



(11)

EP 4 818 597 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
07.10.2026 Bulletin 2026/41

(51) International Patent Classification (IPC):
F25B 13/00 ^(2006.01)

(21) Application number: **26162437.3**

(52) Cooperative Patent Classification (CPC):
F25B 13/00; F25B 49/02; F25B 2313/027;
F25B 2313/0292; F25B 2400/13; F25B 2500/09;
F25B 2500/15; F25B 2600/2509; F25B 2600/2513;
F25B 2600/2515; F25B 2700/21152

(22) Date of filing: **04.03.2026**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL
NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH LA MA MD TN

(72) Inventors:
• **DU, Terry Yu Qing**
Taicang, Jiangsu, 215400 (CN)
• **JIE, Li Karen**
Taicang, Jiangsu, 215400 (CN)
• **ZHANG, Gaogao**
Taicang, Jiangsu, 215400 (CN)
• **LU, Wei Qing**
Taicang, Jiangsu, 215400 (CN)

(30) Priority: **04.03.2025 CN 202510251577**

(74) Representative: **Haseltine Lake Kempner LLP**
One Portwall Square
Portwall Lane
Bristol BS1 6BH (GB)

(71) Applicants:
• **Trane Air Conditioning Systems (China) Co. Ltd.**
Suzhou, Jiangsu 215400 (CN)
• **Trane International Inc.**
Davidson, NC 28036 (US)

(54) **INJECTION AND CAPACITY CONTROL IN AN HVACR SYSTEM**

(57) A heating, ventilation, air conditioning, and refrigeration (HVACR) system includes at least one compressor, a heat exchanger, an expander, and a flow control device fluidly connected; and a controller. The flow control device is disposed downstream of the expander and the heat exchanger. The flow control device is further disposed upstream of an injection port of the at least one compressor. When a first operating parameter is greater than a first threshold, the controller is configured to modulate the expander to lower the first operating parameter and to modulate the flow control device to adjust an amount of injection into the injection port.

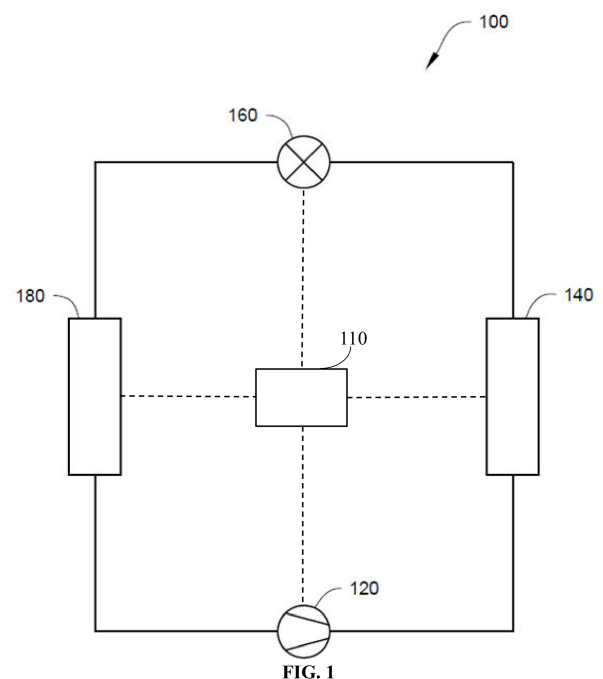


FIG. 1

EP 4 818 597 A1

Description

FIELD

[0001] The embodiments described herein pertain generally to systems and methods for injection and/or capacity control of a heating, ventilation, air conditioning, and refrigeration (HVACR) system. More specifically, the embodiments described herein pertain to injection and/or capacity control by modulating an expander and/or flow control device(s) in an HVACR system.

BACKGROUND

[0002] An HVACR system typically includes a compressor, a condenser, an expander, and an evaporator, forming a refrigeration circuit. In a cooling cycle or cooling mode, refrigerant vapor is generally compressed by the compressor, and then condensed to liquid refrigerant in the condenser. The liquid refrigerant can then be directed through the expander to reduce the temperature and become a liquid/vapor refrigerant mixture (two-phase refrigerant mixture). The two-phase refrigerant mixture can be directed into the evaporator to exchange heat with, for example, air or water moving across the evaporator. The two-phase refrigerant mixture can be vaporized to refrigerant vapor in the evaporator.

[0003] Some HVACR systems may be able to operate in a heating cycle. These HVACR systems are typically called heat pumps. During a heating cycle or heating mode, the process is generally reversed from the process in the cooling cycle. In the heating cycle, the evaporator in the cooling cycle functions as a condenser, and the condenser functions as an evaporator. After being compressed by the compressor, the compressed refrigerant vapor is typically directed to the evaporator first to release heat to, for example, the indoor air, which also condenses the refrigerant vapor to liquid refrigerant. The liquid refrigerant is then typically directed to the condenser through the expander to become a two-phase refrigerant mixture.

SUMMARY

[0004] In some HVACR systems, such as manifold-compressor systems with enhanced vapor injection (EVI) technology, where two or more compressors (such as scroll compressors, each having an injection port) are arranged in parallel, a flow control device such as a solenoid valve may be needed upstream of each injection port, to e.g., open or close the vapor injection. Because the pressure at the injection port may be oscillating, when a solenoid valve is used, the solenoid valve may be opened when the injection port pressure is high; and because the frequency of oscillating may also be relatively high, the solenoid valve may be damaged. That is, the pressure pulsations in the middle of the compressor(s) may cause the solenoid valve to conduct in reverse

at a very high frequency, which can damage the solenoid valve. In some embodiments, a check valve may be added between the solenoid valve and the injection port to prevent or reduce the damage to the solenoid valve.

However, such a solution may not help to adjust the heating and/or cooling capacity when there is a need for adjusting the liquid/wet injection to control the discharge temperature. In addition, due to the piping and compressor differences, or when the distribution of the liquid/wet injection is not desired, the compressors may have different discharge temperatures. As a result, too much liquid refrigerant may be injected into the compressor with a lower discharge temperature. The combination of the check valve and the solenoid valve may not be sufficient.

[0005] Features in the embodiments disclosed herein may provide a flow control device (e.g., a stepper-motor-actuated electric valve or a ball valve or the like, whose degree of opening can be continually adjustable) in the system between the compressors and an economizer, to open or close the injection. An expander (whose degree of opening can be continually adjustable) may be used for the economizer, whose outlet can be connected to the injection ports of the compressors arranged in parallel. When the discharge temperature of the compressor is lower than a threshold, vapor injection can be conducted, and the expander can be adjusted to control the refrigerant injection to change the heating and/or cooling capacity to meet the load requirements. When the discharge temperature is higher than the threshold, liquid/wet injection can be conducted, the expander can be adjusted to control the liquid refrigerant injection to control the discharge temperature, and the flow control device can be controlled to adjust the injection and the heating and/or cooling capacity. When a compressor has a much lower discharge temperature than other compressor(s), for liquid/wet injection, the flow control device can be controlled to balance the discharge temperature(s) of the compressors so that the discharge temperature(s) can be close to a target temperature. The expander can also be controlled to adjust the outlet temperature of the economizer to obtain an optimum evaporator inlet velocity and an optimum evaporating temperature.

[0006] Features in the embodiments disclosed herein may provide a degree-of-opening-adjustable flow control device that can withstand reverse pressure, preventing damage to the flow control device caused by the pressure pulsations from the compressor injection port. By adjusting the amount of injection, the heating or cooling capacity of the system can be controlled. When the discharge temperature is high, the heating or cooling capacity can be controlled by adjusting the degree of opening of the flow control device for the compressor injection port. In the event of discharge temperature imbalance, adjusting the degree of opening of the flow control device for the compressor injection port can prevent the compressor from excessive liquid injection, which may otherwise lead

to higher energy consumption. Adjusting the expander for the economizer to control the inlet temperature of the expander and the enthalpy of the expander can optimize the flow rate at the evaporator inlet.

[0007] In an example embodiment, a heating, ventilation, air conditioning, and refrigeration (HVACR) system is provided. The HVACR system includes at least one compressor, a heat exchanger, an expander, and a flow control device fluidly connected; and a controller. The flow control device is disposed downstream of the expander and the heat exchanger. The flow control device is further disposed upstream of an injection port of the at least one compressor. When a first operating parameter is greater than a first threshold, the controller is configured to modulate the expander to lower the first operating parameter and to modulate the flow control device to adjust an amount of injection into the injection port.

[0008] In another example embodiment, a method of operating a heating, ventilation, air conditioning, and refrigeration (HVACR) system is provided. The HVACR system includes at least one compressor, a heat exchanger, an expander, and a flow control device fluidly connected; and a controller. The flow control device is disposed downstream of the expander and the heat exchanger. The flow control device is further disposed upstream of an injection port of the at least one compressor. The method includes when a first operating parameter is greater than a first threshold, the controller modulating the expander to lower the first operating parameter and modulating the flow control device to adjust an amount of injection into the injection port.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The accompanying drawings illustrate various embodiments of systems, methods, and embodiments of various other aspects of the disclosure. Any person with ordinary skills in the art will appreciate that the illustrated element boundaries (e.g. boxes, groups of boxes, or other shapes) in the figures represent one example of the boundaries. It may be that in some examples one element may be designed as multiple elements or that multiple elements may be designed as one element. In some examples, an element shown as an internal component of one element may be implemented as an external component in another, and vice versa. Non-limiting and non-exhaustive descriptions are described with reference to the following drawings. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating principles. In the detailed description that follows, embodiments are described as illustrations only since various changes and modifications may become apparent to those skilled in the art from the following detailed description.

FIG. 1 illustrates a schematic diagram of an HVACR system including a refrigerant circuit, arranged in accordance with at least some embodiments de-

scribed herein.

FIG. 2 illustrates a schematic diagram of an HVACR system in the cooling mode, arranged in accordance with at least some embodiments described herein.

FIG. 3 illustrates a schematic diagram of an HVACR system in the heating mode, arranged in accordance with at least some embodiments described herein.

FIG. 4 is a flow chart illustrating an example processing flow for an injection control, arranged in accordance with at least some embodiments described herein.

FIG. 5 is a flow chart illustrating an example processing flow for an injection control, arranged in accordance with at least some embodiments described herein.

FIG. 6 is a flow chart illustrating an example processing flow for an injection control, arranged in accordance with at least some embodiments described herein.

DETAILED DESCRIPTION

[0010] In the following detailed description, particular embodiments of the present disclosure are described herein with reference to the accompanying drawings, which form a part of the description. In this description, as well as in the drawings, like-referenced numbers represent elements that may perform the same, similar, or equivalent functions, unless context dictates otherwise. Furthermore, unless otherwise noted, the description of each successive drawing may reference features from one or more of the previous drawings to provide clearer context and a more substantive explanation of the current example embodiment. Still, the example embodiments described in the detailed description, drawings, and claims are not intended to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein and illustrated in the drawings, may be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

[0011] It is to be understood that the disclosed embodiments are merely examples of the disclosure, which may be embodied in various forms. Well-known functions or constructions are not described in detail to avoid obscuring the present disclosure in unnecessary detail. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present disclosure in virtually any appropriately detailed structure.

[0012] Additionally, the present disclosure may be described herein in terms of functional block components and various processing steps. It is to be understood that

such functional blocks may be realized by any number of hardware and/or software components configured to perform the specified functions.

[0013] The scope of the disclosure should be determined by the appended claims and their legal equivalents, rather than by the examples given herein. For example, the steps recited in any method claims may be executed in any order and are not limited to the order presented in the claims. Moreover, no element is essential to the practice of the disclosure unless specifically described herein as "critical" or "essential".

[0014] As referenced herein, "directly" upstream or "directly" downstream means that no other components of a fluid circuit, other than fluid lines/connections/pipes for conveying the fluid are provided between such directly related elements. As referenced herein, "upstream" and "downstream" may refer to the direction of flow of the fluid or a component thereof through the fluid circuit.

[0015] As referenced herein, a "saturated temperature" is a term of art that may refer to a temperature at which a working fluid (e.g., a refrigerant) changes from a liquid to a vapor. It is to be understood that saturated temperature may be referred to as the boiling point. It is also to be understood that the saturation temperature of a liquid may vary depending on the pressure. For example, the saturation temperature of a liquid may increase as pressure increases.

[0016] As referenced herein, a degree of "superheat" is a term of art that may refer to a difference between the refrigerant's temperature and refrigerant's saturated temperature at a given pressure. It is to be understood that the degree of superheat can be the refrigerant's temperature minus the refrigerant's saturated temperature at the given pressure. It is also to be understood that the degree of superheat typically is a positive value and is for a vapor.

[0017] As referenced herein, the term "modulating" (or "modulate", "modulation", and the like) is a term of art that may refer to an action of controlling or adjusting a position or state of a device such as a flow control device (e.g., a valve such as a stepper-motor-actuated electric valve or a ball valve or other valve, a damper, a pump, and the like), an expander, and the like. It is to be understood that the device can be configured to control a fluid (e.g., working fluid) to flow through e.g., a passage (e.g., a pipe and the like). The device can have a fully-closed position or state at which the fluid can be prevented from flowing through the passage via the device. The device can also have a fully-open position or state at which the fluid can be flowing through the passage via the device without being blocked by the device. The device can further have a partially-open (or partially-closed) position or state at which the fluid can be flowing through the passage via the device with the fluid being partially blocked by the device. It is also to be understood that "modulating" a device includes controlling or adjusting a position or state of the device from a fully-open position or state, to a partially-open or partially-closed position or

state, and/or to a fully-closed position or state; or from a fully-closed position or state, to a partially-closed or partially-open position or state, and/or to a fully-open position or state. It is further to be understood that "modulating" a device is different from simply turning on or off (or simply open or close) the device, where "modulating" the device may include controlling or adjusting the device at a partially-open (or partially-closed) position or state (e.g., 5% open or closed, 10% open or closed, 15% open or closed, ... 95% open or closed, etc.).

[0018] FIG. 1 illustrates a schematic diagram of an HVACR system including a refrigerant circuit 100, arranged in accordance with at least some embodiments described herein.

[0019] In an example embodiment, the refrigerant circuit 100 can include a compressor 120, a condenser 140, an expander 160, and an evaporator 180. The refrigerant circuit 100 may also include a controller 110 configured to communicate with and/or control the operations of the compressor 120, the condenser 140, the expander 160, the evaporator 180, and/or other components (e.g., flow control device, sensor(s), or the like) of the HVACR system.

[0020] In an example embodiment, the controller 110 may include (or be connected to) a memory such as RAM and ROM and execute software (including, e.g., algorithms) that can be stored in the RAM (particularly during execution), the ROM (on a generally permanent basis), or another non-transitory computer readable medium such as other memory or disc. If necessary, the controller 110 can be connected to such memory or a disc drive to read such software. A microprocessor or other programmable device with suitable memory and I/O devices could also be used as the controller 110. It is to be understood that the processes and/or steps described in any of the figures can be conducted, implemented, and/or performed by one or more controllers including e.g., the controller 110 and/or any other suitable controller, unless otherwise specified.

[0021] In an example embodiment, the refrigerant circuit 100 can generally be applied in a variety of systems used to control an environmental condition (e.g., temperature, humidity, air quality, or the like) in a conditioned space. The conditioned space can be a space within an office building, a commercial building, a factory, a laboratory, a data center, a residential building, or the like. In an embodiment, the refrigerant circuit 100 can be configured to be a cooling system (e.g., an air conditioning system) capable of operating in a cooling mode. In an embodiment, the refrigerant circuit 100 can be configured to be a heat pump that can operate in a heating/defrost mode. It is appreciated that the refrigerant circuit 100 can be configured to operate in a cooling mode and/or a heating/defrosting mode. In an example embodiment, an HVACR system can include a refrigerant circuit 100 to heat or cool a process fluid (e.g., air, water and/or glycol, solution, or the like). A working fluid (e.g., one or more refrigerants) can flow through the refrigerant circuit 100

and be utilized to heat or cool the process fluid.

[0022] In an example embodiment, the compressor 120, the condenser 140, the expander 160, and the evaporator 180 can be fluidly connected. An "expander" as described herein may also be referred to as an expansion device. In an embodiment, the expander 160 can be an expansion valve, expansion plate, expansion vessel, orifice, or the like, or other such types of expansion mechanisms. It is to be understood that the expander 160 may be any suitable type of expander used in the field for expanding a working fluid to cause the working fluid to decrease in pressure and temperature.

[0023] It is to be understood that the refrigerant circuit 100 is an example and can be configured to include more or less components. For example, in an embodiment, the refrigerant circuit 100 can include other components such as, but not limited to, an economizer heat exchanger, one or more flow control devices (e.g., a valve such as a solenoid valve, a check valve, a butterfly valve, a ball valve, and the like; a damper, a pump; or the like.), a lubricant separator, a receiver tank, a dryer, a suction-liquid heat exchanger, one or more sensors (e.g., a temperature sensor, a pressure sensor, etc.), or the like.

[0024] In an example embodiment, the refrigerant circuit 100 can operate according to generally known principles. The refrigerant circuit 100 can be configured to heat and/or cool a liquid process fluid. The liquid process fluid can be a heat transfer fluid or medium (e.g., a liquid such as, but not limited to, water or the like). The refrigerant circuit 100 may be generally representative of a liquid chiller system. The refrigerant circuit 100 can alternatively be configured to heat and/or cool a gaseous process fluid (e.g., a heat transfer medium or fluid (e.g., a gas such as, but not limited to, air or the like), in which case the refrigerant circuit 100 may be generally representative of an air conditioner and/or heat pump.

[0025] In an example embodiment, the refrigerant circuit 100 can operate as a vapor-compression circuit such that the compressor 120 compresses a working fluid (e.g., a heat transfer fluid such as, but not limited to, refrigerant, fluorine, or the like) from a relatively lower pressure gas to a relatively higher-pressure gas. The relatively higher-pressure gas is at a relatively higher temperature, being discharged from the compressor 120 and flowing through the condenser 140. In accordance with generally known principles, the working fluid flows through the condenser 140 and rejects heat to the process fluid (e.g., water, solution, air, or the like), thereby cooling the working fluid. The cooled working fluid, which is now in a liquid form, flows to the expander 160 that can reduce the pressure of the working fluid. As a result, a portion of the working fluid is converted to a gaseous form. The working fluid, which is now in a mixed liquid and gaseous form flows to the evaporator 180. The working fluid flows through the evaporator 180 and absorbs heat from the process fluid (e.g., a heat transfer medium such as, but not limited to, water, a solution, air, fluorine, or the like, etc.), heating the working fluid, and converting it to a

gaseous form. The gaseous working fluid then returns to the compressor 120. The above-described process continues while the heat transfer circuit is operating, for example, in a cooling mode (e.g., while the compressor 120 is enabled).

[0026] In an example embodiment, the compressor 120 can compress the working fluid. Lubricant can be supplied to the compressor to provide lubrication for its moving parts. A lubricant may include one or more types of lubricants. For example, a lubricant can be, but is not limited to, polyolester oils, oil blends, or the like. The lubricant can be discharged from the compressor with the working fluid. Thus, the working fluid discharged from the compressor may contain lubricant. In some refrigerant circuits, the lubricant can also be separated from the working fluid and the separated lubricant can be circulated back to the compressor. In other refrigerant circuits, the lubricant can be circulated with the working fluid and can then be supplied through a suction inlet of the compressor as part of the working fluid. In an example embodiment, the working fluid may also include one or more additional components other than lubricant(s) and/or refrigerant(s).

[0027] FIG. 2 illustrates a schematic diagram of an HVACR system 200 in the cooling mode, arranged in accordance with at least some embodiments described herein. FIG. 3 illustrates a schematic diagram of the HVACR system 200 in the heating mode, arranged in accordance with at least some embodiments described herein. It is to be understood that the system 200 can include the refrigerant circuit 100 of FIG. 1. It is also to be understood that the direction of the arrows in FIG. 2 indicates the direction of the working fluid flow in a cooling mode, and the direction of the arrows in FIG. 3 indicates the direction of the working fluid flow in a heating mode.

[0028] As shown in FIGS. 2 and 3, the system 200 includes at least one compressor 10, a heat exchanger 20, a heat exchanger 30, a first expander 41, a second expander 42, and a flow control device 50. In an example embodiment, the heat exchanger 30 can be a coil. The flow control device 50 can be a four-way valve. The (at least one) compressor 10 can include one, two, three, or more compressors. The first expander 41 and the second expander 42 can be combined as one expander and additional corresponding flow control devices (e.g., check valves) can be disposed at the locations of the first expander 41 and the second expander 42, respectively.

[0029] In an example embodiment, the compressor 10 can compress low-pressure and low-temperature refrigerant gas into high-pressure and high-temperature refrigerant gas. The heat exchanger 20 and the heat exchanger 30 can serve as evaporator or condenser. The evaporator can absorb heat and evaporate the refrigerant liquid into refrigerant gas, and the condenser can dissipate heat and condense the refrigerant gas into refrigerant liquid. The expander (41, 42) can throttle the high-pressure refrigerant liquid to a low-pressure

state. The flow control device 50 can be used to switch the system 200 in different modes (e.g., a cooling mode, a heating mode, etc.).

[0030] In an example embodiment, the compressor 10 can have an outlet end 12 (e.g., a discharge pipe or end connecting to the discharge port of the compressor 10), an inlet end 11 (e.g., a suction and/or lubricant pipe or end connecting to the suction and/or lubricant port of the compressor 10), and an injection end 89 (e.g., an injection pipe or end connecting to the injection port of the compressor 10). The compressor(s) 10 can be arranged in parallel (e.g., the discharge pipes or ends 12 can be merged into a common discharge pipe and the suction and/or lubricant pipes or ends 11 can be separated from a common suction and/or lubricant pipe).

[0031] In an example embodiment, the compressor 10, the heat exchanger 20, and the heat exchanger 30 can all be connected to the flow control device 50. The flow control device 50 can be used to selectively communicate the heat exchanger 30 or the heat exchanger 20 with the outlet end 12 or the inlet end 11. The communication between the heat exchanger 20 and the heat exchanger 30 can be through the expander (41, 42).

[0032] In an example embodiment, the heat exchanger 20 can have a liquid phase end 21 and a gas phase end 22. The liquid phase end 21 can be connected to the expander 41, and the gas phase end 22 can be connected to the compressor 10 through the flow control device 50. The heat exchanger 30 can have a distribution end 31 and a reflux end 32. The distribution end 31 can be connected to the expander 42, and the reflux end 32 can be connected to the compressor 10 through the flow control device 50.

[0033] In an example embodiment, the system 200 can work in a cooling mode and/or a heating mode. As shown in FIG. 3, in the heating mode, the flow control device 50 can communicate the outlet end 12 with the heat exchanger 20 and communicates the inlet end 11 with the heat exchanger 30. The heat exchanger 20 serves as the condenser, and the heat exchanger 30 serves as the evaporator. The refrigerant in the system 200 can enter the heat exchanger 20 from the outlet end 12 of the compressor 10 through the flow control device 50, condense into refrigerant liquid in the heat exchanger 20, pass the optional heat exchanger 85 and enter the expander 42, and then enter the heat exchanger 30 from the expander 42. After evaporating into refrigerant gas in the heat exchanger 30, the refrigerant can return to the inlet end 11 of the compressor 10 through the flow control device 50.

[0034] As shown in FIG. 2, in the cooling mode, the flow control device 50 can communicate the outlet end 12 with the heat exchanger 30 and communicates the inlet end 11 with the heat exchanger 20. The heat exchanger 20 serves as the evaporator, and the heat exchanger 30 serves as the condenser. The refrigerant in the system 200 can enter the heat exchanger 30 from the outlet end 12 of the compressor 10 through the flow control device

50, condense into refrigerant liquid in the heat exchanger 30, enter the expander 41, and then enter the heat exchanger 20 from the expander 41. After evaporating into refrigerant gas in the heat exchanger 20, the refrigerant can return to the inlet end 11 of the compressor 10 through the flow control device 50.

[0035] In an example embodiment, the refrigerant in the system 200 can flow through the first expander 41 in the cooling mode and through the second expander 42 in the heating mode. This can ensure that the refrigerant has a suitable expansion process and pressure control in different modes, thereby improving the efficiency and heat exchange capacity of the system 200.

[0036] In an example embodiment, the system 200 can further optionally include a first check valve 91 and a second check valve 92 to prevent refrigerant backflow in different modes and ensure the correctness of refrigerant flow direction. The first check valve 91 can be provided between the liquid phase end 21 of the heat exchanger 20 and the first expander 41, and the second check valve 92 can be provided between the distribution end 31 of the heat exchanger 30 and the second expander 42.

[0037] In an example embodiment, the system 200 can further optionally include a filter dryer 93 disposed between the heat exchanger 20 and the heat exchanger 30, which can effectively filter impurities in the refrigerant, prevent moisture accumulation, improve refrigerant flow efficiency, protect key components in the system 200, and extend the service life of the system 200. Specifically, the filter dryer 93 can be connected between the first check valve 91 and the first expander 41 in the cooling mode, and can be connected between the second check valve 92 and the second expander 42 in the heating mode.

[0038] In an example embodiment, the system 200 can further optionally include a heat exchanger 85 disposed downstream of the filter dryer 93. The heat exchanger 85 can be an economizer. A temperature sensor 86 can be disposed at or near or downstream of the outlet of the economizer 85. In an example embodiment, the heat exchanger 85 can be a brazed plate heat exchanger. A first flow of working fluid (e.g., refrigerant) can flow through the heat exchanger 85 to exchange heat with a second flow of working fluid. The first flow of working fluid passed through the heat exchanger 85 can be split into a second flow of working fluid passing through the heat exchanger 85 via the optional expander 87 to exchange heat with the first flow of working fluid, and into a third flow of working fluid flowing towards the expander 41 in the cooling mode (or towards the expander 42 in the heating mode of FIG. 3). It is to be understood that the system 200 can further include a receiver (not shown) between the expander 41 and the heat exchanger 20. The expander 87 can be modulated (e.g., by the controller 110 of FIG. 1) to control the second flow of working fluid passing through the heat exchanger 85.

[0039] In an example embodiment, the outlet (downstream of the expander 87) of the heat exchanger 85 can

connect to an optional distributor 81 (e.g., a Y-shape pipe or connector or the like, etc.). It is to be understood that the number of outlets of the distributor 81 can be based on the number of the compressors 10 in the system. The outlet(s) of the distributor 81 can connect to the optional flow control device(s) 83. Each of the flow control device(s) 83 can connect to an injection port of each compressor 10 via the injection end or pipe 89. The flow control device(s) 83 can be modulated (e.g., by the controller 110 of FIG. 1) to control the vapor and/or liquid/wet injection flowing through the injection ends or pipe(s) 89 into the injection port(s) of the compressor(s) 10. The flow control device 83 can be a stepper-motor-actuated electric valve, a ball valve, or the like.

[0040] In an example embodiment, in the cooling mode, one flow path of the working fluid in the system 200 can be "compressor 10-heat exchanger 30-second check valve 92-filter dryer 93-heat exchanger 85-first expander 41-heat exchanger 20-compressor 10". In the heating mode (of FIG. 3), one flow path of the working fluid in the system 200 can be "compressor 10-heat exchanger 20-first check valve 91-filter dryer 93-heat exchanger 85-second expander 42-heat exchanger 30-compressor 10". The injection flow path of the working fluid can be "filter dryer 93- expander 87-heat exchanger 85-distributor 81-flow control device 83-compressor 10".

[0041] FIG. 4 is a flow chart illustrating an example processing flow 400 for an injection control, arranged in accordance with at least some embodiments described herein.

[0042] It is to be understood that the processing flow 400 disclosed herein can be conducted by one or more controllers including e.g., the controller 110 of FIG. 1 and/or any other suitable controller, unless otherwise specified.

[0043] It is also to be understood that the processing flow 400 can include one or more operations, actions, or functions as illustrated by one or more of blocks 410, 420, 430, 440, and 450. These various operations, functions, or actions may, for example, correspond to software, program code, or program instructions executable by a processor (e.g., a controller) that causes the functions to be performed. Although illustrated as discrete blocks, obvious modifications may be made, e.g., two or more of the blocks may be re-ordered; further blocks may be added; and various blocks may be divided into additional blocks, combined into fewer blocks, or eliminated, depending on the desired implementation. It is to be understood that before the processing flow 400, operations including initializations or the like may be performed. For example, system parameters may be initialized. It is to be understood that the processes, operations, or actions described in FIGS. 1-3 may be implemented or performed by the controller. Processing flow 400 may begin at block 410.

[0044] At block 410 (Initialize), the controller may be configured to e.g., start the HVACR system and initialize the components (e.g., sensors such as temperature

sensors, pressure sensors, etc.) of the system. Processing may proceed from block 410 to block 420.

[0045] At block 420 (Determine First Parameter), the controller may be configured to determine a load requirement e.g., based on the demand (e.g., a setpoint, etc.). The controller may also be configured to determine the minimum number of compressors (e.g., compressor 120 of FIG. 1, compressor 10 of FIGS. 2 and 3) required to be run and/or to turn on and/or off one or more compressors based on the load requirement. The controller may further be configured to determine a first operating parameter (e.g., a discharge temperature of the compressor) based on e.g., a measurement from the temperature sensor disposed at or near or downstream of the discharge port of the compressor. Processing may proceed from block 420 to block 430.

[0046] At block 430 (Exceed Threshold?), the controller may be configured to determine whether the first parameter determined at block 420 exceeds a threshold. When the first parameter exceeds the threshold (e.g., the discharge temperature is higher than a desired limit), processing may proceed from block 430 to block 440. When the first parameter does not exceed the threshold (e.g., the discharge temperature is not higher than the limit), processing may proceed from block 430 to block 450.

[0047] At block 440 (Modulate Valve and Expander), the controller may be configured to modulate a degree of opening of the expander (e.g., the expander 87 of FIGS. 2 and 3), to lower the first parameter towards or to reach the threshold (e.g., the discharge temperature limit). The controller may also be configured to modulate (e.g., decrease) a degree of opening of the flow control device (e.g., the flow control device 83 of FIGS. 2 and 3), to adjust the capacity of the system (e.g., to adjust a leaving water temperature or the like) e.g., based on the load requirement. Processing may proceed from block 440 back to block 420.

[0048] It is to be understood that when the discharge temperature exceeds the desired limit, wet/liquid injection may be performed. The expander 87 can be modulated to adjust or lower the discharge temperature to or towards the desired limit, and the flow control device 83 can be modulated (e.g., partially opened/closed and the degree of opening can be decreased) to control the amount of injection and/or to adjust the capacity. For example, when the leaving water temperature exceeds a target, the energy or capacity demand can be determined based on the water temperature feedback, and the flow control device 83 can be modulated accordingly. It is also to be understood that modulating the flow control device 83 can achieve an overlapping capacity that exceeds the capacity of a single compressor.

[0049] It is further to be understood that in the embodiments disclosed herein, when modulating the flow control device 83, increased back pressure may raise the pressure inside the economizer 85, reducing the temperature difference for heat exchange of the two-phase refriger-

ant, thereby decreasing the heat exchange amount. This may adjust the enthalpy and liquid amount of the refrigerant entering the compressor injection port, thus lowering the discharge temperature. When the discharge temperature decreases, the modulation of the expander 87 can be triggered. The frequency of modulating the flow control device 83 can be e.g., an iteration of the processing flow 400 (e.g., a water temperature cycle), while the frequency of modulating the expander 87 can be in real-time (e.g., based on the discharge temperature).

[0050] At block 450 (Modulate Expander), the controller may be configured to modulate a degree of opening of the expander 87 to adjust the capacity of the system (e.g., to adjust a leaving water temperature or the like) e.g., based on the load requirement. Processing may proceed from block 450 back to block 420.

[0051] It is to be understood that when the discharge temperature is below a control target, vapor injection may be performed. Energy or capacity regulation can be achieved through the expander 87 to modulate the amount of working fluid injected to the compressor 10. For example, the heating capacity of the system can be increased when the expander 87 is modulated as ON compared with the condition when the expander 87 is modulated as OFF, and such increase may be more significant when the ambient temperature is lower. By modulating the expander 87, stable cooling capacity and/or heating capacity can be achieved, resulting in a smooth temperature transition. Staged control or modulation of the expander 87 may allow for superheat or injection adjustments during dynamic processes.

[0052] FIG. 5 is a flow chart illustrating an example processing flow 500 for an injection control, arranged in accordance with at least some embodiments described herein.

[0053] It is to be understood that the processing flow 500 disclosed herein can be conducted by one or more controllers including e.g., the controller 110 of FIG. 1 and/or any other suitable controller, unless otherwise specified.

[0054] It is also to be understood that the processing flow 500 can include one or more operations, actions, or functions as illustrated by one or more of blocks 510, 520, 530, 540, and 550. These various operations, functions, or actions may, for example, correspond to software, program code, or program instructions executable by a processor (e.g., a controller) that causes the functions to be performed. Although illustrated as discrete blocks, obvious modifications may be made, e.g., two or more of the blocks may be re-ordered; further blocks may be added; and various blocks may be divided into additional blocks, combined into fewer blocks, or eliminated, depending on the desired implementation. It is to be understood that before the processing flow 500, operations including initializations or the like may be performed. For example, system parameters may be initialized. It is to be understood that the processes, operations, or actions described in FIGS. 1-3 may be implemented or per-

formed by the controller. Processing flow 500 may begin at block 510.

[0055] At block 510 (Initialize), the controller may be configured to e.g., start the HVACR system and initialize the components (e.g., sensors such as temperature sensors, pressure sensors, etc.) of the system. Processing may proceed from block 510 to block 520.

[0056] At block 520 (Determine Second Parameter), for each running compressor, the controller may be configured to determine an operating parameter (e.g., a discharge temperature of the compressor) based on e.g., a measurement from the temperature sensor disposed at or near or downstream of the discharge port of the compressor. For each running compressor, the controller may also be configured to determine a pressure ratio (e.g., a ratio of the discharge pressure to the suction pressure). When the pressure ratio does not exceed a threshold, no modulation of the flow control device 83 may be performed until the next iteration of the processing flow 500. When the pressure ratio exceeds the ratio threshold, the controller may further be configured to determine a second operating parameter (e.g., the largest difference between the first operating parameters (e.g., the discharge temperatures or the like) of any pair of running compressors, or the largest difference among the first operating parameters of all running compressors). Processing may proceed from block 520 to block 530.

[0057] At block 530 (Exceed Threshold?), the controller may be configured to determine whether the second parameter determined at block 520 exceeds a threshold. When the second parameter exceeds the difference threshold, processing may proceed from block 530 to block 540. When the second parameter does not exceed the difference threshold, processing may proceed from block 530 to block 550.

[0058] At block 540 (Modulate Valve), the controller may be configured to modulate (e.g., decrease) a degree of opening of the flow control device (e.g., the flow control device 83 of FIGS. 2 and 3), to adjust the first operating parameter (e.g., the discharge temperature) of the running compressor having a lower first parameter, to lower the second parameter towards the difference threshold. Processing may proceed from block 540 back to block 520.

[0059] At block 550 (Take No Action), no modulation of the flow control device 83 may be performed until the next iteration of the processing flow 500. Processing may proceed from block 550 back to block 520.

[0060] It is to be understood that running compressors arranged in parallel may exhibit some differences in discharge temperatures due to e.g., the design of the suction piping, individual compressor variations, and/or uneven distribution of the working fluid injection. For example, working fluid in the injection pipe tends to enter the upstream compressor first, resulting in lower discharge temperatures for those compressors. If working fluid at the economizer 85 outlet is unevenly distributed, it

may cause significant discharge temperature differences. Controlling high discharge temperatures (e.g., discharge temperatures higher than a first threshold) but not the low ones (e.g., discharge temperatures lower than a second threshold which is lower than the first threshold) may lead to excessive working fluid injection into compressors with lower discharge temperatures, reducing energy efficiency and necessitating adjustments. Features in the embodiments disclosed herein may modulate (e.g., decrease the degree of opening) the flow control device 83 (e.g., of the compressor having a lower discharge temperature) when the discharge temperature difference of any running compressor-pair exceeds a threshold.

[0061] FIG. 6 is a flow chart illustrating an example processing flow 600 for an injection control, arranged in accordance with at least some embodiments described herein.

[0062] It is to be understood that the processing flow 600 disclosed herein can be conducted by one or more controllers including e.g., the controller 110 of FIG. 1 and/or any other suitable controller, unless otherwise specified.

[0063] It is also to be understood that the processing flow 600 can include one or more operations, actions, or functions as illustrated by one or more of blocks 610, 620, 630, 640, and 650. These various operations, functions, or actions may, for example, correspond to software, program code, or program instructions executable by a processor (e.g., a controller) that causes the functions to be performed. Although illustrated as discrete blocks, obvious modifications may be made, e.g., two or more of the blocks may be re-ordered; further blocks may be added; and various blocks may be divided into additional blocks, combined into fewer blocks, or eliminated, depending on the desired implementation. It is to be understood that before the processing flow 600, operations including initializations or the like may be performed. For example, system parameters may be initialized. It is to be understood that the processes, operations, or actions described in FIGS. 1-3 may be implemented or performed by the controller. Processing flow 600 may begin at block 610.

[0064] At block 610 (Initialize), the controller may be configured to e.g., start the HVACR system and initialize the components (e.g., sensors such as temperature sensors, pressure sensors, etc.) of the system. Processing may proceed from block 610 to block 620.

[0065] At block 620 (Determine Third Parameter), the controller may be configured to determine some operating parameters (e.g., a suction temperature of the compressor, a suction pressure of the compressor, a temperature at or near or downstream of the outlet of the expander 87 or of the economizer 85, etc.) based on e.g., measurements from the sensors. The controller may also be configured to determine a third operating parameter (e.g., a velocity such as a velocity of working fluid at or near the inlet of the evaporator, at or near the inlet of the

coil, at or near or upstream of a distributor of the coil, etc.) based on a mass flow, which can be determined based on the determined operating parameters. Processing may proceed from block 620 to block 630.

[0066] At block 630 (Out of Range?), the controller may be configured to determine whether the third parameter determined at block 620 is out of a range (e.g., below a minimum threshold or above a maximum threshold). When the third parameter is out of the range, processing may proceed from block 630 to block 640. When the third parameter is not out of the range (e.g., within the range), processing may proceed from block 630 to block 650.

[0067] At block 640 (Modulate Expander and/or Valve), the controller may be configured to modulate a degree of opening of the expander 87 and/or a degree of opening of the flow control device 83, to adjust the third parameter toward the range. In an example embodiment, when the third parameter is below the minimum threshold and the first parameter (e.g., a discharge temperature) does not exceed the desired limit, the controller may be configured to modulate (e.g., decrease) a degree of opening of the expander 87, to adjust the third parameter toward the range. When the third parameter is below the minimum threshold and the first parameter exceeds the desired limit, the controller may be configured to modulate (e.g., decrease) a degree of opening of the flow control device 83, to adjust the third parameter toward the range.

[0068] In an example embodiment, when the third parameter is above the maximum threshold and the first parameter (e.g., a discharge temperature) does not exceed the desired limit, the controller may be configured to determine an operating parameter such as a superheat of the expander 87. When the superheat exceeds a threshold, the controller may be configured to e.g., adjust (e.g., increase) a setpoint of the superheat. When the superheat does not exceed the superheat threshold, no modulation of the flow control device 83 and/or the expander 87 may be performed until the next iteration of the processing flow 600. When the third parameter is above the maximum threshold and the first parameter exceeds the desired limit, the controller may be configured to modulate (e.g., decrease) a degree of opening of the flow control device 83, to adjust the third parameter toward the range. Processing may proceed from block 640 back to block 620.

[0069] At block 650 (Take No Action), no modulation of the flow control device 83 and/or the expander 87 may be performed until the next iteration of the processing flow 600. Processing may proceed from block 650 back to block 620.

[0070] It is to be understood that a desired or optimal working fluid velocity (e.g., a velocity of working fluid at or near the inlet of the evaporator, at or near the inlet of the coil, at or near or upstream of a distributor of the coil, at or near an outlet of the expander or of the economizer, etc.) may be needed for the optimized working fluid distribution at the evaporator inlet. The modulation of the expander 87 can change the temperature at the economi-

zer outlet, control the dryness and flow rate of the working fluid at the expander (41 or 42) outlet, and thereby control the velocity at the evaporator inlet, achieving an optimal evaporating temperature. A temperature sensor 86 can be disposed at or near or downstream of the outlet of the economizer, and the velocity at the economizer can be determined based on a measurement of such temperature sensor 86, the suction pressure, and the suction temperature. By adjusting the measurement of such temperature sensor 86 (e.g., by modulating the flow control device 83 and/or the expander 87), the velocity can be brought into the optimal range, avoiding non-desired working fluid distribution. It is also to be understood that when such temperature sensor 86 is not available, the degree of opening of the expander 87 can be modulated based on e.g., a change or changes in a suction superheat.

[0071] Features in the embodiments disclosed herein may provide a system with the enhanced vapor injection technology and with compressors arranged in parallel to maximize the system's operating map and energy efficiency. It to be understood that the system can adjust the number of compressors being switched on or off to regulate or adjust the (heating and/or cooling) capacity and can regulate energy or capacity by adjusting the amount of vapor and/or liquid/wet injection. In the cooling mode, the temperature and enthalpy entering the expander can be adjusted to achieve various enthalpy differences and cooling capacities at similar working fluid flow rates. In the heating mode, adjusting the amount of injection can result in different working fluid flow rates through the condenser, achieving different working fluid flow rates and heating capacities under similar enthalpy differences. However, when the pressure differences (between the discharge pressure and the suction pressure) is higher than a threshold, where wet steam or liquid needs to be injected, energy or capacity regulation may not be achieved by partially closing the expander because partially closing the expander may cause the injection to become superheated, leading to an increase in injection temperature and resulting in the compressor discharge temperature exceeding its limit. In such cases, using an on-off valve may not effectively regulate energy or capacity. Features in the embodiments disclosed herein may provide a solution to effectively regulate the energy and/or capacity.

[0072] It is to be understood that when the discharge temperature is higher than a threshold, if the compressor injects enthalpy, the load can become too large, which may lead to compressor bearing overload. In addition, due to the inconsistencies in discharge temperatures between compressors or issues with the distribution of wet steam for injection, some compressors may have lower discharge temperatures than others. Controlling high discharge temperatures (e.g., discharge temperatures higher than a first threshold) but not the low ones (e.g., discharge temperatures lower than a second threshold which is lower than the first threshold) may

result in compressors with lower discharge temperatures injecting excessive amounts of liquid refrigerant, which may not be resolved by using check valves or on-off valves. Features in the embodiments disclosed herein may provide a degree-of-opening-adjustable flow control device (e.g., a stepper-motor-actuated electric valve or a ball valve or the like) with corresponding control methods to (i) withstand reverse pressure, preventing valve damage caused by pressure pulsations, (ii) control the cooling capacity or heating capacity by adjusting the amount of injection and to control the precision of the leaving water temperature, (iii) control the cooling capacity or heating capacity by adjusting the degree of opening of the compressor injection valve when the discharge temperatures is higher than a threshold, (iv) to adjust flow control device to provide minimal injection and to avoid excessively high discharge temperatures when the compressor bearing load is too high, (v) adjust the degree of opening of the compressor injection valve to prevent excessive wet/liquid injection into the compressor, which may otherwise lead to higher energy consumption, when there is discharge temperature imbalance, and (vi) adjust the expander to control its inlet temperature and enthalpy to optimize the flow rate at the evaporator inlet, avoiding uneven frosting and ensuring effective heating.

ASPECTS:

[0073] It is to be understood that any one of aspects can be combined with each other.

[0074] Aspect 1. A heating, ventilation, air conditioning, and refrigeration (HVACR) system, comprising: at least one compressor, a heat exchanger, an expander, and a flow control device fluidly connected; and a controller, wherein the flow control device is disposed downstream of the expander and the heat exchanger, the flow control device is further disposed upstream of an injection port of the at least one compressor, when a first operating parameter is greater than a first threshold, the controller is configured to modulate the expander to lower the first operating parameter and to modulate the flow control device to adjust an amount of injection into the injection port.

[0075] Aspect 2. The HVACR system of aspect 1, wherein the flow control device is a stepper-motor-actuated electric valve.

[0076] Aspect 3. The HVACR system of aspect 1 or aspect 2, wherein the heat exchanger is an economizer, the expander is configured to adjust a working fluid flowing into the economizer.

[0077] Aspect 4. The HVACR system of any one of aspects 1-3, wherein the first operating parameter is a discharge temperature.

[0078] Aspect 5. The HVACR system of any one of aspects 1-4, wherein when the first operating parameter is not greater than the first threshold, the controller is further configured to modulate the expander to adjust an operating capacity.

[0079] Aspect 6. The HVACR system of aspect 5, wherein the operating capacity includes a leaving water temperature.

[0080] Aspect 7. The HVACR system of any one of aspects 1-6, wherein the at least one compressor includes two or more compressors, when a difference among first operating parameters of the two or more compressors is greater than a second threshold, the controller is further configured to modulate the flow control device to lower the difference.

[0081] Aspect 8. The HVACR system of any one of aspects 1-7, wherein the controller is further configured to determine a velocity of a working fluid, when the velocity is outside of a predetermined range, the controller is further configured to modulate the expander to adjust the velocity.

[0082] Aspect 9. The HVACR system of aspect 8, further comprising: a temperature sensor disposed at or around an outlet of the heat exchanger, wherein the controller is configured to determine the velocity based on a suction temperature, a suction pressure, and a measurement from the temperature sensor.

[0083] Aspect 10. The HVACR system of aspect 8, wherein the controller is configured to modulate the expander to adjust the velocity based on a change in a suction superheat.

[0084] Aspect 11. A method of operating a heating, ventilation, air conditioning, and refrigeration (HVACR) system, the HVACR system including at least one compressor, a heat exchanger, an expander, and a flow control device fluidly connected; and a controller, wherein the flow control device is disposed downstream of the expander and the heat exchanger, the flow control device is further disposed upstream of an injection port of the at least one compressor, the method comprising: when a first operating parameter is greater than a first threshold, the controller modulating the expander to lower the first operating parameter and modulating the flow control device to adjust an amount of injection into the injection port.

[0085] Aspect 12. The method of aspect 11, wherein the flow control device is a stepper-motor-actuated electric valve.

[0086] Aspect 13. The method of aspect 11 or aspect 12, wherein the heat exchanger is an economizer, the expander is configured to adjust a working fluid flowing into the economizer.

[0087] Aspect 14. The method of any one of aspects 11-13, wherein the first operating parameter is a discharge temperature.

[0088] Aspect 15. The method of any one of aspects 11-14, further comprising: when the first operating parameter is not greater than the first threshold, the controller further modulating the expander to adjust an operating capacity.

[0089] Aspect 16. The method of aspect 15, wherein the operating capacity includes a leaving water temperature.

[0090] Aspect 17. The method of any one of aspects 11-16, wherein the at least one compressor includes two or more compressors, the method further comprising: when a difference among first operating parameters of the two or more compressors is greater than a second threshold, the controller further modulating the flow control device to lower the difference.

[0091] Aspect 18. The method of any one of aspects 11-17, further comprising: the controller further determining a velocity of a working fluid, and when the velocity is outside of a predetermined range, the controller further modulating the expander to adjust the velocity.

[0092] Aspect 19. The method of aspect 18, further comprising: the controller determining the velocity based on a suction temperature, a suction pressure, and a measurement from a temperature sensor, wherein the temperature sensor is disposed at or around an outlet of the heat exchanger.

[0093] Aspect 20. The method of aspect 18, further comprising: the controller modulating the expander to adjust the velocity based on a change in a suction superheat.

[0094] The terminology used in this specification is intended to describe particular embodiments and is not intended to be limiting. The terms "a," "an," and "the" include the plural forms as well, unless clearly indicated otherwise. The terms "comprises" and/or "comprising," when used in this specification, specify the presence of the stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, and/or components.

[0095] With regard to the preceding description, it is to be understood that changes may be made in detail, especially in matters of the construction materials employed and the shape, size, and arrangement of parts without departing from the scope of the present disclosure. This specification and the embodiments described are exemplary only, with the true scope and spirit of the disclosure being indicated by the claims that follow.

Claims

1. A heating, ventilation, air conditioning, and refrigeration (HVACR) system, comprising:

at least one compressor, a heat exchanger, an expander, and a flow control device fluidly connected; and

a controller,

wherein the flow control device is disposed downstream of the expander and the heat exchanger, the flow control device is further disposed upstream of an injection port of the at least one compressor,

when a first operating parameter is greater than a first threshold, the controller is configured to

- modulate the expander to lower the first operating parameter and to modulate the flow control device to adjust an amount of injection into the injection port.
2. The HVACR system of claim 1, wherein the flow control device is a stepper-motor-actuated electric valve.
 3. The HVACR system of claim 1 or claim 2, wherein the heat exchanger is an economizer, the expander is configured to adjust a working fluid flowing into the economizer.
 4. The HVACR system of any one of claims 1-3, wherein the first operating parameter is a discharge temperature.
 5. The HVACR system of any one of claims 1-4, wherein when the first operating parameter is not greater than the first threshold, the controller is further configured to modulate the expander to adjust an operating capacity.
 6. The HVACR system of claim 5, wherein the operating capacity includes a leaving water temperature.
 7. The HVACR system of any one of claim 1-6, wherein the at least one compressor includes two or more compressors,
when a difference among first operating parameters of the two or more compressors is greater than a second threshold, the controller is further configured to modulate the flow control device to lower the difference.
 8. The HVACR system of any one of claims 1-7, wherein the controller is further configured to determine a velocity of a working fluid,
when the velocity is outside of a predetermined range, the controller is further configured to modulate the expander to adjust the velocity.
 9. The HVACR system of claim 8, further comprising:
a temperature sensor disposed at or around an outlet of the heat exchanger,
wherein the controller is configured to determine the velocity based on a suction temperature, a suction pressure, and a measurement from the temperature sensor.
 10. The HVACR system of claim 8 or claim 9, wherein the controller is configured to modulate the expander to adjust the velocity based on a change in a suction superheat.
 11. A method of operating the HVACR system of any one of claims 1-10, the method comprising:
when a first operating parameter is greater than a first threshold, the controller modulating the expander to lower the first operating parameter and modulating the flow control device to adjust an amount of injection into the injection port.
 12. The method of claim 11, further comprising:
when the first operating parameter is not greater than the first threshold, the controller further modulating the expander to adjust an operating capacity.
 13. The method of claim 11 or claim 12, wherein the at least one compressor includes two or more compressors, the method further comprising:
when a difference among first operating parameters of the two or more compressors is greater than a second threshold, the controller further modulating the flow control device to lower the difference.
 14. The method of any one of claims 11-13, further comprising:
the controller further determining a velocity of a working fluid, and
when the velocity is outside of a predetermined range, the controller further modulating the expander to adjust the velocity.
 15. The method of claim 14, further comprising:
the controller determining the velocity based on a suction temperature, a suction pressure, and a measurement from a temperature sensor, wherein the temperature sensor is disposed at or around an outlet of the heat exchanger; or
the controller modulating the expander to adjust the velocity based on a change in a suction superheat.

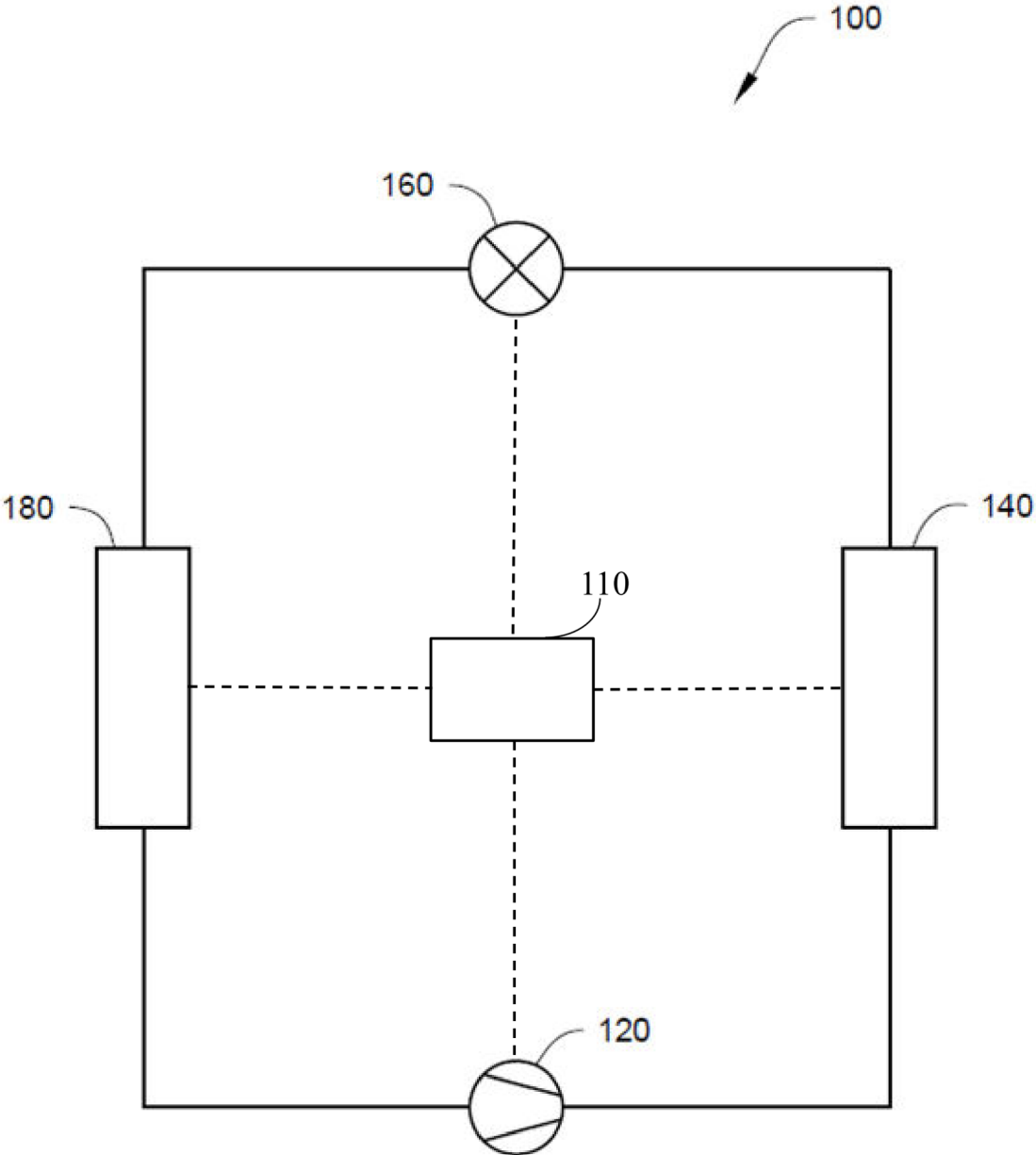


FIG. 1

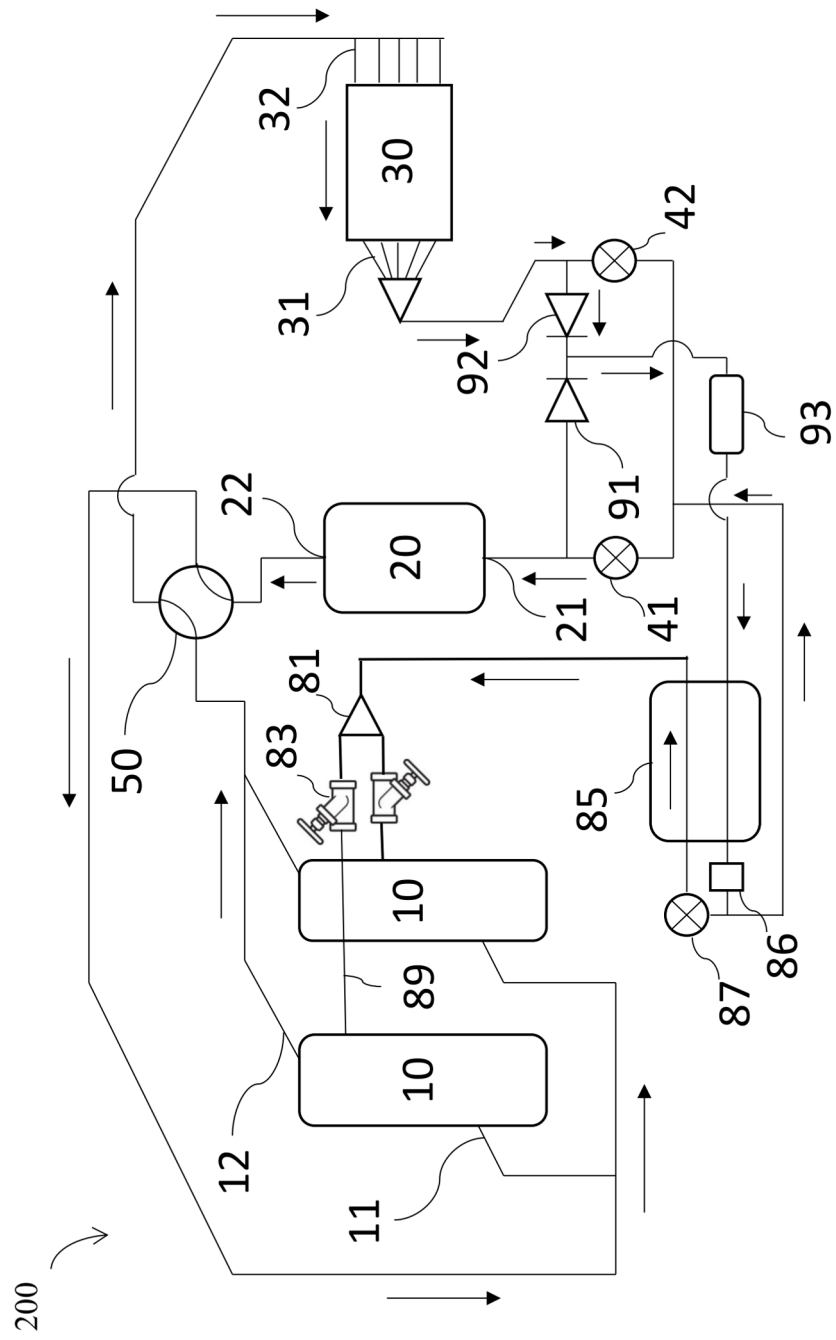
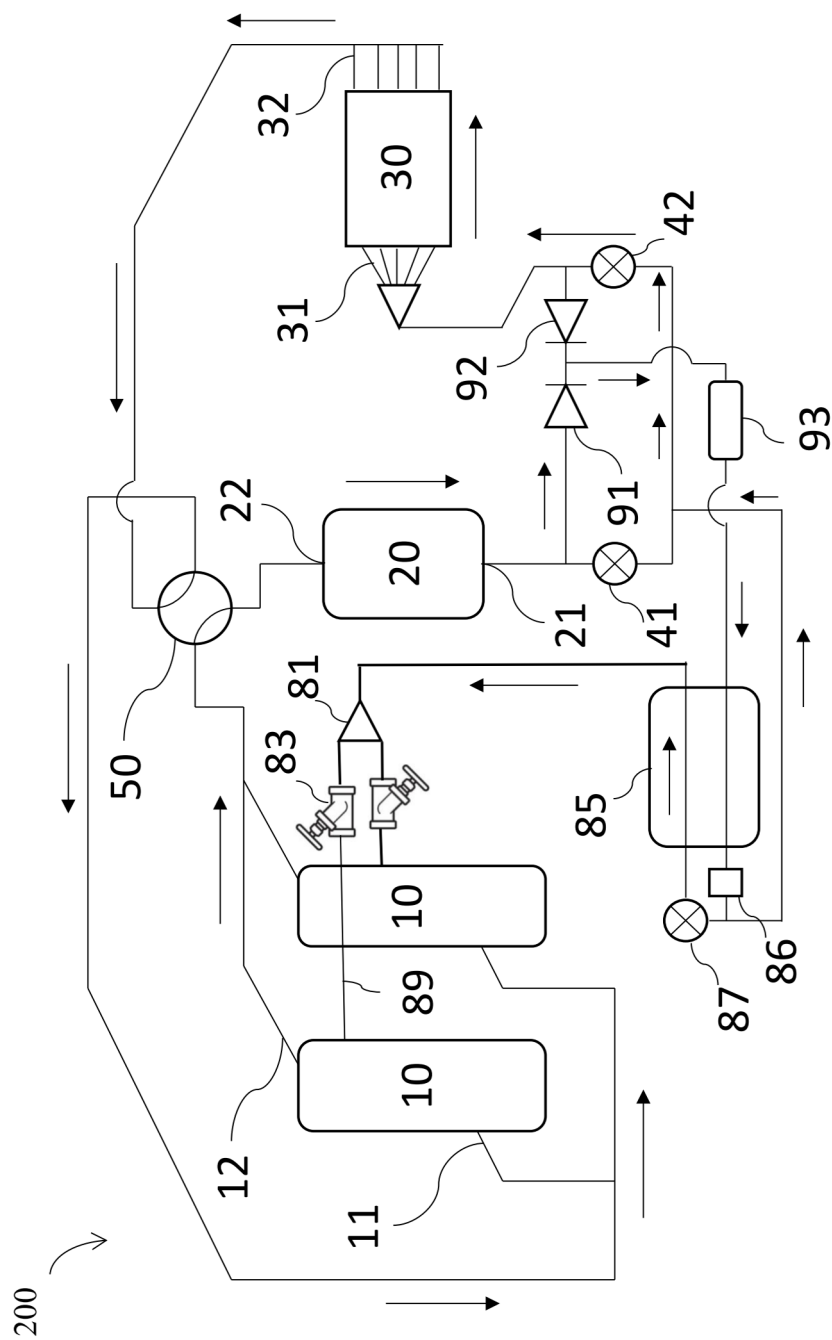
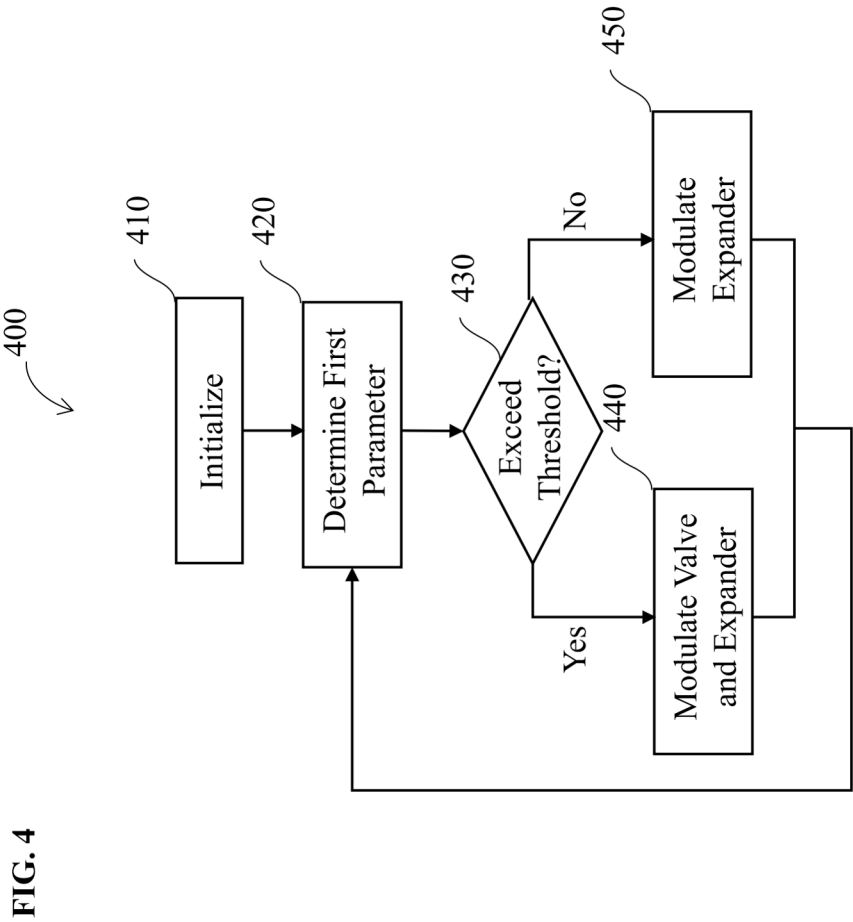
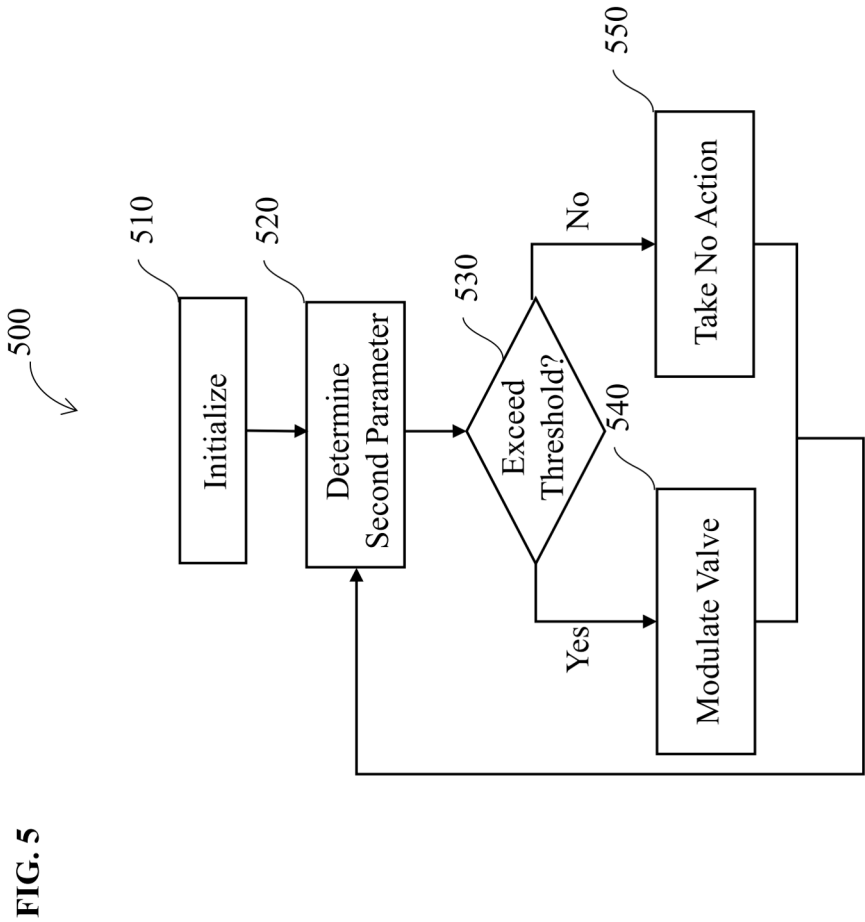


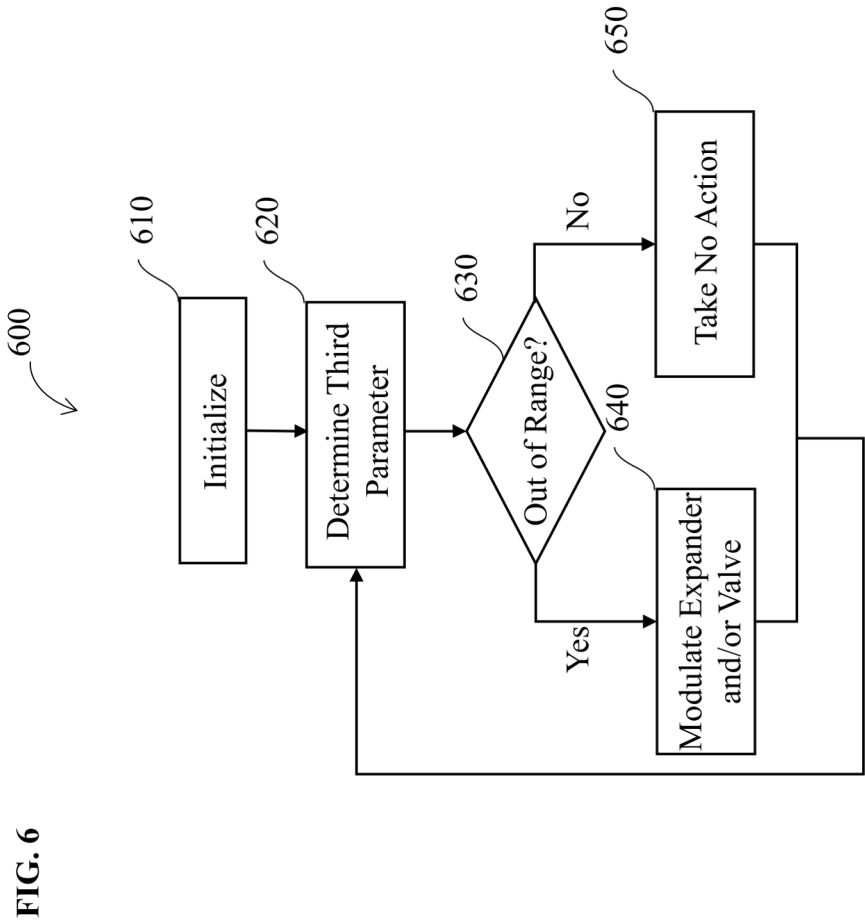
FIG. 2

FIG. 3











EUROPEAN SEARCH REPORT

Application Number

EP 26 16 2437

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2011/174005 A1 (TAKEGAMI MASAOKI [JP] ET AL) 21 July 2011 (2011-07-21) * paragraphs [0033] - [0037], [0078] - [0086], [0237] - [0239]; claims; figures 1,4,5 *	1-15	INV. F25B13/00
X	EP 2 224 191 B1 (LG ELECTRONICS INC [KR]) 28 December 2016 (2016-12-28) * paragraphs [0029] - [0072]; figures *	1-15	
A	US 2015/096321 A1 (KAWANO SATOSHI [JP] ET AL) 9 April 2015 (2015-04-09) * paragraphs [0078] - [0091]; claims; figures 1-3 *	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			F25B
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
Munich		10 July 2026	Ritter, Christoph
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			

EPO FORM 1503 03.82 (P24C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 26 16 2437

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

10-07-2026

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
US 2011174005	A1	21-07-2011	CN	102099639	A	15-06-2011
			EP	2320159	A1	11-05-2011
			JP	2010054186	A	11-03-2010
			US	2011174005	A1	21-07-2011
			WO	2010013392	A1	04-02-2010

EP 2224191	B1	28-12-2016	EP	2224191	A2	01-09-2010
			ES	2619706	T3	26-06-2017
			KR	20100096858	A	02-09-2010
			US	2010212342	A1	26-08-2010

US 2015096321	A1	09-04-2015	AU	2013264129	A1	22-01-2015
			AU	2016202008	A1	21-04-2016
			BR 11	2014028992	A2	27-06-2017
			CN	104321597	A	28-01-2015
			CN	105605816	A	25-05-2016
			CN	106839496	A	13-06-2017
			EP	2878901	A1	03-06-2015
			EP	3139109	A1	08-03-2017
			EP	3208557	A1	23-08-2017
			ES	2650403	T3	18-01-2018
			ES	2664970	T3	24-04-2018
			ES	2704573	T3	18-03-2019
			JP	5500240	B2	21-05-2014
			JP	2014001917	A	09-01-2014
			KR	20150020219	A	25-02-2015
			KR	20160042152	A	18-04-2016
			US	2015096321	A1	09-04-2015
			US	2017336120	A1	23-11-2017
			WO	2013175912	A1	28-11-2013
