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(54) **SYSTEMS AND METHODS FOR OPERATING A REFRIGERATION SYSTEM**

(57) Methods and systems for operating a refrigeration system for refrigerating a product are provided. A first temperature of the refrigerant downstream of a condenser and upstream of an evaporator may be obtained. A first pressure of the refrigerant downstream of the condenser and upstream of the evaporator may be obtained. A second pressure of the refrigerant downstream of the evaporator and upstream of a compressor and/or a temperature of the product being refrigerated may be ob-

tained. A first valve, disposed between the condenser and the evaporator, may be controlled based on the first temperature and the first pressure to maintain a pre-determined cooling set-point for the refrigeration system. A second valve of the refrigeration system, coupled to the compressor, may be controlled based on the second pressure or the temperature of the product to optimize a capacity of a compressor of the refrigeration system.

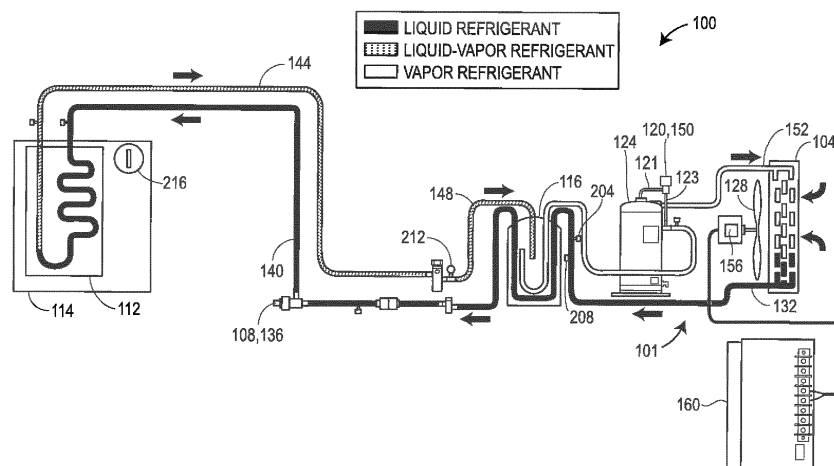


FIG. 1

Description

FIELD OF THE DISCLOSURE

[0001] The present disclosure relates generally to refrigeration systems and, more specifically, to operating a refrigeration system in a more efficient manner.

BACKGROUND

[0002] Refrigeration systems are commonly employed to cool, preserve, and store products such as milk, juice, and fruits. Conventional refrigeration systems typically utilize a closed-loop process in which refrigerant is continually circulated through a condenser, an expansion valve, an evaporator, and a compressor. The condenser cools and condenses the refrigerant into a saturated liquid. The saturated liquid refrigerant then travels through the expansion valve, which reduces the pressure, and, in turn, the temperature, of the refrigerant. The refrigerant then passes through the evaporator, at which point the saturated liquid refrigerant extracts or absorbs heat from an external fluid (e.g., milk, air, water), thereby cooling the external fluid. The extraction or absorption of heat from the external fluid vaporizes the refrigerant, turning it into a superheated gas refrigerant. The superheated gas refrigerant then flows into the compressor, which increases the pressure and the temperature of the refrigerant. The vapor refrigerant then passes back through the condenser, where the cycle begins again.

[0003] There are, however, many problems associated with these conventional refrigeration systems. For example, when these conventional refrigeration systems experience low flow rates and/or when the external fluid is to be cooled to a temperature near freezing, ice may form on the surface of the evaporator. Ice formation can damage the evaporator, and reduces the cooling capacity of the system and, in turn, increases energy consumption. Moreover, the components in these conventional refrigeration systems are typically cycled, leading to inefficiencies and increased energy consumption. For example, the compressor typically cycles on and off based on the temperature of the cooling medium. This cycling is not only inefficient, but because in practice the temperature of the cooling medium can be quite unstable, it can make it quite difficult to maintain the desired product temperature. Further yet, as the capacity of the condenser depends on the conditions of the evaporator (e.g., the desired temperature of the product being cooled), this limits available system capacity when the temperature of the product being cooled is higher, thus increasing the duration of the cooling cycle and, in turn, increasing energy consumption.

SUMMARY

[0004] One aspect of the present disclosure provides a method for operating a refrigeration system for refrigerating a product. The refrigeration system includes a

condenser, an evaporator downstream of the condenser, a compressor downstream of the evaporator, and a refrigerant flowing through the refrigeration system. The method includes obtaining, from a first transducer coupled to the refrigeration system, a first temperature of the refrigerant downstream of the condenser and upstream of the evaporator. The method includes obtaining, from a second transducer coupled to the refrigeration system, a first pressure of the refrigerant downstream of the condenser and upstream of the evaporator. The method also includes obtaining, from a third transducer coupled to the refrigeration system, a second pressure of the refrigerant downstream of the evaporator and upstream of the compressor or a temperature of the product being refrigerated. The method further includes controlling, via a processor communicatively coupled to the refrigeration system, a degree of opening of a first valve of the refrigeration system disposed between the condenser and the evaporator, based on the first temperature and the first pressure, to maintain a pre-determined cooling set-point for the refrigeration system, and a second valve of the refrigeration system coupled to the compressor, based on the second pressure or the temperature of the product, to optimize a capacity of the compressor.

[0005] Another aspect of the present disclosure provides a refrigeration system for refrigerating a product. The refrigeration system includes a condenser, an evaporator disposed downstream of the condenser, a compressor disposed downstream of the evaporator, first, second, and third transducers, and a controller. The first transducer is disposed immediately downstream of the condenser and is configured to obtain a first temperature of a refrigerant downstream of the condenser and upstream of the evaporator. The second transducer is disposed immediately downstream of the condenser and is configured to obtain a first pressure of the refrigerant downstream of the condenser and upstream of the evaporator. The third transducer is disposed immediately downstream of the evaporator and is configured to obtain a second pressure of the refrigerant downstream of the evaporator and upstream of the compressor or a temperature of the product being refrigerated. The controller is communicatively coupled to the first, second, and third transducers. The controller is configured to control a first control valve disposed downstream of the condenser and upstream of the evaporator based on the obtained first temperature and the first pressure to maintain a pre-determined cooling set-point, the controller configured to control a second control valve coupled to the compressor based on the obtained second pressure or the temperature of the product to optimize a capacity of compressor.

[0006] Yet another aspect of the present disclosure provides a method of operating a refrigeration system for refrigerating a product, the refrigeration system having a condenser, an evaporator downstream of the condenser, a compressor downstream of the evaporator, and a refrigerant flowing through the refrigeration system. The

method includes obtaining, from a first transducer coupled to the refrigeration system, a first temperature of the refrigerant downstream of the condenser and upstream of the evaporator, obtaining, from a second transducer coupled to the refrigeration system, a first pressure of the refrigerant downstream of the condenser and upstream of the evaporator, and obtaining, from a third transducer coupled to the refrigeration system, a second pressure of the refrigerant downstream of the evaporator and upstream of the compressor or a temperature of the product being refrigerated. The method further includes controlling, via a processor communicatively coupled to the refrigeration system, a degree of opening of an electronic stepper valve disposed between the condenser and the evaporator, based on the temperature and the pressure, to maintain a pre-determined cooling set-point for the refrigeration system, such that the evaporator is flooded with liquid refrigerant, or controlling, via a processor communicatively coupled to the refrigeration system, a solenoid valve coupled to the compressor, based on the pressure or the temperature of the product, to optimize a capacity of the compressor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007]

FIG. 1 is a schematic diagram of a refrigeration system assembled in accordance with the teachings of the present disclosure.

FIG. 2 is a schematic diagram of an intelligent control board that can be coupled to the refrigeration system illustrated in FIG. 1.

FIG. 3 is a schematic diagram illustrating the intelligent control board shown in FIG. 2 communicatively coupled to the refrigeration system shown in FIG. 1.

FIG. 4 is a process flow chart showing one version of a method for operating a refrigeration system in accordance with the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0008] FIG. 1 illustrates a schematic diagram of a refrigeration system 100 assembled in accordance with the teachings of the present disclosure. The refrigeration system 100 is a closed-loop system through which a refrigerant or a coolant is continually circulated as part of a refrigeration or cooling cycle. The refrigeration system 100 in this version can be located at or on a dairy farm and is used to refrigerate or cool milk, for example, but it can instead be used at or in a commercial facility (e.g., at or in a supermarket), an industrial facility (e.g., at or in a power plant), or some other location to cool or refrigerate milk and/or other products (e.g., juice, yogurt, meat,

cheese, etc.).

[0009] The closed-loop refrigeration system 100 generally includes a condenser 104, a first control valve 108, an evaporator 112, an accumulator / heat exchanger 116, a second control valve 120, a compressor 124, and a condenser fan 128. Generally conventional plumbing 101 extends between each of these components as depicted and carries a refrigerant, in the conventional manner. The condenser 104 is generally configured to condense and sub-cool the refrigerant into a high-pressure liquid. The sub-cooled, high-pressure liquid flows from the condenser 104 to the first control valve 108 via a conduit 132 of the plumbing 101. The first control valve 108, which in this version is an electronic stepper valve 136 that can move between closed and multiple different open positions (e.g., 0-2500 different positions) to reduce the pressure of the refrigerant, converts the refrigerant from a high-pressure liquid to a low-pressure liquid. The low-pressure liquid refrigerant then flows from the electronic stepper valve 136 to the evaporator 112 via a conduit 140 of the plumbing 101. As will be described in greater detail below, the opening through the first control valve 108 can be controlled to ensure that the refrigerant leaving the condenser 104 is sufficiently sub-cooled such that the evaporator 112 is flooded with liquid refrigerant and, as a result, a saturated suction is provided.

[0010] As the refrigeration system 100 in the depicted version is located at or on a dairy farm, the evaporator 112 is mounted in a milk cooler 114 used to accumulate and cool milk from the milking process. Thus, when the liquid refrigerant passes through the evaporator 112, the saturated liquid refrigerant extracts or absorbs heat from the milk cooler, thereby cooling the milk and vaporizing the refrigerant. However, unlike conventional evaporators, which completely vaporize the refrigerant, the evaporator 112, because it is flooded with liquid refrigerant and a saturated suction is provided, only partially vaporizes the refrigerant. Thus, when the refrigerant leaves the evaporator 112, the refrigerant occupies a partially liquid / partially gaseous phase.

[0011] To prevent liquid from reaching the compressor 124, the liquid/gas mixture flows from the evaporator 112 to the accumulator/heat exchanger 116 via a conduit 144 of the plumbing 101. As shown in FIG. 1, the accumulator/heat exchanger 116 is in thermal communication with conduit 132 from the condenser, which carries super cooled refrigerant. The conduit 132 therefore cools the liquid/vapor mixture carried in conduit 144 and the cooled liquid falls to the bottom of the accumulator/heat exchanger 116. The vapor flows onto the compressor 124. At this point, the refrigerant is in vapor or gaseous form, but is at a lower superheated temperature (e.g., 1-5° F) than typically seen in conventional refrigeration systems. The vapor refrigerant then flows from the accumulator/heat exchanger 116 to the compressor 124 via a conduit 148 of the plumbing 101. The second control valve 120, which in this version can be a solenoid valve 150, is coupled to the compressor 124 via conduits 121, 123.

The second valve 120 can, when desired, be controlled to unload or load the compressor 124 to vary the capacity of the compressor 124, as will be described in greater detail below. A benefit of using a solenoid valve is that solenoid valves are very quick-acting with short valve member travel distances and times between open and closed positions.

[0012] The compressor 124 compresses the vapor refrigerant, thereby increasing its pressure and temperature. The vapor refrigerant then flows from the compressor 124 back to the condenser 104 via a conduit 152 of the plumbing 101, at which point the cycle begins again. The condenser fan 128 is positioned adjacent to or near the condenser 104 to force a condensing medium (e.g., air) through the condenser 104, thereby cooling the refrigerant flowing through the condenser 104. The condenser fan 128 is driven by a condenser fan motor 156, which is coupled to the condenser fan 128. The condenser fan motor 156 is itself controlled (e.g., driven) by a fan control drive 160 communicatively coupled to the fan motor 156. As will be described in greater detail below, the fan control drive 160 can be controlled to control the condenser fan motor 156, and thus the speed of the condenser fan 128, to maintain or achieve a desired condensing temperature.

[0013] Referring still to FIG. 1, the refrigeration system 100 further includes a plurality of transducers (e.g., sensors) generally configured to obtain (e.g., detect, sense) data, such as pressure(s), temperature(s), flow rate(s), etc., indicative of the operation and performance of the refrigeration system 100. In this version, the refrigeration system 100 includes a first pressure transducer 204, a first temperature transducer 208, a second pressure transducer 212, and a second temperature transducer 216. It should be understood that the temperature and pressure transducers 204-216 can generally be any commercially available sensors such as, for example, the 2CP5 sensor manufactured by Sensata Technologies, Inc.

[0014] The first pressure transducer 204 is positioned downstream of the condenser 104 and at or along the conduit 132 between the condenser 104 and the first control valve 108 (i.e., in a high pressure area of the system 100). So positioned, the first pressure transducer 204 is configured to obtain a pressure of the refrigerant leaving the condenser 104 (referred to herein as a first pressure of the refrigerant). The first temperature transducer 208, in the depicted version of the system 100, is also positioned downstream of the condenser 104 and at or along the conduit 132 between the condenser 104 and the first control valve 108 (i.e., in the high temperature area of the system 100). Moreover, in this version, the first temperature transducer 208 is upstream of the first pressure transducer 204, but in other versions the transducer 208 can be downstream of the transducer 204. So positioned, the first temperature transducer 208 is configured to obtain a temperature of the refrigerant leaving the condenser 104 (referred to herein as a first temperature of the

refrigerant). The second pressure transducer 212 is positioned downstream of the evaporator 112 and at or along the conduit 144 between the evaporator 112 and the accumulator / heat exchanger 116 (i.e., in a low pressure area of the system 100). So positioned, the second pressure transducer 212 is configured to obtain a pressure of the refrigerant leaving the evaporator 112 (referred to herein as a second pressure of the refrigerant). The second temperature transducer 216, which is also referred to herein as a product temperature transducer, is generally positioned near, at, or in the product to be refrigerated to obtain a temperature of the product being refrigerated (e.g., milk). Because the refrigeration system 100 in this version is used to cool milk, the product temperature transducer 216 in this version is positioned near, on, or within the milk cooler containing the milk to be cooled.

[0015] It will be appreciated that the refrigeration system 100 illustrated in FIG. 1 can vary and yet still fall within the principles of the present disclosure. In other versions, the refrigeration system 100 can include additional, different, or fewer components than the components described above. The first control valve 108 can, for example, be an expansion valve or any other suitable control valve. In some versions, the refrigeration system 100 can include a conventional evaporator, configured to produce superheated vapor refrigerant, instead of the evaporator 112 disclosed, which produces a mixed vapor-liquid refrigerant. The evaporator 112 need not be mounted in the milk cooler 114. Instead, the evaporator 112 can be mounted to an exterior surface of the milk cooler 114 or coupled to the milk cooler 114 in a different manner (e.g., via a conduit or line). When the refrigeration system 100 is used to cool other than or in addition to milk, the evaporator 112 can be mounted in or coupled to a different external environment such as, for example, a display case containing one or more products to be refrigerated. In the versions in which the refrigeration system 100 includes a conventional evaporator, the refrigeration system 100 may not include the accumulator/heat exchanger 116, as the refrigerant would be totally vaporized in the evaporator prior to reaching the compressor 124. In some versions, the refrigeration system 100 may not include the second control valve 120, in which case the refrigeration system 100 would not permit adjustment of the capacity of the compressor 124. In other versions, the refrigeration system 100 can include additional, different, or fewer transducers. As an example, the refrigeration system 100 may not include both the second pressure transducer 212 and the second temperature transducer 216. As another example, the refrigeration system 100 can include an additional temperature transducer disposed adjacent to or near the second pressure transducer 212. Moreover, any of the transducers 204-216 can be positioned elsewhere and still perform the intended functionality described above.

[0016] FIG. 2 illustrates one version of an intelligent control board 250 that can be communicatively coupled

with or connected to the refrigeration system 100 to improve the performance of the refrigeration system 100. The intelligent control board 250 generally includes a controller 254 configured to monitor and control the operation of the refrigeration system 100 and a panel 258 that includes one or more indicators for providing visual feedback about the operation of the refrigeration system 100.

[0017] As shown in FIG. 2, the controller 254 includes a processor 262, a memory 266, a communications interface 270, and computing logic 274. The processor 262 can be a general processor, a digital signal processor, ASIC, field programmable gate array, graphics processing unit, analog circuit, digital circuit, or any other known or later developed processor. The processor 262 operates pursuant to instructions in the memory 266. The memory 266 can be a volatile memory or a non-volatile memory. The memory 266 can include one or more of a read-only memory (ROM), random-access memory (RAM), a flash memory, an electronic erasable program read-only memory (EEPROM), or other type of memory. The memory 266 can include an optical, magnetic (hard drive), or any other form of data storage device.

[0018] The communications interface 270 is provided to enable or facilitate electronic communication between the controller 254 and the components of the refrigeration system 100. The communications interface 270 can be or include, for example, one or more universal serial bus (USB) ports, one or more Ethernet ports, and/or one or more other ports or interfaces. The electronic communication may occur via any known communications protocol, including, by way of example, USB, RS-232, RS-485, WiFi, Bluetooth, and/or any other suitable communications protocol.

[0019] The logic 274 generally includes one or more control routines and/or one or more sub-routines embodied as computer-readable instructions stored on the memory 266. The control routines and/or sub-routines may perform PID (proportional-integral-derivative), fuzzy logic, nonlinear, or any other suitable type of control. The processor 262 generally executes the logic 274 to perform actions related to the operation of the refrigeration system 100. The logic 274 may, when executed, cause the processor 262 to (i) obtain data (e.g., pressure data, temperature data) from one or more of the transducers 204-216, (ii) control the first control valve 108 of the refrigeration system 100 based on the obtained data to maintain a pre-determined level of sub-cooling, (iii) control the second control valve 120 of the refrigeration system 100 based on the obtained data to optimize a capacity of the compressor 124, (iv) control the fan control drive 160, and thus the condenser fan 128, based on the obtained data to adjust a condensing temperature of the condenser 104, (v) detect fault conditions or errors in the refrigeration system 100, and/or perform other desired functionality.

[0020] Although not depicted herein, the controller 254 may also include one or more bit switches that allow a

user of the refrigeration system 100 to select from a number of different programmed options associated with different features of the refrigeration system 100. The programmed options may, for example, include an anti-short cycle that prevents premature cycling of the compressor 124, and an alarm or fault condition output that provides visual feedback (e.g., via the panel 258) when alarm or fault conditions are detected. By selecting the bit (or bits) corresponding to the desired option(s), the user of the refrigeration system 100 can trigger (or turn-off) one or more different features of the refrigeration system 100.

[0021] As shown in FIG. 2, the panel 258 in this version includes two light-emitting diodes (LEDs) 278, 282 configured to provide visual feedback about the operation of the refrigeration system 100. The LED 278 emits a red light (i.e., light having a wavelength in a range of 620-750 nm) through a hole 286 in the control board 250 when the controller 254 detects a fault or alarm condition in the refrigeration system 100. The LED 278 may emit one red light or a series of red lights (i.e., flashes of red light) depending upon the detected fault condition. The LED 278 may, for example, emit one red light when the fault condition is a bit-switch setting error, two flashes of red light when the fault condition involves the transducer 208, three flashes of red light when the fault condition involves the transducer 212, fourth flashes of red light when the fault condition involves the temperature transducer 220, and seven flashes of red light when the fault condition involves the fan control drive 160. Meanwhile, the LED 282 emits a green light (i.e., light having a wavelength in a range of between 495-570 nm) through a hole 290 in the control board 250. The LED 282 may emit one green light or a series of green lights (i.e., flashes of green light) depending upon the operating conditions. The LED 282 may, for example, always emit a solid green light so long as the refrigeration system 100 is on and operating normally, but emit one flash of green light when the anti-cycle option is active.

[0022] Though not illustrated herein, the components of the intelligent control board 250 can be arranged in any known manner. One of ordinary skill in the art will also appreciate that the control board 250 can include additional or different components. The controller 254 can, for example, include additional components, such as a relay, converter, or gauge, which are not explicitly depicted herein. The panel 258 can, for example, include more or less LEDs, LEDs that emit different colors of light, LEDs that emit different patterns of light (e.g., corresponding to different fault conditions), different light sources for providing visual feedback, a user interface, and/or some other means of providing visual feedback about the operation of the refrigeration system 100.

[0023] FIG. 3 is a schematic diagram that illustrates the intelligent control board 250 coupled with or connected to the refrigeration system 100. As illustrated, the control board 250 is coupled with or connected to the fan control drive 160 via a communication network 300, the

first control valve 108 via a communication network 304, the second control valve 120 via a communication network 308, the first pressure transducer 204 via a communication network 312, the first temperature transducer 208 via a communication network 316, the second pressure transducer 212 via a communication network 320, and the second temperature transducer 216 via a communication network 324. As used herein, the phrases "in communication" and "coupled" are defined to mean directly connected to or indirectly connected through one or more intermediate components. Such intermediate components may include hardware and/or software based components.

[0024] It will be appreciated that the networks 300-324 may be wireless networks, wired networks, or combinations of a wired and a wireless network (e.g., a cellular telephone network and/or 802.11x compliant network), and may include a publicly accessible network, such as the Internet, a private network, or a combination thereof. The type and configuration of the networks 300-324 is implementation dependent, and any type of communications networks which facilitate the described communications between the intelligent control board 250 and the components of the refrigeration system 100, available now or later developed, may be used.

[0025] With the intelligent control board 250 coupled with or connected to the refrigeration system 100 in this manner, the controller 254 is configured to transmit signals (e.g., control signals, data requests) to and receive signals (e.g., data) from the fan control drive 160, the first control valve 108, the second control valve 120, and any of the transducers 204-216. The controller 254 can thus communicate with the transducers 204-216 and control the fan control drive 160, the first control valve 108, and the second control valve 120.

[0026] When the refrigeration system 100 is operational and refrigerant is circulated through the components of the refrigeration system 100 in the manner described above, the transducers 204-216 may obtain data associated with and indicative of the operation of the refrigeration system 100 (i.e., the refrigeration cycle). Specifically, the first pressure transducer 204 may obtain (e.g., detect, measure) the pressure of the refrigerant downstream of the condenser 104 but upstream of the valve 108 (i.e., the first pressure of the refrigerant), the first temperature transducer 208 may obtain the temperature of the refrigerant downstream of the condenser 104 but upstream of the valve 108 (i.e., the first temperature of the refrigerant), the second pressure transducer 212 may obtain the pressure of the refrigerant downstream of the evaporator 112 but upstream of the accumulator/heat exchanger 116 (i.e., the second pressure of the refrigerant), the second temperature transducer 216 may obtain the temperature of the product to be cooled, or combinations thereof. The above-described data may be automatically obtained when the refrigeration system 100 is operational and/or obtained in response to a request received from the controller 254. The above-described data may be ob-

tained simultaneously (e.g., the first temperature and the first pressure may be obtained at the same time), at different times, or a combination thereof (e.g., some of the data can be obtained simultaneously while some data can be obtained at different times).

[0027] The controller 254 may then obtain the data obtained by one or more of the transducers 204-216 via the respective networks 312-328. The data may be automatically transmitted to the controller 254 (i.e., automatically obtained by the controller 254) and/or transmitted to the controller 254 in response to a request received from the controller 254. Once obtained, the data may be stored in the memory 266 or another memory.

[0028] Based on or using the obtained data, the controller 254 may control (e.g., adjust) components of the refrigeration system 100, particularly the first control valve 108, the second control valve 120, and/or the fan control drive 160. The controller 254 is generally configured to control the components of the refrigeration system 100 such that the refrigeration system 100 operates in the desired manner discussed herein.

[0029] The controller 254 may control (e.g., close or adjust the degree of opening of) the first control valve 108, which in the illustrated version takes the form of the electronic stepper valve 136, based on the first temperature and the first pressure. This is done to maintain a pre-determined (e.g., factory programmed) cooling set-point for the refrigeration system 100. The pre-determined cooling set-point corresponds to the desired sub-cooling level for the refrigerant when leaving the condenser 104. The desired sub-cooling level corresponds to the sub-cooling level at which the evaporator 112 is desirably flooded with liquid refrigerant. Flooding the evaporator 112 in this way provides a saturated suction leaving the evaporator 112, which results in the refrigerant leaving the evaporator 112 in a mixed liquid/vapor state and at a lower temperature than typically seen in conventional refrigeration systems. Beneficially, this increases the efficiency of the evaporator 112, keeps the motor of the compressor 124 cooler, and increases the volumetric efficiency of the compressor 124.

[0030] To determine whether the refrigeration system 100 is operating at, below, or above this pre-determined cooling set-point, the controller 254 can calculate, based on the first pressure and the first temperature, the current sub-cooling level of the refrigerant when leaving the condenser 104. In some versions, the controller 254 can calculate the current sub-cooling level by correlating the first pressure to an expected temperature and then comparing the expected temperature with the measured temperature, the first temperature. The controller 254 may, in turn, compare the calculated sub-cooling level of the refrigerant with the pre-determined cooling set-point. When the calculated sub-cooling level is at least substantially equal (e.g., equal) to the pre-determined cooling set-point, the controller 254 may determine that the refrigeration system 100 is substantially operating at this pre-determined cooling set-point, such that the controller

254 need not control (e.g., adjust) the first control valve 108. When, however, the calculated current sub-cooling level is determined to be less than or greater than the pre-determined cooling set-point, the controller 254 adjusts (e.g., opens, closes) the first control valve 108 until the controller 254 determines that the current sub-cooling level is substantially equal to the pre-determined cooling set-point (i.e., until the desired level of sub-cooling has been achieved and maintained). By opening the valve 108 further, more refrigerant will flow through and the sub-cooling at the condenser 104 will result in a higher temperature refrigerant. By contrast, closing or reducing the opening of the valve 108 will reduce flow through the conduit 132, which decreases the pressure and temperature of the sub-cooled refrigerant exiting the condenser 104. It will be appreciated that the control of the first control valve 108 is an iterative and continuous process. And, in this version, the control valve 108 is or includes the electronic stepper valve 136, which has 2500 different positions to facilitate fine-tuned adjustments. Of course, other types of adjustable port valves could be used.

[0031] The controller 254 may control the second control valve 120, which in the illustrated version takes the form of the solenoid valve 150, based on the second pressure and/or the temperature of the product being refrigerated. This is done to control a capacity of the compressor 124. As briefly discussed above, when system capacity is too low (e.g., when the temperature of the product being cooled is higher than expected), conventional systems compensate by increasing the duration of the cooling cycle, thereby increasing energy consumption. Conversely, when system capacity is too high (e.g., when the temperature of the product being cooled is lower than expected, under low flow conditions), the product being cooled may freeze. The system 100 disclosed herein advantageously prevents either situation by controlling (e.g., adjusting) the capacity of the compressor 124 in accordance with the operating conditions of the refrigeration system 100.

[0032] To determine whether the capacity of the compressor 124 needs to be adjusted, the controller 254 can compare the second pressure (the pressure of the refrigerant when leaving the evaporator 112) or the product temperature to a pre-determined (e.g., factory programmed) second pressure set-point or a product temperature set-point. This pre-determined set-point corresponds to a desired, if not ideal, capacity for the compressor 124. When the second pressure or product temperature is substantially equal to the pre-determined second pressure set-point or product temperature set-point, the controller 254 may determine that the current capacity of the compressor 124 is adequate (if not ideal), in which case the controller 254 does not control the solenoid valve 150. When, however, the second pressure or product temperature is less or greater than the pre-determined second pressure or product temperature set-point, the controller 254 may control the solenoid valve 150 to provide a controlled reduction or controlled in-

crease (when the capacity has been previously reduced) of the capacity of the compressor 124.

[0033] Specifically, when the second pressure or product temperature is less than the pre-determined second pressure or product temperature set-point, the controller 254 energizes the solenoid valve 150, which causes the solenoid valve 150 to open, thereby unloading and decreasing the capacity of the compressor 124. The controller 254 energizes the solenoid valve 150 for at least minimum pre-determined amount of time (e.g., 1 second), but may energize the solenoid valve 150 until the second pressure or product temperature is greater than the pre-determined second pressure or product temperature set-point, with the exception that the controller 254 may, to protect the compressor 124, only energize the solenoid valve 150 for a maximum pre-determined amount of time (e.g., 9 seconds). The controller 254 may, when the solenoid valve 150 is being energized, simultaneously suspend control of the first control valve 108 and the condenser fan 128.

[0034] Conversely, when the second pressure or product temperature is greater than the pre-determined second pressure set-point or product temperature set-point, the controller 254 de-energizes the solenoid valve 150, which causes the solenoid valve 150 to close, thereby loading and increasing the capacity of the compressor 124. The controller 254 de-energizes the solenoid valve 150 for at least minimum pre-determined amount of time (e.g., 3 seconds), but may de-energize the solenoid valve 150 until the second pressure or product temperature is less than the pre-determined second pressure or product temperature set-point.

[0035] Thus far, the solenoid is described as being energized to open and, as such, constitutes a naturally closed solenoid. One advantage of a naturally closed solenoid is that energy is only required to unload the compressor 124. In other versions, however, a naturally open solenoid could be used such that it would be energized to close.

[0036] As with the electronic stepper valve 136, it will be appreciated that the control of the solenoid valve 150 can be an iterative and continuous process. In fact, the controller 254 can self-regulate its control of the solenoid valve 150, provided such control complies with the above-described minimum and maximum time periods, based on how fast the second pressure (the pressure obtained by the second pressure transducer 212) falls when the compressor 124 is loaded and how fast the second pressure increases when the compressor 124 is unloaded.

[0037] At least initially (e.g., when the controller 254 first receives a run signal), the fan control drive 160 operates the condenser fan 128 at full time for a short period of time (e.g., 3 seconds). Following this short period of time, however, the controller 254 may control the fan control drive 160 based on the first pressure to control (e.g., adjust) the speed of the condenser fan 128. As the first pressure rises up to a pre-determined pressure point

(e.g., 170 psi), the fan control drive 160 can control the fan 128 such that the fan 128 operates at a pre-determined minimum speed. When the first pressure rises above this pre-determined pressure point, and until the first pressure reaches a pre-determined maximum pressure point (e.g., 230 psi), the fan control drive 160 can increase the speed of the fan 128. When the first pressure reaches the pre-determined maximum pressure point, the fan 128 is operating at full speed, and any pressure above this pre-determined maximum pressure has no impact on the speed of the fan 128. Controlling the speed of the fan 128 in this manner can allow the refrigeration system 100 to operate in a more stable manner during lower or cooler ambient conditions.

[0038] In this version, the controller 254 may simultaneously control the electronic stepper valve 136, the solenoid valve 150, and the fan control drive 160. As such, the controller 254 may open the electronic stepper valve 136 and, at the same time, energize the solenoid valve 150. In other versions, however, the controller 254 may only control two or more of the electronic stepper valve 136, the solenoid valve 150, and the fan control drive 160 at different times. In further versions, the controller 254 may only control one or two, rather than all, of the electronic stepper valve 136, the solenoid valve 150, and the fan control drive 160.

[0039] The controller 254 may instruct the panel 258 to provide visual feedback about the operation of the refrigeration system 100. The controller 254 may instruct the LED 278 of the panel 258 to emit one or a series of lights, as described above, when the controller 254 detects one or more fault or alarm conditions. In some cases, the controller 254 may detect one or more fault or alarm conditions based on the obtained data. The pressure and/or temperature data may, for example, indicate that the transducer 204, the transducer 208, the transducer 212, and/or the transducer 216 is not functioning properly. The controller 254, by virtue of its connection with the fan control drive 160, may detect that the condenser fan 128, the fan motor 132, and/or the fan control drive 160 is not functioning properly. In some cases, the controller 254 may detect a problem with one of the networks 300-324 connecting the controller 254 to the various components of the refrigeration system 100. The controller 254 may, alternatively or additionally, detect that the bit-switches are not functioning properly or were not properly set. The controller 254 may, alternatively or additionally, instruct the LED 282 of the panel 258 to emit a solid green light when the refrigeration system 100 is operating normally, and instruct the LED 282 of the panel 258 to emit one flash of green light when the anti-cycle option is active. In turn, the panel 258 may provide the requested visual feedback via the LEDs 278, 282, as instructed. Accordingly, a user of the refrigeration system 100 can easily and quickly identify problems with the control process for the refrigeration system 100.

[0040] As also illustrated in FIG. 3, in some cases, a hand-held diagnostic tool 350 can be coupled with or

connected to the intelligent control board 250 via a communication network 354, which can be a wireless network, a wired network, or a combination thereof. The hand-held diagnostic tool 350 can include a processor, a memory, one or more input devices (e.g., a keyboard), a display, and/or other components, as known in the art. In any event, the hand-held diagnostic tool 350 allows a user of the refrigeration system 100 to install the intelligent control board 250, configure various components of the system 100 (e.g., the controller 254), and monitor, in real-time, operating conditions of the refrigeration system 100.

[0041] FIG. 4 illustrates one version of a method or process of operating the refrigeration system 100 of the present disclosure. Although the method or process is described below as being performed by or using the transducers 204-216 and the controller 254, the method or process may, alternatively, be performed by some other component. The method or process is described as including various tasks performed in a sequence, but it should be appreciated that some of the tasks of the method or process can be performed simultaneously and some or all can be performed in a different order. In other versions, the method or process may include additional, fewer, or different tasks, or a different sequence of tasks. As an example, one or more of the tasks (e.g., the task of obtaining the first temperature, the task of obtaining the first pressure, the task of obtaining the second pressure) can be repeated any number of times.

[0042] In one version, referring to the "blocks" in FIG. 4, the method includes (i) obtaining, from a first transducer (e.g., the transducer 208) coupled to the refrigeration system 100, a first temperature of the refrigerant leaving a condenser (e.g., the condenser 104) (block 400), (ii) obtaining, from a second transducer (e.g., the transducer 204) coupled to the refrigeration system 100, a first pressure of the refrigerant leaving the condenser (block 404), and (iii) obtaining, from a third transducer (e.g., the transducer 212 or 216) coupled to the refrigeration system 100, a second pressure of the refrigerant leaving an evaporator (e.g., the evaporator 112) or a temperature of the product being refrigerated (block 408). In some versions, obtaining the second pressure or the temperature of the product includes obtaining the second pressure (e.g., via the transducer 212), while in other versions, obtaining the second pressure or the temperature of the product includes obtaining the temperature of the product (e.g., via the transducer 216). In yet another version, obtaining the second pressure or the temperature of the product can include obtaining the second pressure and obtaining the temperature of the product.

[0043] In one version, the method also includes controlling, via a processor (e.g., the processor 262) communicatively coupled to the refrigeration system 100, a first valve (e.g., the valve 108) of the refrigeration system 100 based on the first temperature and the first pressure to maintain a pre-determined cooling set-point for the refrigeration system 100 (block 412). In one version, the

first valve can be an electronic stepper valve (e.g., the stepper valve 136) disposed between the condenser and the evaporator. In some versions, the method further includes calculating, via the processor, a current cooling level of the refrigerant leaving the condenser based on the first temperature and the first pressure. In these versions, controlling the first valve may include controlling the first valve based on the calculated current cooling level. In some versions, controlling the first valve includes opening or closing the first valve when the calculated current cooling level is different from the pre-determined cooling set-point. In one version, the method further includes comparing the current cooling level of the refrigerant with the pre-determined cooling set-point, the pre-determined cooling set-point being the desired cooling level for the refrigerant when leaving the condenser. Controlling the first valve may include controlling the first valve based on the comparing.

[0044] In one version, the method also includes controlling, via the processor, a second valve (e.g., the valve 120) of the refrigeration system 100 based on the second pressure or the temperature of the product to optimize a capacity of a compressor (e.g., the compressor 124) of the refrigeration system 100 (block 416). In one version, the second valve can be a solenoid valve (e.g., the solenoid valve 150) disposed between the evaporator and the compressor. In some versions, the method further includes comparing the obtained second pressure or product temperature with a pre-determined second pressure or product temperature set-point. In these versions, controlling the second valve of the refrigeration system may include controlling the second valve based on the comparing. In some versions, such as when the second valve is a solenoid valve, controlling the second valve includes energizing the solenoid valve when the second pressure or product temperature is less than the pre-determined second pressure or product temperature set-point, and de-energizing the solenoid valve when the second pressure or product temperature is greater than the pre-determined second pressure or product temperature set-point. In one version, the method further includes suspending control of the first control valve when the solenoid valve is de-energized.

[0045] Based on the foregoing description, it should be appreciated that the devices, systems, and methods described herein facilitate a more efficient refrigeration system for refrigerating a product. This is accomplished by obtaining data associated with the operation of the refrigeration system, controlling a first control valve based on the pressure and temperature of the refrigerant leaving a condenser of the refrigeration system, and controlling a second control valve based on the pressure of the refrigerant leaving an evaporator or based on a temperature of the product being refrigerated.

[0046] By controlling the first control valve in this manner, a pre-determined cooling set-point for the refrigeration system can be maintained. This ensures that the refrigerant leaving the condenser is sufficiently cooled

such that the evaporator is flooded with liquid refrigerant and, as a result, a saturated suction is provided. In turn, when exiting the evaporator, the refrigerant is at a lower superheat than it otherwise would be (in conventional refrigeration systems), which keeps the motor of the compressor cooler and increases the volumetric efficiency of the compressor. By controlling the second control valve in the above-outlined manner, the capacity of the compressor can be controlled. Under low-load conditions and/or low set-point temperatures, the capacity of the compressor can be reduced in a controlled manner. Such a controlled reduction helps to maintain a desirable evaporator condition, allowing the product to be cooled closer to freezing temperatures and reducing the likelihood that ice will form on the evaporator. When, however, large volumes of product are to be refrigerated or the desired temperature of the product is higher, the capacity of the compressor can be increased in a controlled manner. In this way, the duration of the refrigeration cycle need not be increased (as in a conventional refrigeration system), improving product quality and reducing energy consumption. Additionally, by controlling the capacity of the compressor in such a controlled manner, the compressor no longer needs to be cycled on and off, stabilizing the temperature of the cooling medium for the condenser will be more stable and, ultimately, making it easier to maintain the desired product temperature.

[0047] Preferred embodiments of this disclosure are described herein, including the best mode or modes known to the inventors for carrying out the disclosure. Although numerous examples are shown and described herein, those of skill in the art will readily understand that details of the various embodiments need not be mutually exclusive. Instead, those of skill in the art upon reading the teachings herein should be able to combine one or more features of one embodiment with one or more features of the remaining embodiments. Further, it also should be understood that the illustrated embodiments are exemplary only, and should not be taken as limiting the scope of the disclosure. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the aspects of the exemplary embodiment or embodiments of the disclosure, and do not pose a limitation on the scope of the disclosure. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the disclosure.

Claims

1. A method of operating a refrigeration system (100) for refrigerating a product, the refrigeration system having a condenser (104), an evaporator (112) downstream of the condenser (104), a compressor

(124) downstream of the evaporator (112), and a refrigerant flowing through the refrigeration system (100), the method comprising:

- obtaining, from a first transducer (208) coupled to the refrigeration system (100), a first temperature of the refrigerant downstream of the condenser (104) and upstream of the evaporator (112);
 - obtaining, from a second transducer (204) coupled to the refrigeration system (100), a first pressure of the refrigerant downstream of the condenser (104) and upstream of the evaporator (112);
 - obtaining, from a third transducer (212, 216) coupled to the refrigeration system (100), a second pressure of the refrigerant downstream of the evaporator (112) and upstream of the compressor (124) or a temperature of the product being refrigerated; and
 - controlling, via a processor (262) communicatively coupled to the refrigeration system (100), a degree of opening of a first valve (108) of the refrigeration system (100) disposed between the condenser (104) and the evaporator (112), based on the first temperature and the first pressure, to maintain a pre-determined cooling set-point for the refrigeration system (100), and/or a second valve (120) of the refrigeration system (100) coupled to the compressor (124), based on the second pressure or the temperature of the product, to optimize a capacity of the compressor (124).
2. The method of claim 1, wherein controlling the first valve (108) and controlling the second valve (120) occur simultaneously.
 3. The method of claim 1 or 2, wherein obtaining the first temperature, the first pressure, and the temperature of the product or the second pressure occur simultaneously.
 4. The method of any one of the preceding claims, wherein controlling the degree of opening of the first valve (108) comprises controlling a degree of opening of an electronic stepper valve (136) disposed between the condenser (104) and the evaporator (112) and/or wherein controlling the second valve (120) comprises controlling a solenoid valve (150) coupled to the compressor (124).
 5. The method of any one of the preceding claims, further comprising calculating, via the processor (262), a current cooling level of the refrigerant leaving the condenser based on the first temperature and the first pressure, wherein controlling the degree of opening of the first valve of the refrigeration system

(100) comprises controlling the degree of opening of the first valve (108) of the refrigeration system (100) based on the calculated current cooling level, preferably wherein controlling the degree of opening of the first valve (108) of the refrigeration system (100) comprises increasing or decreasing the degree of opening of the first valve (108) of the refrigeration system (100) when the calculated cooling level is different from the pre-determined cooling set-point, further preferably comprising comparing, via the processor (262), the calculated cooling level of the refrigerant with the pre-determined cooling set-point, the pre-determined cooling set-point being the desired cooling level for the refrigerant when leaving the condenser (104), wherein controlling the degree of opening of the first valve (108) of the refrigeration system (100) comprises controlling the degree of opening of the first valve (108) of the refrigeration system (100) based on the comparing.

6. The method of any one of the preceding claims, further comprising comparing the obtained second pressure or product temperature with a predetermined second pressure or product temperature set-point, wherein controlling the second valve (120) of the refrigeration system (100) comprises opening or closing the second valve (120) based on the comparing, preferably wherein controlling the second valve (120) comprises energizing the solenoid valve (150) when the second pressure or product temperature is less than the pre-determined second pressure or product temperature set-point, and de-energizing the solenoid valve (150) when the second pressure or product temperature is greater than the pre-determined second pressure or product temperature set-point, further preferably comprising suspending control of the first valve (108) when the solenoid valve (150) is de-energized.
7. The method of any one of the preceding claims, wherein obtaining the second pressure or the temperature of the product comprises obtaining the second pressure of the refrigerant downstream of the evaporator (112) and upstream of the compressor, and wherein controlling the second valve (120) comprises controlling the second valve (120) based on the second pressure of the refrigerant or wherein obtaining the second pressure or the temperature of the product comprises obtaining the temperature of the product, and wherein controlling the second valve (120) comprises controlling the second valve based on the temperature of the product.
8. The method of any one of the preceding claims, further comprising adjusting, via the processor (262), a speed of an electric fan (128) coupled to the condenser (104) based on the first pressure.

9. The method of any one of the preceding claims, further comprising generating, via the processor (262), a visual indicator when a fault condition is detected in the refrigeration system (100).
10. A refrigeration system (100) for refrigerating a product, comprising:
- a condenser (104);
 - an evaporator (112) disposed downstream of the condenser (104);
 - a compressor (124) disposed downstream of the evaporator (112);
 - a first transducer (208) disposed immediately downstream of the condenser (104), the first transducer (208) configured to obtain a first temperature of a refrigerant downstream of the condenser (104) and upstream of the evaporator (112);
 - a second transducer (204) disposed immediately downstream of the condenser (104), the second transducer (204) configured to obtain a first pressure of the refrigerant downstream of the condenser (104) and upstream of the evaporator (112);
 - a third transducer (212,216) disposed immediately downstream of the evaporator (112), the third transducer (212, 216) configured to obtain a second pressure of the refrigerant downstream of the evaporator (112) and upstream of the compressor (124) or a temperature of the product being refrigerated; and
 - a controller (262) communicatively coupled to the first, second, and third transducers (208, 204, 212, 216), the controller (262) configured to control a first valve (108) disposed downstream of the condenser (104) and upstream of the evaporator (112) based on the obtained first temperature and the first pressure to maintain a pre-determined cooling set-point, the controller (262) configured to control a second valve (120) coupled to the compressor (124) based on the obtained second pressure or the temperature of the product to optimize a capacity of compressor (124).
11. The refrigeration system (100) of claim 10, wherein the first valve (108) is an electronic stepper valve (136) configured to reduce the pressure of the refrigerant and/or wherein the second valve (120) is a solenoid valve (150) configured to load or unload the compressor (124).
12. The refrigeration system (100) of claim 10 or 11, further comprising: a fan (128) arranged to pull a refrigeration medium across the condenser (104); and a fan drive (160) configured to control a speed of the fan (128), wherein the controller (254) is configured to control the fan drive (160) based on the obtained first pressure.
13. The refrigeration system (100) of any one of claims 10 to 12, further comprising a hand-held device (350) communicatively coupled to the controller (254), the hand held device (350) configured to allow a user to remotely monitor the refrigeration system (100).
14. The refrigeration system (100) of any one of claims 10 to 13, wherein the controller (254) is configured to calculate a current cooling level of the refrigerant downstream of the condenser (104) and upstream of the evaporator (112) based on the obtained first temperature and first pressure, and wherein the controller (254) is configured to control the first valve (108) of the refrigeration system (100) based on the calculated cooling level, preferably wherein the controller (254) is configured to compare the current cooling level of the refrigerant with the pre-determined cooling set-point, the pre-determined cooling set-point being the desired cooling level for the refrigerant when leaving the condenser (104), and wherein the controller (254) is configured to control the first valve (109) of the refrigeration system (100) based on the comparison.
15. The refrigeration system of any one of claims 10 to 14, wherein the controller (254) is configured to compare the obtained second pressure or temperature with a pre-determined second pressure or temperature set-point, and wherein the controller (254) is configured to control the second valve (120) of the refrigeration system (100) based on the comparison, preferably wherein the controller (254) is configured to energize the second valve (120) when the obtained second pressure or temperature is less than the pre-determined second pressure or temperature set-point, and de-energize the second valve (120) when the obtained second pressure or temperature is greater than the pre-determined second pressure or temperature set-point.

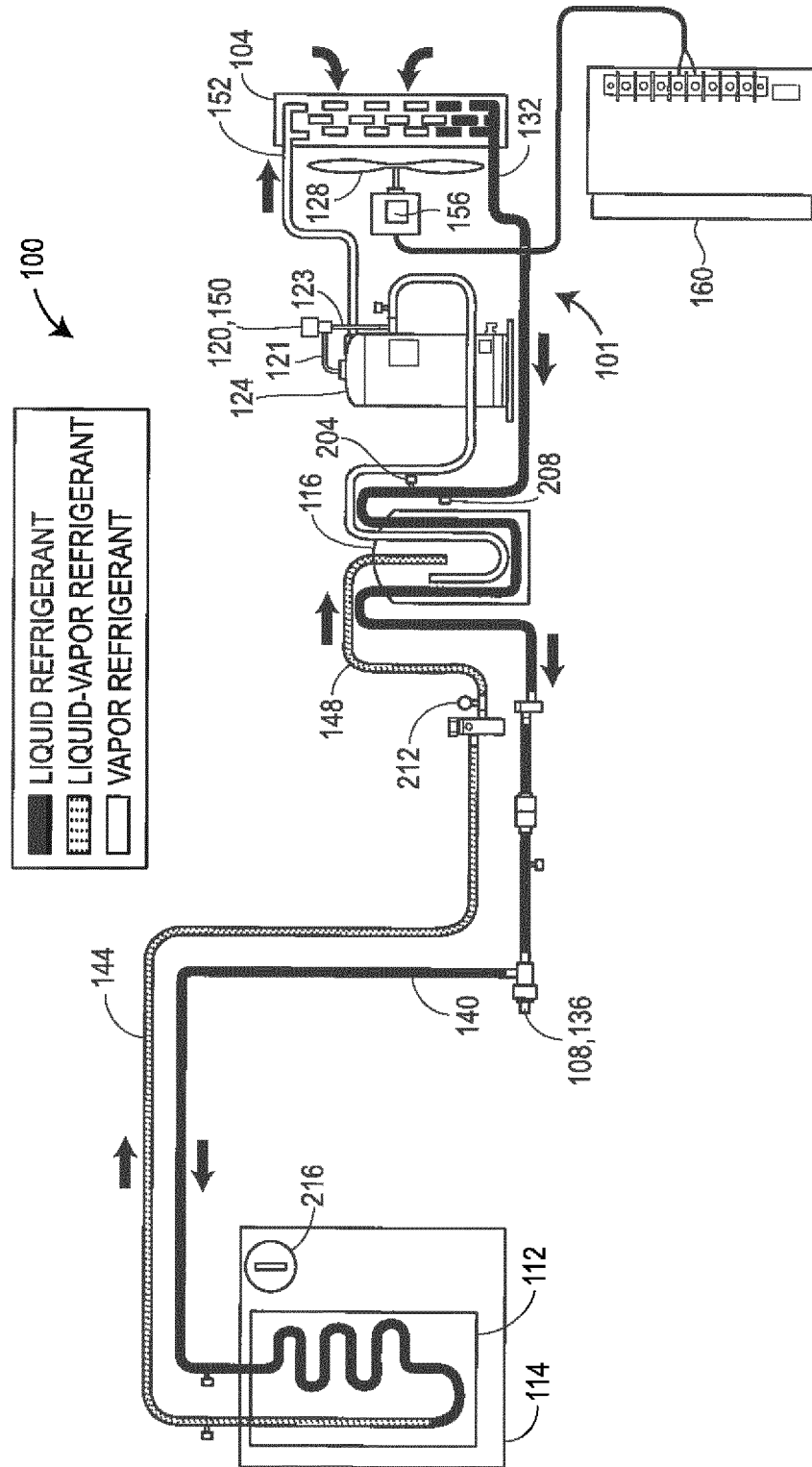


FIG. 1

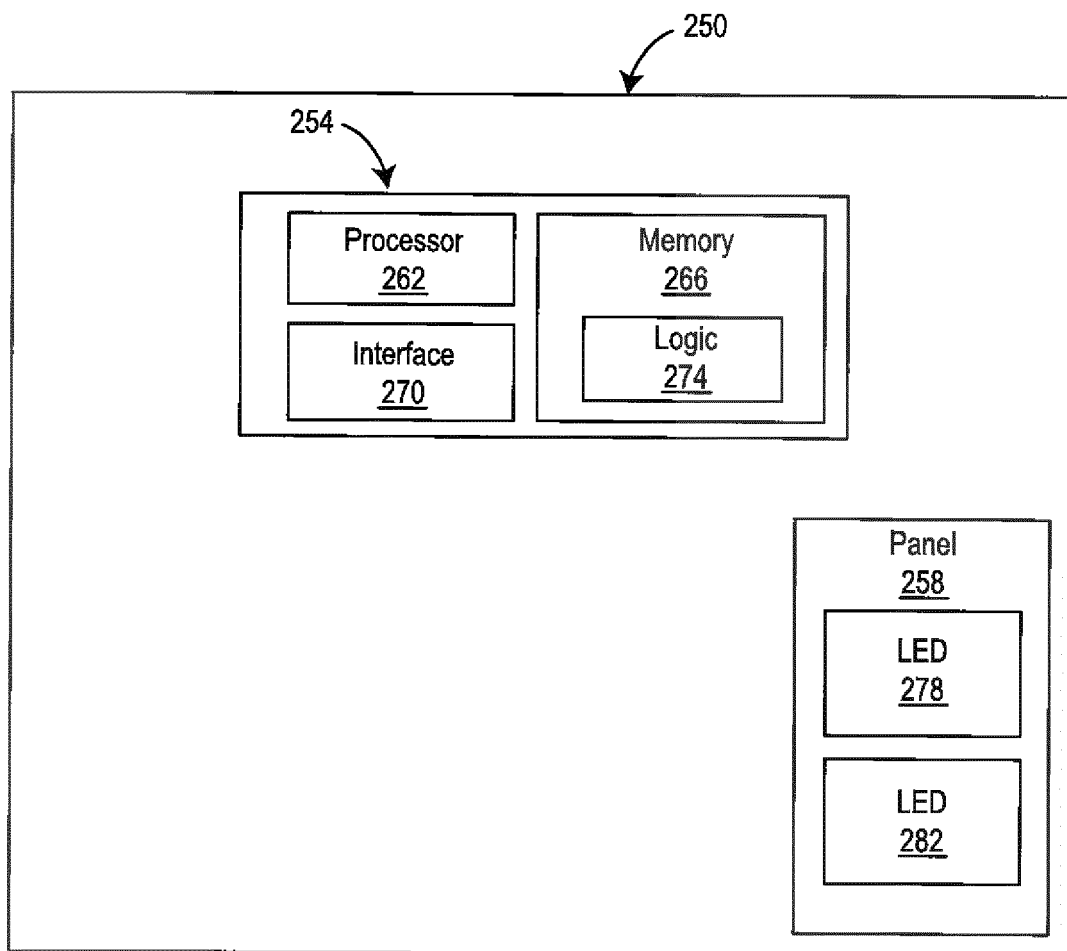


FIG. 2

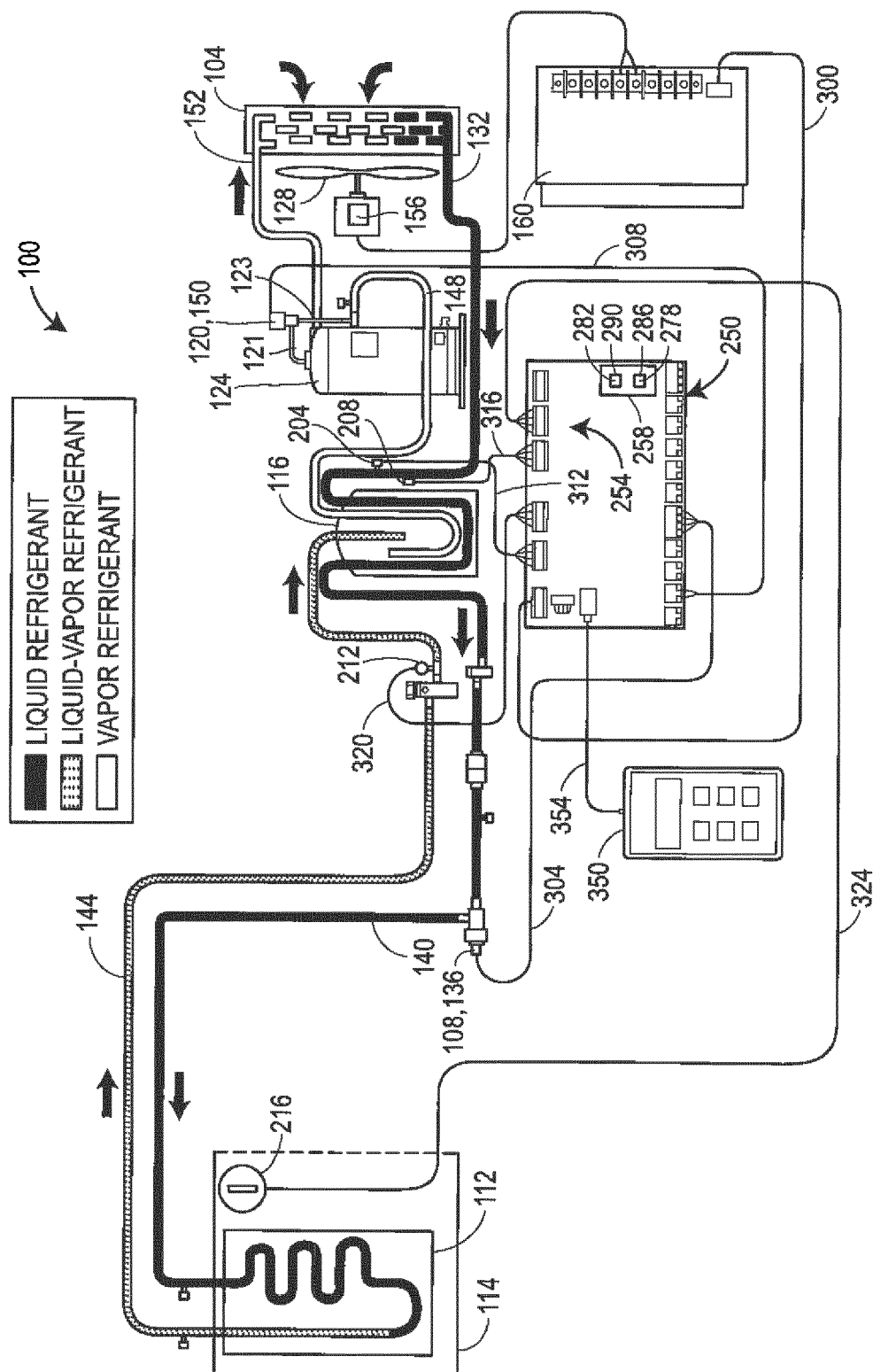


FIG. 3

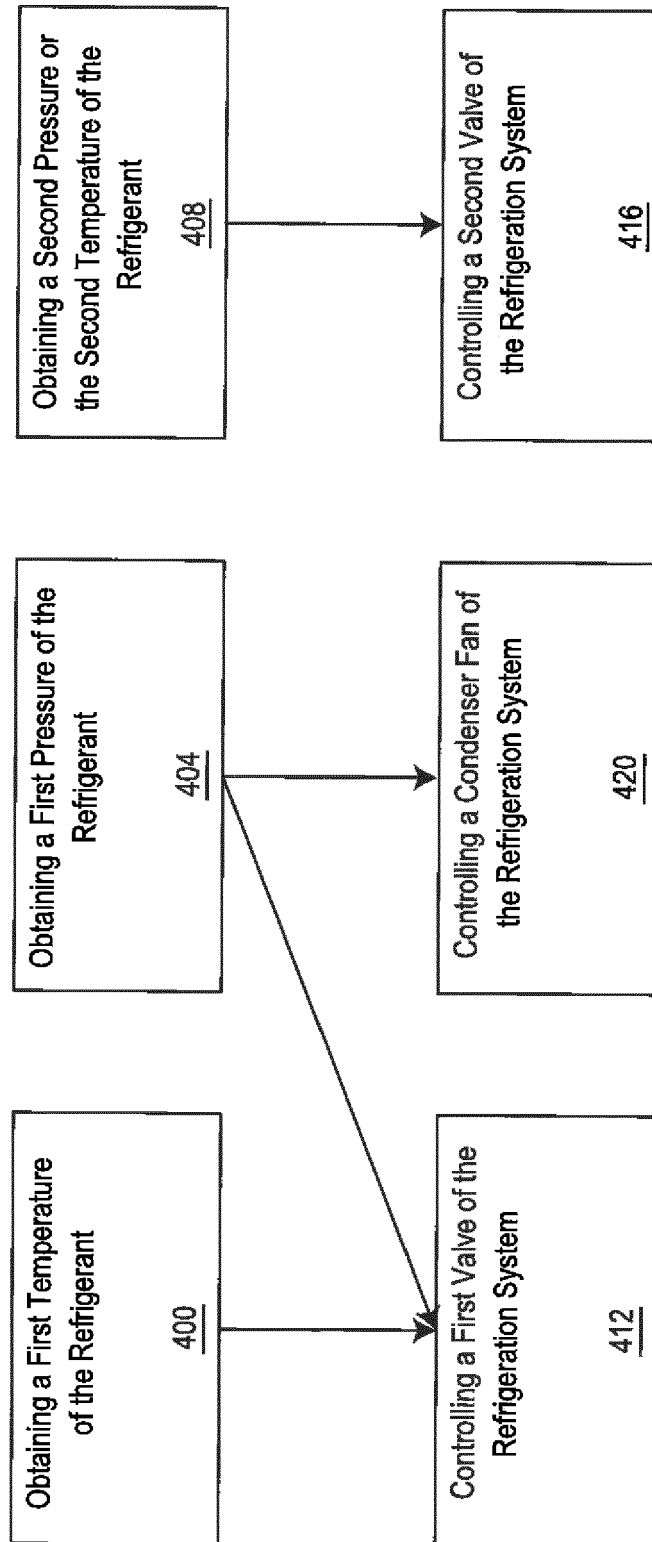


FIG. 4



EUROPEAN SEARCH REPORT

Application Number
EP 15 17 9651

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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 10 December 2015	Examiner Amous, Moez
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			

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