R-744 booster refrigerant circuit of the invention and a circuit with multi-ejectors.

[0113] The COP of the R-744 booster refrigerant circuit of the invention is greater than the circuit with multi-ejectors at ambient temperatures from 12°C to 32°C.

[0114] The figure 11 shows a diagram comparison of annual energy consumption in different locations between the R-744 booster refrigerant circuit of the invention and a circuit with multi-ejectors.

[0115] The annual energy consumption of the R-744 booster refrigerant circuit of the invention is lower than

the circuit with multi-ejectors in every analyzed location, being especially lower in Athens and Seville.

[0116] The figure 12 also shows an embodiment which is a variation of the first embodiment of the booster refrigerant circuit of the invention wherein the three-way valve is replaced by a four way-valve having pinched one of way of the four-way valve. Therefore, the four-way valve operates as a switch mechanism connecting alternatively the second heat exchanger to the adaptative volume compressor (AVC) (3) or to the R-744 vapor line (24) at inlet of the parallel compressor (2).

Claims

1. A booster refrigerant circuit comprising:

- a tank (8) configured to store a liquid and vapor R-744
- a first R-744 liquid line (22), for circulating the liquid R-744 from the tank (8);
- a suction line (30);
- a medium-temperature line (21), for circulating the liquid R-744 connected to the first R-744 liquid line (22), and comprising at least one medium-temperature expansion valve (13) connected to at least one medium-temperature evaporator (15) connected to the suction line (30), which connects with at least one medium-temperature compressor (1);
- a low-temperature line (23), connected to the first R-744 liquid line (22), and comprising at least one low-temperature expansion valve (14) connected to at least one low-temperature evaporator (16) connected to at least one low-temperature compressor (17) connected to the suction line (30);
- a cooling line (31);
- a gas-cooler (4), connected to the at least one medium temperature compressor (1) by means of the cooling line (31);
- at least a first heat exchanger (5) connected to the gas-cooler (4);
- at least a first back-pressure valve (7), connected to the first heat exchanger (5), for reducing the pressure of the cooled flow, returning the cooled flow to the tank (8); and
- a R-744 vapor line (24), for circulating the vapor R-744, connecting the tank (8) with the first heat exchanger (5) and said first heat exchanger (5) with the suction line (30) upstream the at least one medium-temperature compressor (1).

2. The booster refrigerant circuit according to claim 1, further comprising:

- a second R-744 liquid line (25) for circulating a second flow of liquid R-744 from the tank (8);

- at least a first expansion valve (12), connected to the second R-744 liquid line (25) for expanding the second flow of liquid R-744;
- an internal heat exchanger (11), connected to the first R-744 liquid line (22) and the second R-744 liquid line (25) downstream the first expansion valve (12);

wherein, the second R-744 liquid line (25) connects the internal heat exchanger (11) suction line (30) upstream the at least one medium-temperature compressor (1).

3. The booster refrigerant circuit according to claims 1 or 2, further comprising at least a first motorize valve (18) connected to the R-744 vapor line (24) downstream the first heat exchanger (5).

4. The booster refrigerant circuit according to claim any one of preceding claims further comprising at least a second back-pressure valve (9) connected to the R-744 vapor line (24) upstream the first heat exchanger (5).

5. The booster refrigerant circuit according to claim 4, further comprising at least a second motorize valve (10) connected to the R-744 vapor line (24) in parallel to the at least one second back-pressure valve (9).

6. The booster refrigerant circuit according to claim any one of preceding claims, further comprising:

- at least one parallel compressor (2); and
- a first compression line (26) connected to the R-744 vapor line (24) downstream the first heat exchanger (5) and connecting the at least one parallel compressor (2) to the cooling line (31) downstream the at least one medium-temperature compressor (1).

7. The booster refrigerant circuit according to claim any one of preceding claims, further comprising:

- a high-pressure line (27), connected to the first heat exchanger (5), for circulating a high-pressure flow;
- a low-pressure line (28), connected to the high-pressure line (27) for dividing the cooled flow into the high-pressure flow and a low-pressure flow, and for circulating the low-pressure flow;
- at least one second expansion valve (20) connected to the low-pressure line (28) for expanding the low-pressure flow;
- a second heat exchanger (6) connected to the high-pressure line (27) and the at least one second expansion valve (20).

8. The booster refrigerant circuit according to claim 1

to 6, further comprising:

- a high-pressure line (27), connected to the adiabatic gas-cooler (4), for circulating a high-pressure flow;
- a low-pressure line (28), connected to the high-pressure line (27) for dividing the cooled flow into the high-pressure flow and a low-pressure flow, and for circulating the low-pressure flow;
- a second at least one expansion valve (20) connected to the low-pressure line (28) for expanding the low-pressure flow;
- a second heat exchanger (6) connected to the high-pressure line (27) and the at least one second expansion valve (20).

9. The booster refrigerant circuit according to claims 7 or 8, wherein the low-pressure line (28) is connected to the R-744 vapor line (24) at outlet of the first heat exchanger (5).

10. The booster refrigerant circuit according to 7 to 9, further comprising:

- a three-way valve (19) or a four-way valve connected to the low-pressure line (28) at downstream the second heat exchanger (6), for diverting the low-pressure flow to the R-744 vapor line (24) or to a second compression line (29);
- at least one adaptative volume compressor (3) connected to the second compression line (29)

wherein the second compression line (29) connects the at least one adaptative volume compressor (3) with the low-pressure line (28) downstream the at least one parallel compressor (2) or with the cooling line (21) downstream the at least one medium-temperature compressor (1).

11. A R-744 booster refrigerant system comprising the R-744 booster refrigerant circuit according to any of preceding claims, comprising the at least one second back-pressure valve (9), the at least one second motorize valve (10), the at least one first motorize valve (18), the at least one medium-temperature compressor (1) and the at least one parallel compressor (2), the system also comprising:

- an ambient temperature sensor for detecting an ambient temperature;
- a controller configured to switch between a first operation mode and a second operation mode, based on the ambient temperature detected by the ambient temperature sensor,
- the first operation mode being configured to close the at least one second back-pressure valve (9), open the at least one second motorize valve (10), close the at least one first motorize

valve (18), activate the at least one medium-temperature compressor (1) and activate the at least one parallel compressor (2), and the second operation mode being configured to open the at least one second back-pressure valve (9), close the at least one second motorize valve (10), open the at least one first motorize valve (18), activate the at least one medium-temperature compressor (1) and deactivate the at least one parallel compressor (2).

12. The booster refrigerant system according to claim 11, wherein the controller is further configured to switch between the first operation mode and a third operation mode based on an ambient temperature detected by the ambient temperature sensor, the first operation mode being configured to close the at least one first motorize valve (18), control the at least one second expansion valve (20) so that a superheat temperature approaches a target superheat temperature, activate the at least one medium-temperature compressor (1) and activate the at least one adaptative volume compressor (3), and the third operation mode being configured to open the at least one first motorize valve (18), close the at least one second expansion valve (20), activate the at least one medium-temperature compressor (1) and deactivate the at least one adaptative volume compressor (3).

13. The booster refrigerant system according to claim 12, wherein the controller is further configured to switch among the first operation mode, the second operation mode and the third operation mode based on an ambient temperature detected by the ambient temperature sensor, the first operation mode being configured to close the at least one second back-pressure valve (9), open the at least one second motorize valve (10), control the at least one second expansion valve (20) so that the superheat temperature approaches the target superheat temperature, activate the at least one parallel compressor (2) and activate the at least one adaptative volume compressor (3), the second operation mode being configured to open the at least one second back-pressure valve (9), close the at least one second motorize valve (10), control the at least one second expansion valve (20) so that the superheat temperature approaches the target superheat temperature, deactivate the at least one parallel compressor (2) and activate the at least one adaptative volume compressor (3), and the third operation mode being configured to close the at least one second back-pressure valve (9), close the at least one second motorize valve (10), close the at least one second expansion valve (20), deactivate the at least one parallel compressor (2) and deactivate the at least one adaptative volume

compressor (3),
wherein the controller is further configured to switch
from the third operation mode to the second operation
mode when the ambient temperature exceeds
a first predetermined value, and 5
to switch from the second operation mode to the first
operation mode when the ambient temperature exceeds
a second predetermined value,
the second predetermined value being higher than
the first predetermined value. 10

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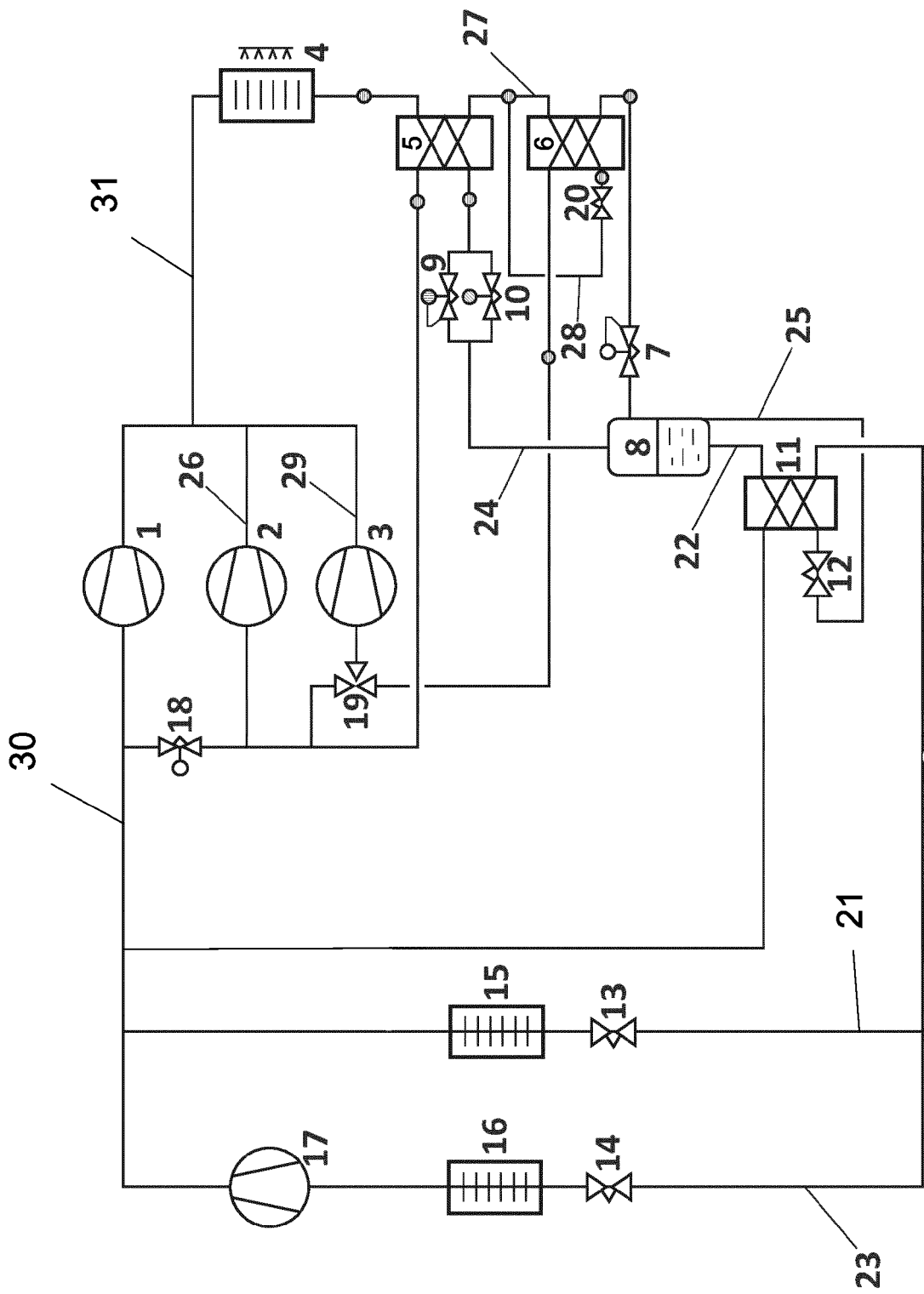


FIG. 1

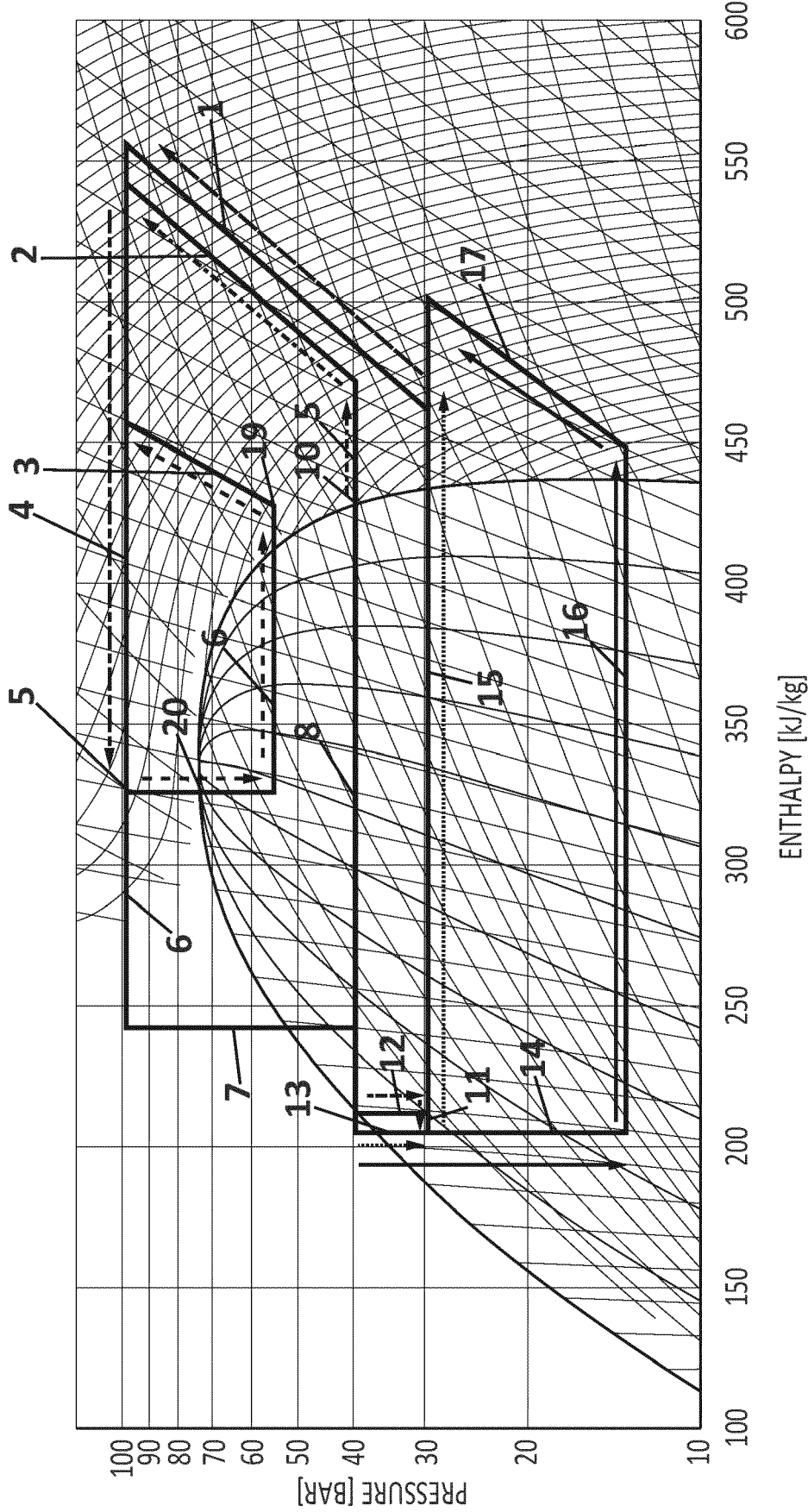


FIG. 2

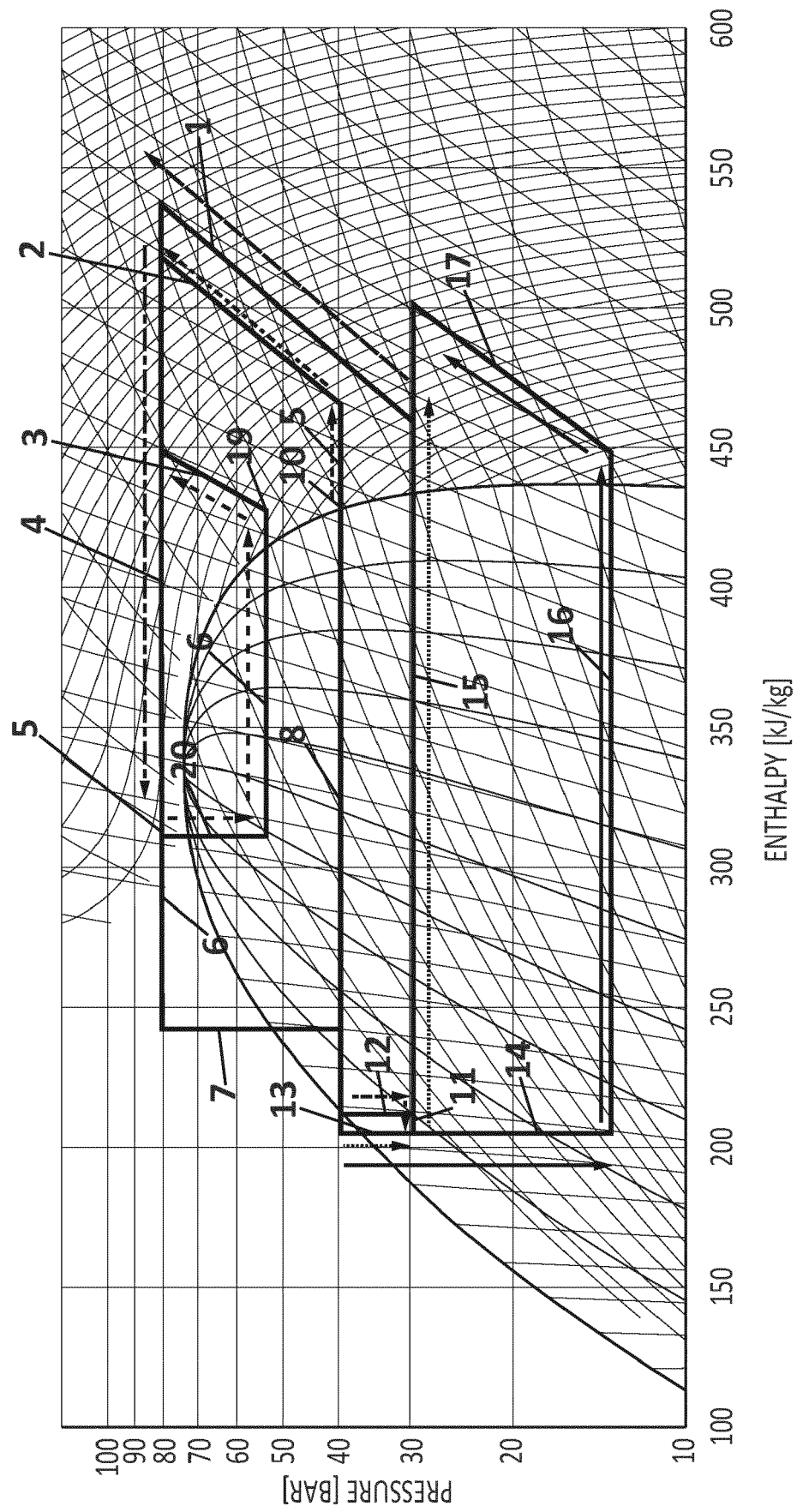


FIG. 3

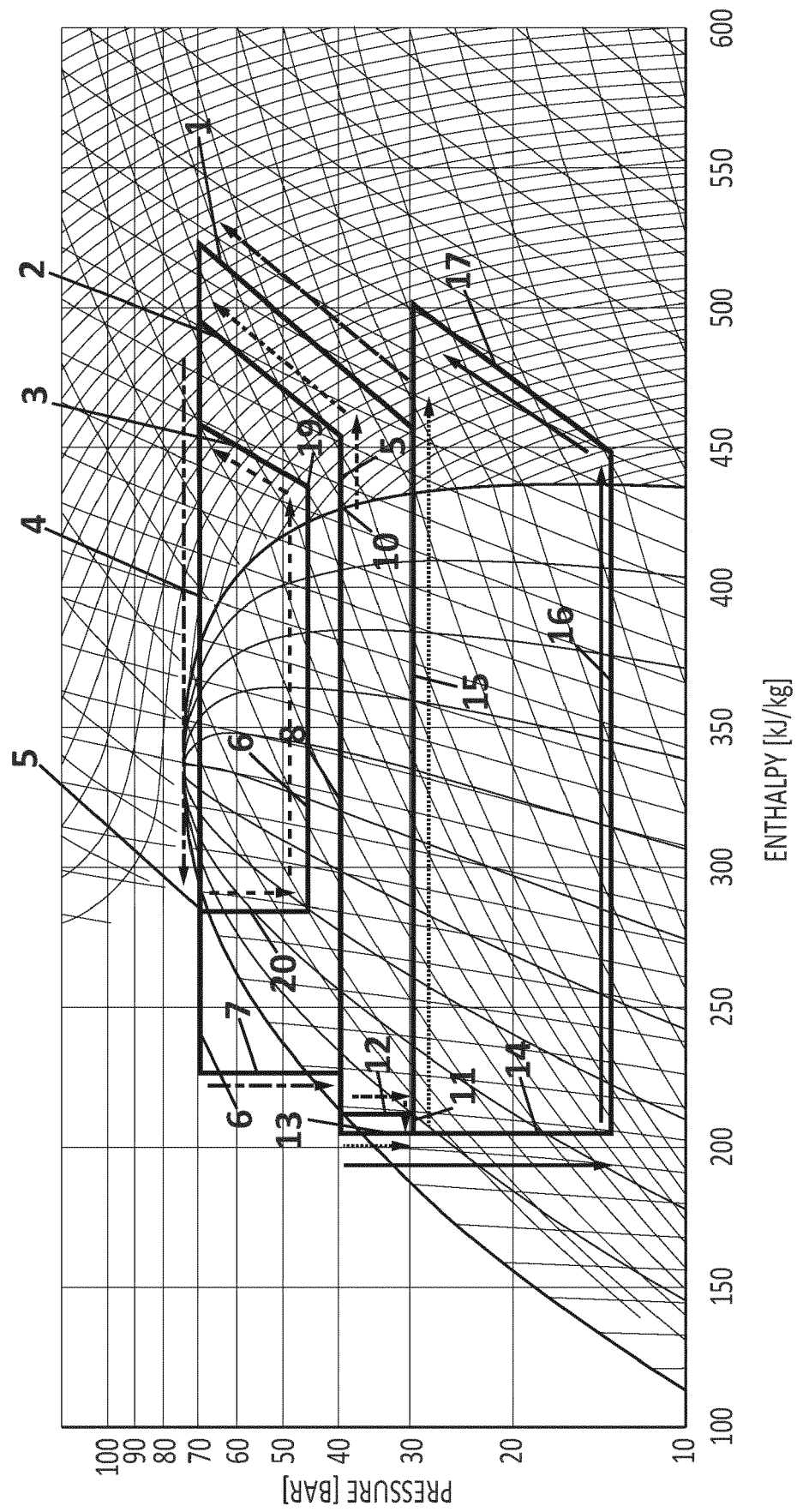


FIG. 4

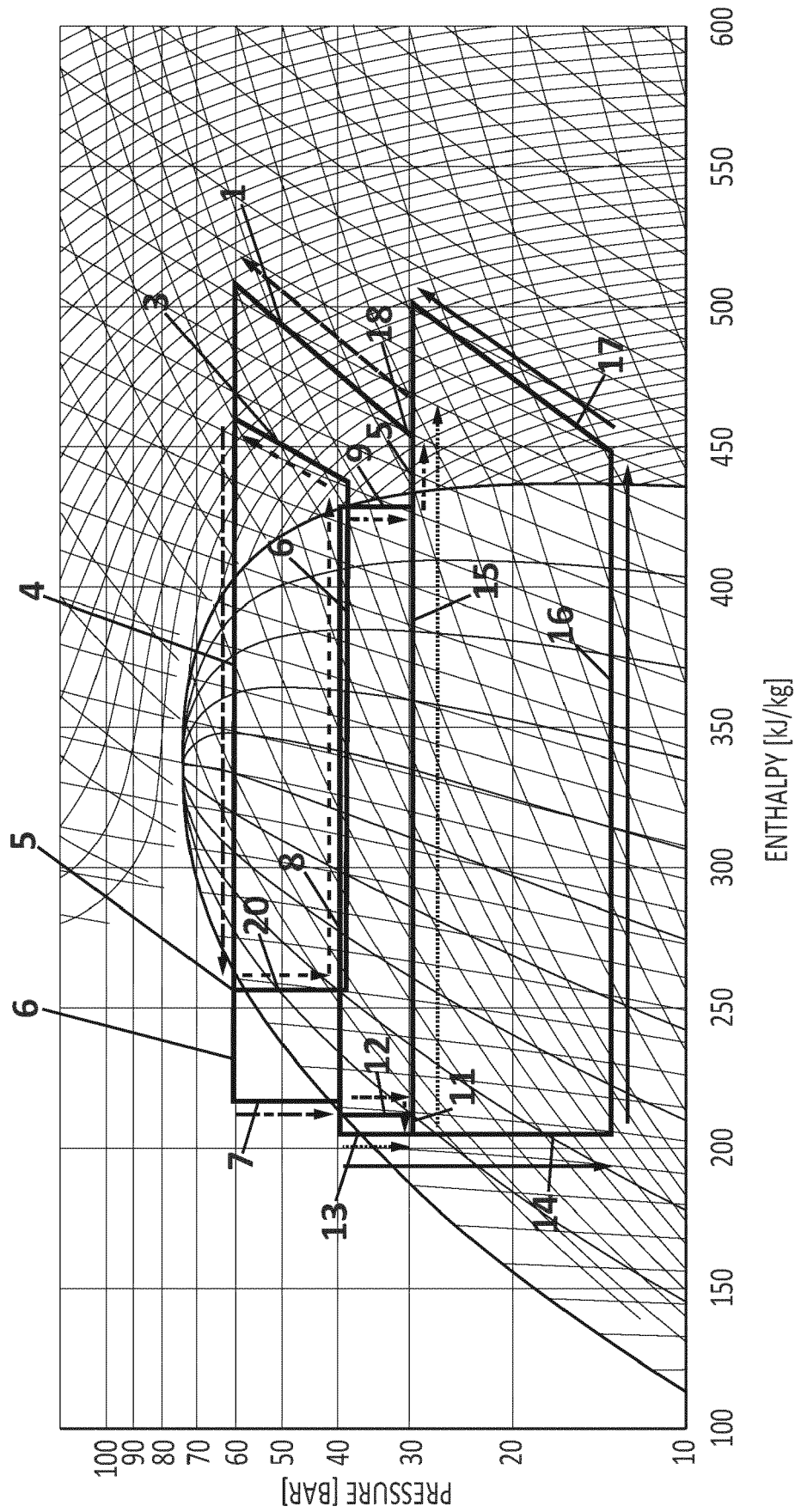


FIG. 5

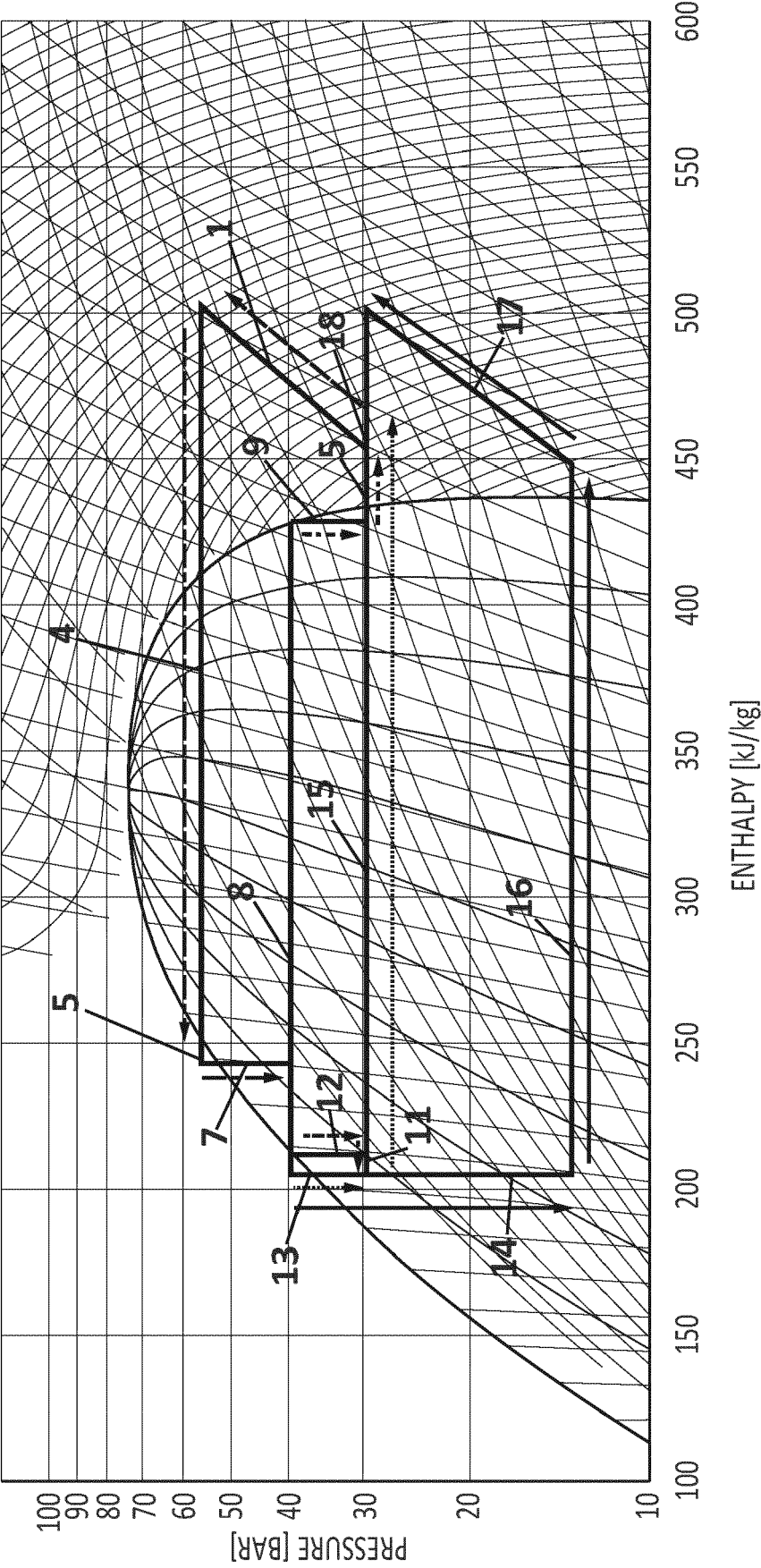


FIG. 6

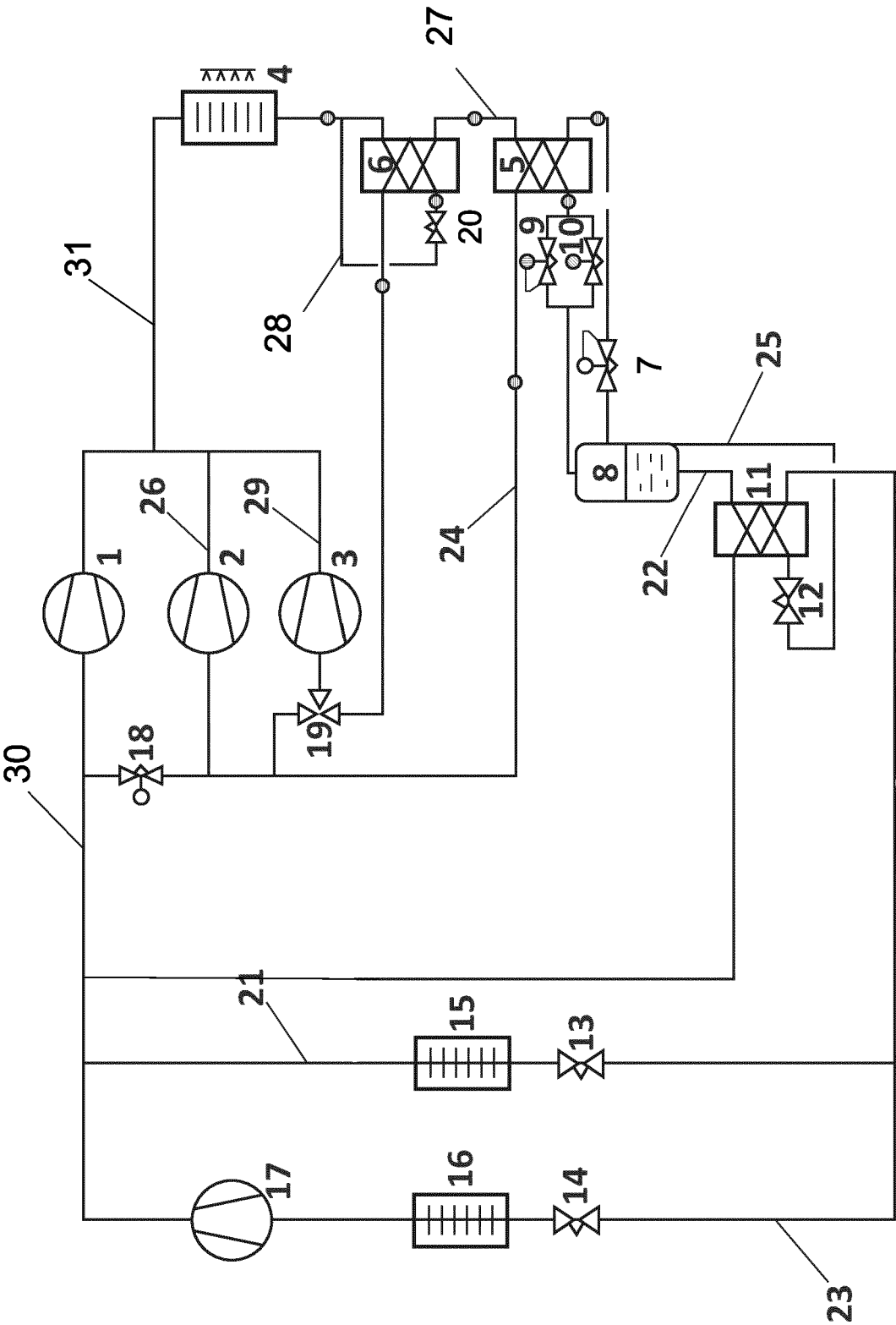


FIG. 7

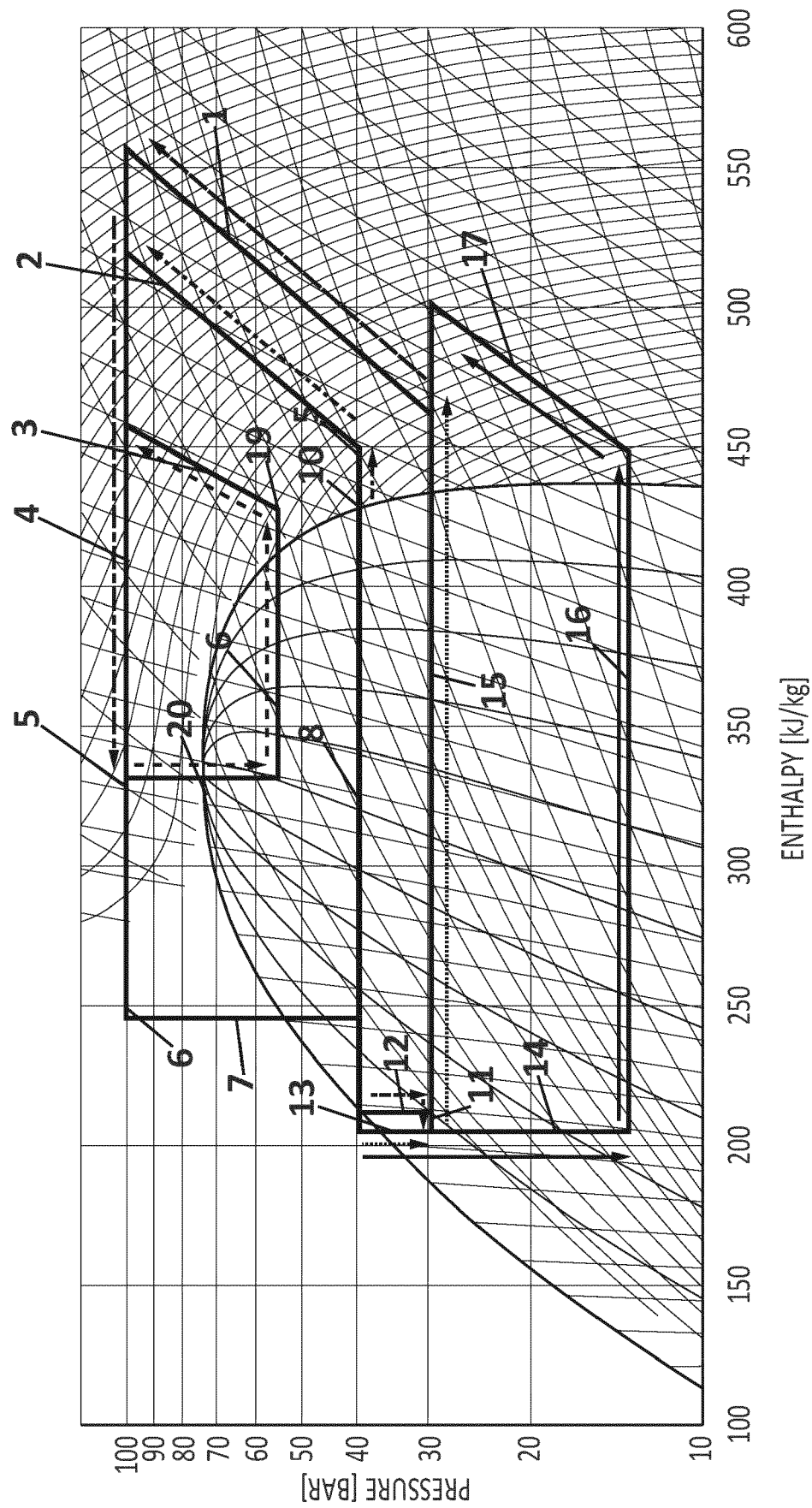


FIG. 8

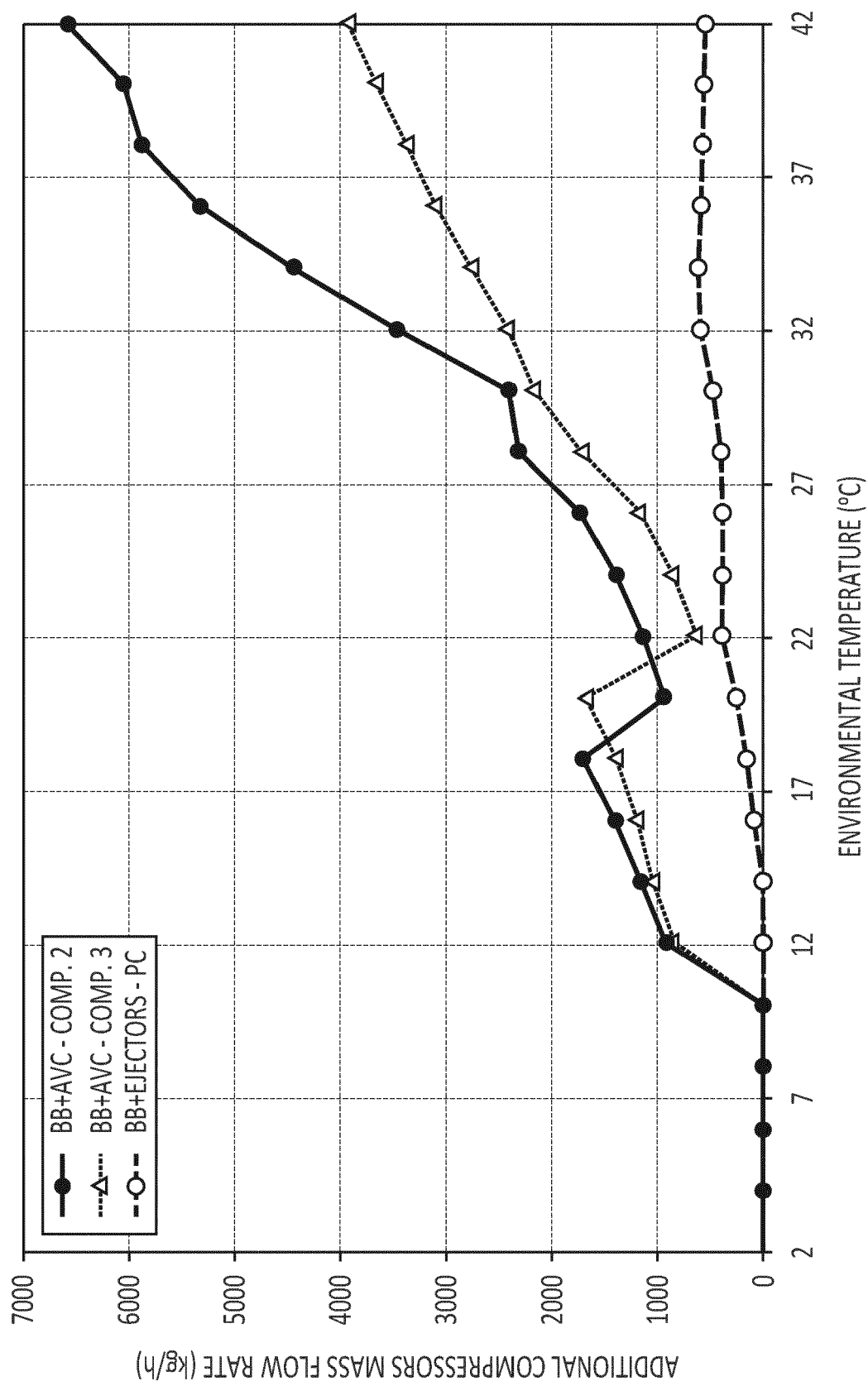
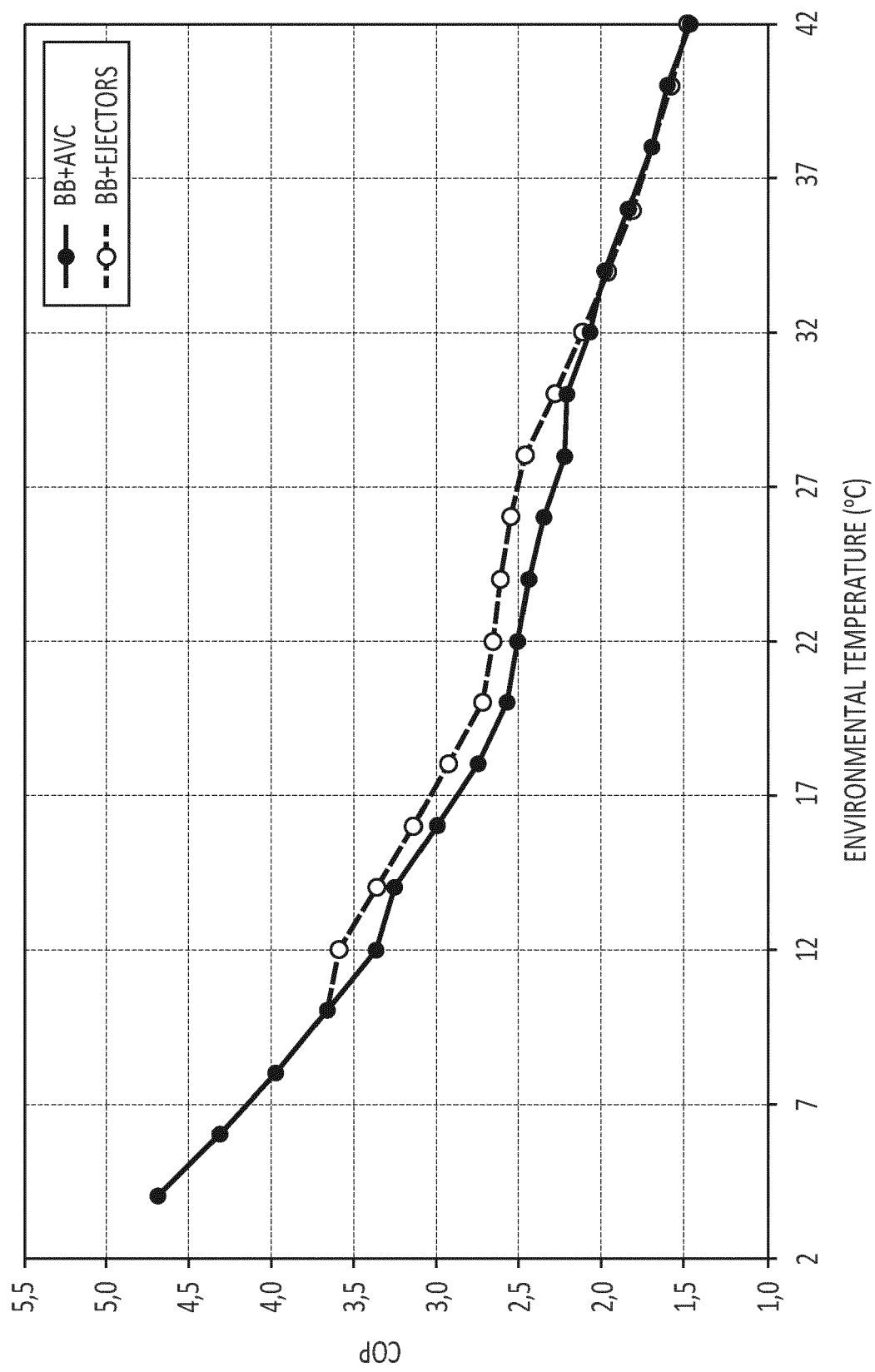


FIG. 9

**FIG. 10**

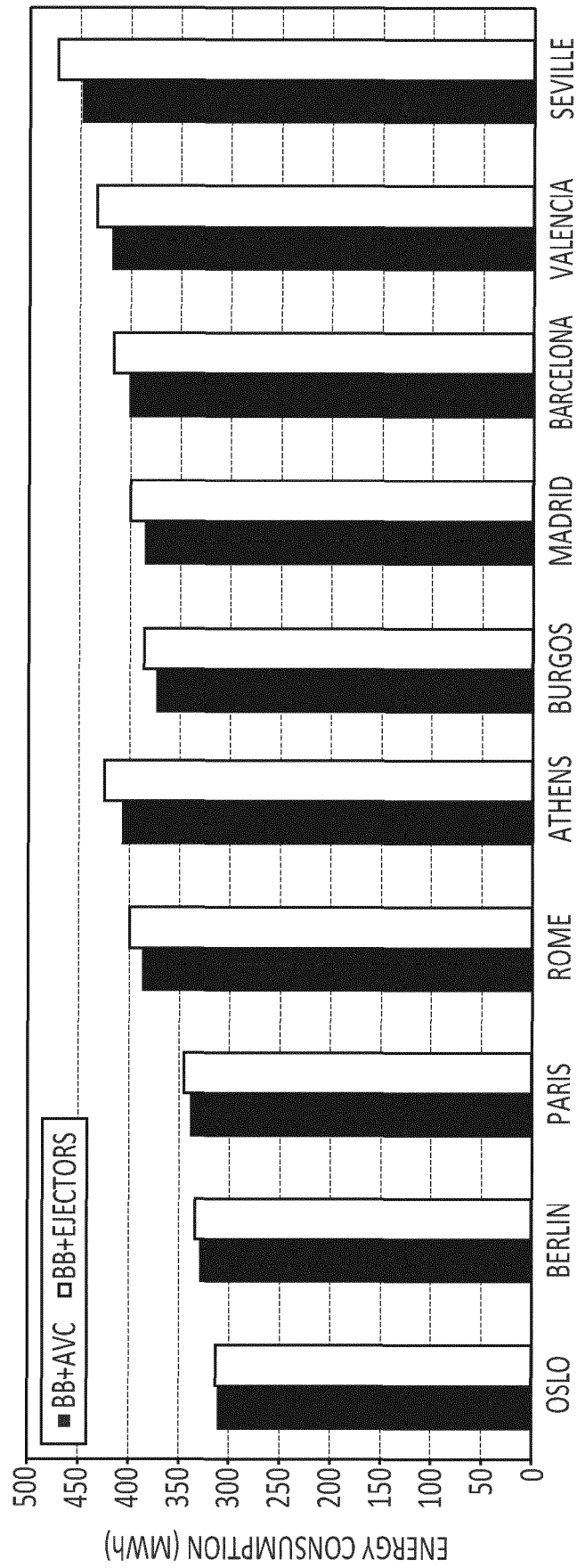


FIG. 11

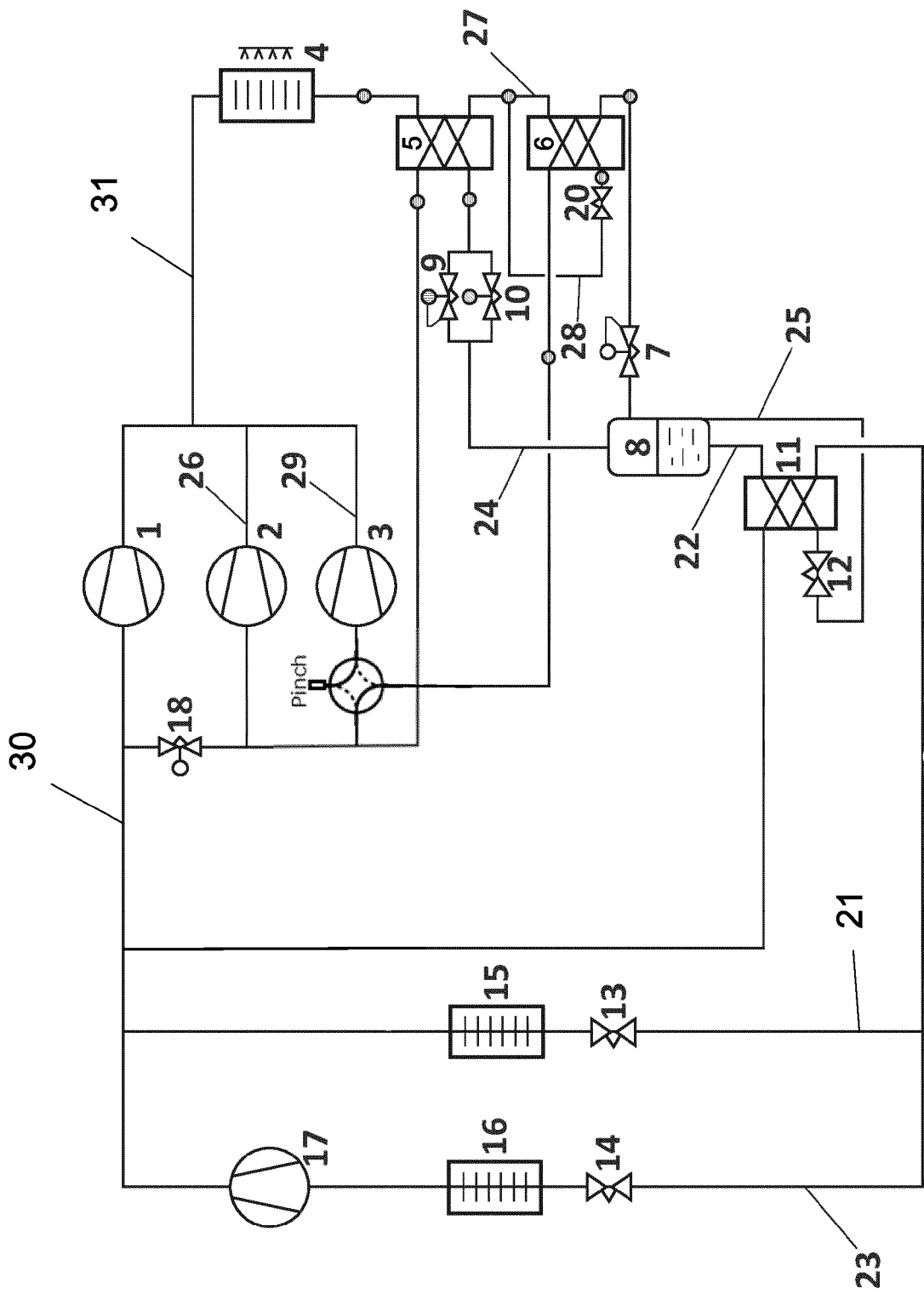


FIG.12



EUROPEAN SEARCH REPORT

 Application Number
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EPO FORM 1503 03.82 (P04C01)

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A	* the whole document *	2,7-13	
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			F25B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 24 August 2020	Examiner Lucic, Anita
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 20 38 2134

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The members are as contained in the European Patent Office EDP file on
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24-08-2020

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