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(54) Title: FLOODED EVAPORATOR FOR A VAPOR COMPRESSION SYSTEM

(57) Abstract: Embodiments of the present disclosure relate to a heating, ventilation, air conditioning, and refrigeration (HVAC&R) system (10) that includes a refrigerant loop, a compressor (32) disposed along the refrigerant loop and configured to circulate refrigerant through the refrigerant loop, an evaporator (38) disposed along the refrigerant loop and configured to place the refrigerant in a heat exchange relationship with a cooling fluid (112), and a tube bundle (82) of the evaporator configured to flow the cooling fluid through the evaporator, where the tube bundle includes a peripheral portion that is non-linear and at least partially conforms to a shape of a shell (76) of the evaporator (38).

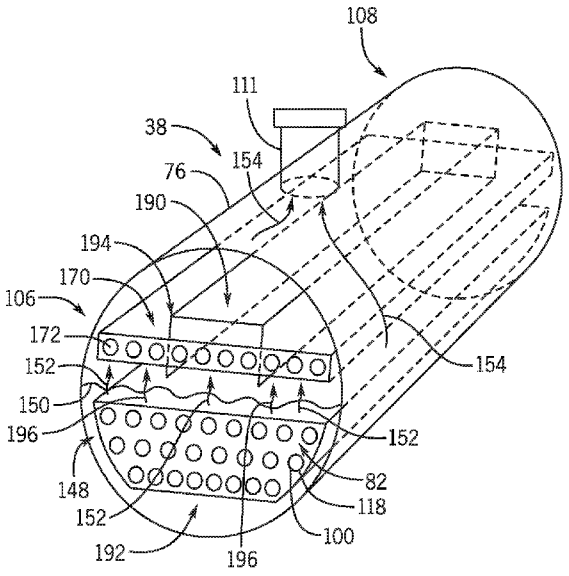


FIG. 9

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Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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FLOODED EVAPORATOR FOR A VAPOR COMPRESSION SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from and the benefit of U.S. Provisional Application Serial No. 62/275,522, filed January 6, 2016, entitled "VAPOR COMPRESSION SYSTEM," the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND

[0002] This application relates generally to vapor compression systems incorporated in air conditioning and refrigeration applications.

[0003] Vapor compression systems utilize a working fluid, typically referred to as a refrigerant that changes phases between vapor, liquid, and combinations thereof in response to being subjected to different temperatures and pressures associated with operation of the vapor compression system. Refrigerants are desired that are friendly to the environment, yet have a coefficient of performance (COP) that is comparable to traditional refrigerants. COP is a ratio of heating or cooling provided to electrical energy consumed, and higher COPs equate to lower operating costs. Unfortunately, there are challenges associated with designing vapor compression system components compatible with environmentally-friendly refrigerants, and more specifically, vapor compression system components that operate to maximize efficiency using such refrigerants.

SUMMARY

[0004] In an embodiment of the present disclosure, a heating, ventilation, air conditioning, and refrigeration (HVAC&R) system includes a refrigerant loop, a compressor disposed along the refrigerant loop and configured to circulate refrigerant through the refrigerant loop, an evaporator disposed along the refrigerant loop and configured to place the refrigerant in a heat exchange relationship with a cooling fluid, and a tube bundle of the evaporator configured to flow the cooling fluid through the evaporator, where the tube bundle includes a peripheral portion that is non-linear and at least partially conforms to a shape of a shell of the evaporator.

[0005] In another embodiment of the present disclosure, a heating, ventilation, air conditioning, and refrigeration (HVAC&R) system includes a refrigerant loop, a compressor disposed along the refrigerant loop and configured to circulate refrigerant through the refrigerant loop, an evaporator disposed along the refrigerant loop and configured to place the refrigerant in a heat exchange relationship with a cooling fluid, a first tube bundle of the evaporator configured to flow the cooling fluid through the evaporator, where the first tube bundle has a peripheral portion that is non-linear and at least partially conforms to a shape of a shell of the evaporator, and a second tube bundle disposed between the first tube bundle and a refrigerant discharge of the evaporator, where the second tube bundle is configured to place the refrigerant in thermal communication with an additional cooling fluid to reduce an amount of liquid refrigerant that is directed from the evaporator to the compressor.

[0006] In still another embodiment of the present disclosure, a heating, ventilation, air conditioning, and refrigeration (HVAC&R) system includes a refrigerant loop, a compressor disposed along the refrigerant loop and configured to circulate refrigerant through the refrigerant loop, an evaporator disposed along the refrigerant loop and configured to place the refrigerant in a heat exchange relationship with a cooling fluid, a first tube bundle of the evaporator configured to flow the cooling fluid through the evaporator, where the first tube bundle has a peripheral portion that is non-linear and at least partially conforms to a shape of a shell of the evaporator, a second tube bundle disposed between the first tube bundle and a refrigerant discharge of the evaporator, where the second tube bundle is configured to place the refrigerant in thermal communication with an additional cooling fluid to reduce an amount of liquid refrigerant that is directed from the evaporator to the compressor, and a cover disposed over at least a portion of the second tube bundle.

BRIEF DESCRIPTION OF THE FIGURES

[0007] FIG. 1 is a perspective view of an embodiment of a building that may utilize a heating, ventilation, air conditioning, and refrigeration (HVAC&R) system in a commercial setting, in accordance with an aspect of the present disclosure;

[0008] FIG. 2 is a perspective view of an embodiment of an HVAC&R system, in accordance with an aspect of the present disclosure;

[0009] FIG. 3 is a schematic of an embodiment of the HVAC&R system of FIG. 2, in accordance with an aspect of the present disclosure;

[0010] FIG. 4 is a schematic of an embodiment of the HVAC&R system of FIG. 2, in accordance with an aspect of the present disclosure;

[0011] FIG. 5 is a cross section of an embodiment of an evaporator of the HVAC&R system of FIGS. 2-4 that includes an improved tube bundle, in accordance with an aspect of the present disclosure;

[0012] FIG. 6 is a cross section of an embodiment of the evaporator of FIG. 5 having an additional tube bundle, in accordance with an aspect of the present disclosure;

[0013] FIG. 7 is a cross section of an embodiment of the evaporator of FIG. 6, in accordance with an aspect of the present disclosure;

[0014] FIG. 8 is a perspective cross section of an embodiment of the evaporator of FIG. 5 having an additional tube bundle configured to flow refrigerant, in accordance with an aspect of the present disclosure; and

[0015] FIG. 9 is a perspective cross section of an embodiment of the evaporator of FIG. 8 having a cover over at least a portion of the additional tube bundle, in accordance with an aspect of the present disclosure.

DETAILED DESCRIPTION

[0016] Embodiments of the present disclosure include an evaporator that may improve an efficiency of a heating, ventilation, air conditioning, and refrigeration (HVAC&R) system. For example, the evaporator may include a tube bundle that places a refrigerant into thermal communication with a cooling fluid that flows through tubes of the tube bundle. The tube bundle may include peripheral portions that are non-linear and/or that substantially conform to a shape of a shell of the evaporator. The peripheral

portions (e.g., edges) of the tube bundle reduce an amount of dead space (e.g., unoccupied space) within the shell, which may increase an amount of thermal energy transfer that may occur in the evaporator, as well as reduce an amount of refrigerant present in the evaporator to achieve a target amount of thermal energy transfer. Further, the evaporator may include an additional tube bundle that is positioned between the tube bundle and a refrigerant discharge (e.g., an outlet). The additional tube bundle may place the refrigerant in thermal communication with an additional cooling fluid (e.g., the cooling fluid in the tube bundle and/or refrigerant) flowing through the additional tube bundle. As such, liquid refrigerant that may be present in the refrigerant directed to the compressor may be removed, which may ultimately enhance an efficiency of the system. Additionally, a cover (e.g., a solid shroud) may be disposed over at least a portion of the additional tube bundle to further remove liquid refrigerant (e.g., entrained liquid) from the refrigerant that is ultimately discharged from the evaporator to the compressor.

[0017] Turning now to the drawings, FIG. 1 is a perspective view of an embodiment of an environment for a heating, ventilation, air conditioning, and refrigeration (HVAC&R) system 10 in a building 12 for a typical commercial setting. The HVAC&R system 10 may include a vapor compression system 14 that supplies a chilled liquid, which may be used to cool the building 12. The HVAC&R system 10 may also include a boiler 16 to supply warm liquid to heat the building 12 and an air distribution system which circulates air through the building 12. The air distribution system can also include an air return duct 18, an air supply duct 20, and/or an air handler 22. In some embodiments, the air handler 22 may include a heat exchanger that is connected to the boiler 16 and the vapor compression system 14 by conduits 24. The heat exchanger in the air handler 22 may receive either heated liquid from the boiler 16 or chilled liquid from the vapor compression system 14, depending on the mode of operation of the HVAC&R system 10. The HVAC&R system 10 is shown with a separate air handler on each floor of building 12, but in other embodiments, the HVAC&R system 10 may include air handlers 22 and/or other components that may be shared between or among floors.

[0018] FIGS. 2 and 3 are embodiments of the vapor compression system 14 that can be used in the HVAC&R system 10. The vapor compression system 14 may circulate a refrigerant through a circuit starting with a compressor 32. The circuit may also include a condenser 34, an expansion valve(s) or device(s) 36, and a liquid chiller or an evaporator 38. The vapor compression system 14 may further include a control panel 40 that has an analog to digital (A/D) converter 42, a microprocessor 44, a non-volatile memory 46, and/or an interface board 48.

[0019] Some examples of fluids that may be used as refrigerants in the vapor compression system 14 are hydrofluorocarbon (HFC) based refrigerants, for example, R-410A, R-407, R-134a, hydrofluoro olefin (HFO), "natural" refrigerants like ammonia (NH_3), R-717, carbon dioxide (CO_2), R-744, or hydrocarbon based refrigerants, water vapor, or any other suitable refrigerant. In some embodiments, the vapor compression system 14 may be configured to efficiently utilize refrigerants having a normal boiling point of about 19 degrees Celsius (66 degrees Fahrenheit) at one atmosphere of pressure, also referred to as low pressure refrigerants, versus a medium pressure refrigerant, such as R-134a. As used herein, "normal boiling point" may refer to a boiling point temperature measured at one atmosphere of pressure.

[0020] In some embodiments, the vapor compression system 14 may use one or more of a variable speed drive (VSDs) 52, a motor 50, the compressor 32, the condenser 34, the expansion valve or device 36, and/or the evaporator 38. The motor 50 may drive the compressor 32 and may be powered by a variable speed drive (VSD) 52. The VSD 52 receives alternating current (AC) power having a particular fixed line voltage and fixed line frequency from an AC power source, and provides power having a variable voltage and frequency to the motor 50. In other embodiments, the motor 50 may be powered directly from an AC or direct current (DC) power source. The motor 50 may include any type of electric motor that can be powered by a VSD or directly from an AC or DC power source, such as a switched reluctance motor, an induction motor, an electronically commutated permanent magnet motor, or another suitable motor.

[0021] The compressor 32 compresses a refrigerant vapor and delivers the vapor to the condenser 34 through a discharge passage. In some embodiments, the compressor 32 may be a centrifugal compressor. The refrigerant vapor delivered by the compressor 32 to the condenser 34 may transfer heat to a cooling fluid (e.g., water or air) in the condenser 34. The refrigerant vapor may condense to a refrigerant liquid in the condenser 34 as a result of thermal heat transfer with the cooling fluid. The liquid refrigerant from the condenser 34 may flow through the expansion device 36 to the evaporator 38. In the illustrated embodiment of FIG. 3, the condenser 34 is water cooled and includes a tube bundle 54 connected to a cooling tower 56, which supplies the cooling fluid to the condenser.

[0022] The liquid refrigerant delivered to the evaporator 38 may absorb heat from another cooling fluid, which may or may not be the same cooling fluid used in the condenser 34. The liquid refrigerant in the evaporator 38 may undergo a phase change from the liquid refrigerant to a refrigerant vapor. As shown in the illustrated embodiment of FIG. 3, the evaporator 38 may include a tube bundle 58 having a supply line 60S and a return line 60R connected to a cooling load 62. The cooling fluid of the evaporator 38 (e.g., water, ethylene glycol, calcium chloride brine, sodium chloride brine, or any other suitable fluid) enters the evaporator 38 via return line 60R and exits the evaporator 38 via supply line 60S. The evaporator 38 may reduce the temperature of the cooling fluid in the tube bundle 58 via thermal heat transfer with the refrigerant. The tube bundle 58 in the evaporator 38 can include a plurality of tubes and/or a plurality of tube bundles. In any case, the vapor refrigerant exits the evaporator 38 and returns to the compressor 32 by a suction line to complete the cycle.

[0023] FIG. 4 is a schematic of the vapor compression system 14 with an intermediate circuit 64 incorporated between condenser 34 and the expansion device 36. The intermediate circuit 64 may have an inlet line 68 that is directly fluidly connected to the condenser 34. In other embodiments, the inlet line 68 may be indirectly fluidly coupled to the condenser 34. As shown in the illustrated embodiment of FIG. 4, the inlet line 68 includes a first expansion device 66 positioned upstream of an intermediate vessel 70. In some embodiments, the intermediate vessel 70 may be a flash tank (e.g., a flash

intercooler). In other embodiments, the intermediate vessel 70 may be configured as a heat exchanger or a "surface economizer." In the illustrated embodiment of FIG. 4, the intermediate vessel 70 is used as a flash tank, and the first expansion device 66 is configured to lower the pressure of (e.g., expand) the liquid refrigerant received from the condenser 34. During the expansion process, a portion of the liquid may vaporize, and thus, the intermediate vessel 70 may be used to separate the vapor from the liquid received from the first expansion device 66. Additionally, the intermediate vessel 70 may provide for further expansion of the liquid refrigerant because of a pressure drop experienced by the liquid refrigerant when entering the intermediate vessel 70 (e.g., due to a rapid increase in volume experienced when entering the intermediate vessel 70). The vapor in the intermediate vessel 70 may be drawn by the compressor 32 through a suction line 74 of the compressor 32. In other embodiments, the vapor in the intermediate vessel may be drawn to an intermediate stage of the compressor 32 (e.g., not the suction stage). The liquid that collects in the intermediate vessel 70 may be at a lower enthalpy than the liquid refrigerant exiting the condenser 34 because of the expansion in the expansion device 66 and/or the intermediate vessel 70. The liquid from intermediate vessel 70 may then flow in line 72 through a second expansion device 36 to the evaporator 38.

[0024] A typical tube bundle of the evaporator 38 (e.g., a flooded evaporator, a falling film evaporator, a hybrid flooded/falling film evaporator, among others) may be arranged to include linear peripheral portions (e.g., edges) that do not conform to a shape of a shell 76 of the evaporator 38. Unfortunately, such arrangements of the tube bundle create openings or cavities between the tube bundle and an inner surface of the shell of the evaporator 38. Typically, baffles are inserted between the linear peripheral portions and the inner surface of shell 76 to block refrigerant (e.g., vapor refrigerant) from bypassing the tube bundle. However, installation of the baffles may be complex and/or time consuming, which may increase manufacturing costs of the evaporator 38. Additionally, an increased amount of refrigerant may be included in the evaporator 38 to fill a space between the tube bundle and the inside surface of the shell 76 to achieve a target amount of thermal energy transfer. Accordingly, embodiments of the present disclosure relate to a tube bundle that includes non-linear peripheral portions (e.g., curved

edges) to reduce dead space in the shell 76 of the evaporator 38 and to reduce manufacturing costs of the evaporator 38.

[0025] For example, FIG. 5 is a cross section of a tube bundle 82 that includes peripheral portions 90, 92, and 94 formed in a shape that substantially conforms to an inner surface 96 of the shell 76. For example, the peripheral portions 90, 92, and/or 94 generally mirror a shape of the inner surface 96 of the shell 76, such that the peripheral portions 90, 92, and/or 94 conform to the inner surface 96 of the shell 76 and reduce unoccupied space between the tube bundle 82 and the shell 76. In some embodiments, the peripheral portion 92 of the tube bundle 82 may include another configuration 98 (shown in dashed line) to even further reduce unoccupied space in the shell 76. Reducing unoccupied space in the shell 76 may eliminate the baffles of typical configurations, which may reduce an assembly time of the heat exchanger, and thus, reduce manufacturing costs.

[0026] As used herein, the peripheral portions 90, 92, and 94 may be defined as edges (e.g., at least a portion of a perimeter) of a cross-section of the tube bundle 82 taken along a plane 99 that is crosswise (e.g., substantially perpendicular) to a central axis 101 of the shell 76. The peripheral portions 90, 92, and 94 may be defined by a collection of tubes 100 of the tube bundle 82 that are disposed along the corresponding portion of the perimeter for each of the peripheral portions 90, 92, and 94. In some embodiments, the combination of the peripheral portions 90, 92, and 94 may form at least 50% of the total perimeter of the cross section of the tube bundle 82, at least 60% of the total perimeter of the cross section of the tube bundle 82, or at least 75% of the total perimeter of the cross section of the tube bundle 82.

[0027] In some embodiments, at least a segment of one of the peripheral portions 90, 92, and/or 94 of the tube bundle 82 may be substantially coincident with a corresponding portion of the inner surface 96 of the shell 76. For purposes herein, "substantially coincident" is intended to refer to tubes 100 positioned as close to the inner surface 96 of the shell 76 as manufacturing processes and/or tolerances allow. Accordingly, a gap 102 may be formed between the tube bundle 82 and the inner surface 96 of the shell 76. In

some embodiments, a distance 104 of the gap 102 is approximately equal to (e.g., within 5% of or within 10% of) a diameter 106 of one of the tubes 100. In other embodiments, the distance 104 of the gap 102 may be less than the diameter 106 of the tubes 100. For example, the distance 104 may be between 0.5 inches and 1 inch, between 0.5 inches and 1.5 inches, or between 0.5 inches and 2 inches. In one embodiment, at least a segment of one of the peripheral portions 90, 92, and/or 94 of the tube bundle 82 can be at least partially curved to conform to the inner surface 96 of the shell 76 (e.g., when the shell is cylindrical).

[0028] As shown in the illustrated embodiment of FIG. 5, the tube bundle 82 includes a variable pitch arrangement of tubes 100 relative to one another (e.g., the tubes 100 of the tube bundle 82 are spaced non-uniformly from one another). Additionally, the tube bundle 82 may also have different spacing between the tubes 100 and the inner surface 96 of the shell 76, such that the tubes 100 have a variable pitch arrangement along at least one segment of the peripheral portions 90, 92, and/or 94. In some embodiments, the tube bundle 82 may be formed by including additional tubes to a typical tube bundle (e.g., a tube bundle that is used in combination with baffles). In other embodiments, the tube bundle 82 may be formed by re-spacing the tubes 100 of a typical tube bundle (e.g., a tube bundle that is used in combination with the baffles). For example, the tubes 100 closest to the peripheral portions 90, 92, and/or 94 may be spaced further from adjacent tubes 100 to enable the tube bundle 82 to reduce dead space (e.g., unoccupied space) in the shell 76. In such embodiments, the tube bundle 82 may include the same number of the tubes 100 as a typical tube bundle. However, in other embodiments, the tube bundle 82 may include any suitable number of the tubes 100. Additionally, the tubes 100 of the tube bundle 82 may include the same diameter as tubes of a typical tube bundle or different diameters. In any case, the tubes 100 may include any suitable diameter (e.g., the tubes 100 may each have a uniform diameter or variable diameters) to achieve a target amount of thermal energy transfer.

[0029] In some cases, vapor refrigerant that absorbs thermal energy from a cooling fluid in the tube bundle 82 may include entrained droplets of liquid refrigerant. The entrained droplets of liquid refrigerant may essentially bypass the tube bundle 82 (e.g.,

the liquid refrigerant does not evaporate) and ultimately enter the compressor 32, which may lead to an increase in power consumption and/or a reduction in efficiency. Therefore, reducing the amount of droplets of liquid refrigerant in the vapor refrigerant may enhance a performance of the HVAC&R system 10. Typically, a mesh plate may be included in the shell 76 above the tube bundle 82 to collect the droplets of liquid refrigerant before the droplets exit the evaporator 38 and enter the compressor 32. Unfortunately, the mesh plate may cause the vapor refrigerant to experience a relatively large pressure drop, which may not enable the HVAC&R system 10 to utilize a low pressure refrigerant.

[0030] FIGS. 6 and 7 illustrate embodiments of an improved evaporator arrangement for removing entrained liquid refrigerant in the evaporator 38 (e.g., a flooded evaporator) before the refrigerant is directed toward the compressor 32. For example, as shown in the illustrated embodiment of FIG. 6, a first water box 102 and a second water box 104 are secured to opposite ends 106 and 108, respectively, of the shell 76 of the evaporator 38. Additionally, the shell 76 has an inlet 110 and a discharge 111 and further includes the tube bundle 82 and an additional tube bundle 114 positioned between the tube bundle 82 and the discharge 111. In some embodiments, the discharge 111 is centrally positioned relative to the opposed ends 106 and 108 of the shell 76. However, in other embodiments, the discharge 111 may be non-centrally positioned relative to the opposed ends 106 and 108 of the shell 76.

[0031] In any case, a cooling fluid 112 may enter the first water box 102 at an inlet 116 and is directed through tubes 118 of the tube bundle 82. Additionally, the cooling fluid 112 may flow through at least one first pass tube 120 of the additional tube bundle 114. As shown in the illustrated embodiment of FIG. 6, the first water box 102 may include a baffle 122 that blocks the cooling fluid 112 from flowing into second pass tubes 124 and third pass tubes 126 of the additional tube bundle 114. Additionally, in some embodiments, the second water box 104 may include a second baffle 128 and a third baffle 130 that may be utilized to direct the cooling fluid 112 into the second pass tubes 124 and block the cooling fluid 112 from flowing into the third pass tubes 126 in the second water box 104. In other embodiments, the second water box 104 may include an

enclosure 131 (e.g., an enclosed turnaround) around an outlet of the at least one first pass tube 120 and an inlet of the second pass tubes 124. Accordingly, the second water box 104 may be configured to receive and combine the cooling fluid 112 flowing out of the third pass tubes 126 and the tubes 118 of the tube bundle 82.

[0032] Therefore, the cooling fluid 112 may flow into the evaporator 38 through the inlet 116 and into both the tubes 118 of the tube bundle 82 and the at least one first pass tube 120 of the additional tube bundle 114. The cooling fluid 112 that flows through the tubes 118 of the tube bundle 82 may be directed out of the shell 76 through a first outlet 132 of the second water box 104. The cooling fluid 112 that flows in the at least one first pass tube 120 of the additional tube bundle 114 may be directed into the second pass tubes 124 of the additional tube bundle 114 by the second baffle 128 and the third baffle 130 in the second water box 104 (or the enclosure 131). The cooling fluid 112 may then flow from the second pass tubes 124 into the third pass tubes 126 in the first water box 102 (e.g., the baffle 122 may block the cooling fluid 112 from flowing into the at least one first pass tube 120 and/or the tubes 118 of the tube bundle 82). In some embodiments (e.g., embodiments that include the second baffle 128 and the third baffle 130), the cooling fluid 112 that flows from the third pass tubes 126 into the second water box 104 may exit the shell 76 through a second outlet 134 of the second water box 104. In other embodiments (e.g., embodiments that include the enclosure 131), the cooling fluid 112 that flows from the third pass tubes 126 may combine with the cooling fluid 112 from the tubes 118 of the tube bundle 82 and exit through the first outlet 132. Therefore, the additional tube bundle 114 acts as a three-pass tube bundle. While the illustrated embodiment of FIG. 6 shows the additional tube bundle 114 as a three-pass tube bundle, it should be recognized that in other embodiments, the additional tube bundle 114 may be configured to direct the cooling fluid 112 through the evaporator 38 using any suitable number of passes (e.g., one, two, four, five, six, seven, eight, nine, ten, or more passes).

[0033] In addition, a refrigerant pump 138 may be positioned between the inlet 110 of the evaporator 38 and the condenser 34 (or the expansion device). Including the refrigerant pump 138 may be beneficial when the refrigerant is a low pressure refrigerant

because the refrigerant pump 138 may increase a pressure of the refrigerant and direct the flow of the refrigerant to the evaporator 38 at relatively low head operating conditions. Therefore, the refrigerant pump 138 may direct the flow of the refrigerant to the evaporator 38 at a desired or target pressure when a pressure of the refrigerant in the condenser 34 would otherwise be insufficient to direct the refrigerant from condenser 34 to the evaporator 38. In some embodiments, the evaporator 38 may be a falling film evaporator. Accordingly, the refrigerant may enter the evaporator 38 at an elevated entry point. Without the refrigerant pump 138, there may be insufficient refrigerant pressure to prevent the refrigerant from flashing at the elevated entry point. However, it should be noted that in other embodiments, the evaporator 38 may include a spray type evaporator, a flooded evaporator, a hybrid flooded/falling film evaporator, or another suitable type of evaporator.

[0034] As shown in the illustrated embodiment of FIG. 6, a primarily liquid refrigerant 148 enters the shell 76 of the evaporator 38 through the inlet 110 (e.g., the liquid refrigerant 148 may be directed to the inlet 110 from the condenser 34, an expansion device, a distributor, and/or a spray device). The liquid refrigerant 148 that enters the shell 76 of the evaporator 38 may absorb thermal energy from the cooling fluid 112 in the tube bundle 82 and/or the additional tube bundle 114, such that the liquid refrigerant 148 may evaporate into vapor refrigerant. For example, refrigerant may collect in the shell 76 around the tubes 118 of the tube bundle 82. The cooling fluid 112 in the tubes 118 may transfer thermal energy (e.g., heat) to the refrigerant 148, such that the refrigerant 148 may evaporate into vapor refrigerant. Accordingly, the vapor refrigerant may pass through the additional tube bundle 114 where the vapor refrigerant may further absorb thermal energy from the cooling fluid 112. Therefore, any liquid refrigerant droplets entrained in the vapor refrigerant may absorb thermal energy and also evaporate into the vapor refrigerant.

[0035] For example, FIG. 7 is a cross section of an embodiment of the evaporator 38 that shows refrigerant 148 having a liquid refrigerant level 150 surrounding the tube bundle 82. After absorbing thermal energy from the cooling fluid 112 in the tube bundle 82, the liquid refrigerant 148 may become a two-phase refrigerant 152 (e.g., a mixture of

vapor refrigerant and liquid refrigerant), in which droplets of the liquid refrigerant 148 may be entrained in vapor refrigerant. The two-phase refrigerant 152 rises and absorbs thermal energy from the cooling fluid 112 in the additional tube bundle 114. As a result, the liquid refrigerant 148 portion of the two-phase refrigerant 152 may be substantially vaporized to form vapor refrigerant 154 (e.g., the vapor refrigerant 154 has less than five weight percent of liquid refrigerant, less than two weight percent of liquid refrigerant, or less than one weight percent of liquid refrigerant). The vapor refrigerant 154 may then be discharged from the shell 76 through the discharge 111, which may direct the vapor refrigerant 154 to the compressor 32. Including the additional tube bundle 114 to vaporize the entrained liquid refrigerant in the two-phase refrigerant 152 may reduce a pressure drop of the refrigerant when compared to typical evaporators (e.g., evaporators that may include a mesh plate). Reducing the amount of pressure drop of the refrigerant through the evaporator 38 may increase an efficiency of the HVAC&R system 10, including embodiments of the HVAC&R system 10 that include a low pressure refrigerant.

[0036] In other embodiments, the evaporator 38 may include a tube bundle 170 that may be configured to flow the refrigerant (e.g., refrigerant exiting the compressor 32) instead of the additional tube bundle 114 that flows the cooling fluid 112. For example, FIG. 8 is a cross section of an embodiment of the evaporator 38 that may include the tube bundle 170 that is configured to flow the refrigerant, and thus place the two-phase refrigerant 152 in a heat exchange relationship with warm refrigerant (e.g., refrigerant from the compressor 32 and/or a subcooler of the condenser 34). In some embodiments, the refrigerant may be directed from the compressor 32 into the tube bundle 170 and then toward the condenser 34. In other embodiments, the refrigerant may be directed from a subcooler of the condenser 34 and into the tube bundle 170 before being directed to the expansion device 36 and/or the inlet 110 to the evaporator 38. As shown in the illustrated embodiment of FIG. 8, the evaporator 38 includes the shell 76 having the tube bundle 82 positioned within the shell 76. The cooling fluid 112 may be directed through the tube bundle 82, such that the liquid refrigerant may absorb thermal energy from the cooling fluid 112 and evaporate into the two-phase refrigerant 152. The tube bundle 170 is positioned between the tube bundle 82 and the discharge 111. The two-phase refrigerant

152 may become the vapor refrigerant 154 after the two-phase refrigerant 152 passes through tubes 172 of the tube bundle 170. The discharge 111 may then direct the vapor refrigerant 154 to the compressor 32.

[0037] As discussed above, the tube bundle 170 may flow discharge gas from the compressor 32 and/or subcooled liquid from the condenser 34 to vaporize the entrained liquid droplets in the two-phase refrigerant 152. In some embodiments, the tube bundle 170 may include a single tube 172 that undergoes multiple passes between the opposite ends 106 and 108 of the evaporator 38. In other embodiments, the tube bundle 170 may include a plurality of tubes 172 that each direct the refrigerant through a single pass of the evaporator 38. In still further embodiments, the tube bundle 170 may include multiple tubes 172, where some of the tubes 172 direct the refrigerant through a single pass of the evaporator 38 and other tubes 172 direct the refrigerant through multiple passes between the opposite ends 106 and 108 of the evaporator 38. In any case, the tube bundle 170 may reduce an amount of droplets of liquid refrigerant in the vapor refrigerant 154. Additionally, the tube bundle 170 may reduce a pressure loss experienced by the refrigerant when compared to typical mesh baffles or mist eliminators. Therefore, the HVAC&R system 10 may be configured to utilize a low pressure refrigerant because of the reduced pressure loss that may be experienced in the evaporator 38.

[0038] FIG. 9 is a cross section of another embodiment of the evaporator 38 that may include the tube bundle 170 and a cover 190 (e.g., a solid shroud) that directs the droplets of liquid refrigerant entrained in the vapor refrigerant 154 to collect in a bottom portion 192 of the shell 76 and surround the tube bundle 82. As shown in the illustrated embodiment of FIG. 9, the evaporator 38 includes the shell 76 having the tube bundle 82 positioned within the shell 76. The cooling fluid 112 may flow through the tubes 118 of the tube bundle 82, thereby placing the cooling fluid 112 into thermal communication with the liquid refrigerant surrounding the tubes 118 of tube bundle 82. The cover 190 may laterally surround the tube bundle 170 (e.g., a portion of the tube bundle 170) and operate using falling film techniques. For example, the two-phase refrigerant 152 may collect within the cover 190 and ultimately be discharged from an open end 194 of the cover 190 toward the tube bundle 82. In some embodiments, the cover 190 may include

a solid shroud (e.g., a plate or baffle with no openings, perforations, or holes). The cover 190 may be formed from any suitable material, such as a metallic material, a polymeric material, and/or another suitable material configured to withstand the relatively high operating temperatures within the evaporator 38.

[0039] In any case, the liquid refrigerant of the two-phase refrigerant 152 may accumulate in the bottom portion 192 of the shell 76. Refrigerant 196, which may include either the two-phase refrigerant 152 or the vapor refrigerant 154, rises from the accumulated liquid refrigerant surrounding the tube bundle 82. Both the two-phase refrigerant 152 and the refrigerant 196 may flow toward and over the tube bundle 170 positioned between the tube bundle 82 and the discharge 111. Accordingly, both the two-phase refrigerant 152 and the refrigerant 196 may become the vapor refrigerant 154 by passing over the tubes 172 of the tube bundle 170 that are not covered by the cover 190. The discharge 111 may then direct the vapor refrigerant 154 to the compressor 32.

[0040] While only certain features and embodiments have been illustrated and described, many modifications and changes may occur to those skilled in the art (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters (e.g., temperatures, pressures, etc.), mounting arrangements, use of materials, colors, orientations, etc.) without materially departing from the novel teachings and advantages of the subject matter recited in the claims. The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention. Furthermore, in an effort to provide a concise description of the exemplary embodiments, all features of an actual implementation may not have been described (i.e., those unrelated to the presently contemplated best mode of carrying out the invention, or those unrelated to enabling the claimed invention). It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation specific decisions may be made. Such a development effort might be complex and time consuming, but would

nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure, without undue experimentation.

CLAIMS:

1. A heating, ventilation, air conditioning, and refrigeration (HVAC&R) system comprising:

a refrigerant loop;

a compressor disposed along the refrigerant loop and configured to circulate refrigerant through the refrigerant loop;

an evaporator disposed along the refrigerant loop and configured to place the refrigerant in a heat exchange relationship with a cooling fluid; and

a tube bundle of the evaporator configured to flow the cooling fluid through the evaporator, wherein the tube bundle comprises a peripheral portion that is non-linear and at least partially conforms to a shape of a shell of the evaporator.

2. The HVAC&R system of claim 1, wherein the evaporator is a flooded evaporator, a falling film evaporator, or a combination thereof.

3. The HVAC&R system of claim 1, comprising an additional tube bundle of the evaporator disposed between the tube bundle and a refrigerant discharge of the evaporator, wherein the additional tube bundle is configured to place the refrigerant in thermal communication with an additional cooling fluid.

4. The HVAC&R system of claim 3, wherein the additional cooling fluid is the cooling fluid.

5. The HVAC&R system of claim 3, wherein the additional cooling fluid is the refrigerant directed to the additional tube bundle from the compressor before the refrigerant is directed to the condenser.

6. The HVAC&R system of claim 1, wherein the tube bundle forms a gap between the peripheral portion and the shell of the evaporator.

7. The HVAC&R system of claim 6, wherein the gap is between 0.5 inches and 1 inch.

8. The HVAC&R system of claim 6, wherein the peripheral portion is defined by a plurality of tubes of the tube bundle, and wherein the gap is formed between the plurality of tubes of the tube bundle and the shell of the evaporator.

9. The HVAC&R system of claim 1, wherein the peripheral portion is at least 50% of a perimeter of a cross-section of the tube bundle, wherein the cross-section is taken along a plane that is crosswise to a central axis of the shell of the evaporator.

10. The HVAC&R system of claim 1, wherein the evaporator does not comprise a baffle between the peripheral portion of the tube bundle and the shell.

11. A heating, ventilation, air conditioning, and refrigeration (HVAC&R) system, comprising:

a refrigerant loop;

a compressor disposed along the refrigerant loop and configured to circulate refrigerant through the refrigerant loop;

an evaporator disposed along the refrigerant loop and configured to place the refrigerant in a heat exchange relationship with a cooling fluid;

a first tube bundle of the evaporator configured to flow the cooling fluid through the evaporator, wherein the first tube bundle comprises a peripheral portion that is non-linear and at least partially conforms to a shape of a shell of the evaporator; and

a second tube bundle disposed between the first tube bundle and a refrigerant discharge of the evaporator, wherein the second tube bundle is configured to place the refrigerant in thermal communication with an additional cooling fluid to reduce an amount of liquid refrigerant that is directed from the evaporator to the compressor.

12. The HVAC&R system of claim 11, wherein the additional cooling fluid is the cooling fluid.

13. The HVAC&R system of claim 11, wherein the additional cooling fluid is the refrigerant directed to the additional tube bundle from the compressor before the refrigerant is directed to the condenser.

14. The HVAC&R system of claim 11, wherein the second tube bundle comprises a single tube that passes the additional cooling fluid between opposing ends of the evaporator multiple times.

15. The HVAC&R system of claim 11, wherein an amount of liquid refrigerant in the refrigerant directed to the compressor from the evaporator is less than 5 weight percent of the refrigerant.

16. The HVAC&R system of claim 11, comprising a condenser disposed along the refrigerant loop and a refrigerant pump disposed along the refrigerant loop and between the condenser and the evaporator.

17. A heating, ventilation, air conditioning, and refrigeration (HVAC&R) system, comprising:

a refrigerant loop;

a compressor disposed along the refrigerant loop and configured to circulate refrigerant through the refrigerant loop;

an evaporator disposed along the refrigerant loop and configured to place the refrigerant in a heat exchange relationship with a cooling fluid;

a first tube bundle of the evaporator configured to flow the cooling fluid through the evaporator, wherein the first tube bundle comprises a peripheral portion that is non-linear and at least partially conforms to a shape of a shell of the evaporator;

an second tube bundle disposed between the first tube bundle and a refrigerant discharge of the evaporator, wherein the second tube bundle is configured to place the refrigerant in thermal communication with an additional cooling fluid to reduce an amount of liquid refrigerant that is directed from the evaporator to the compressor; and

a cover disposed over at least a portion of the second tube bundle.

18. The HVAC&R system of claim 17, wherein the cover is a solid shroud that defines an opening facing the first tube bundle, and wherein the cover is configured to direct liquid refrigerant toward a bottom portion of the evaporator, such that the liquid refrigerant at least partially surrounds the first tube bundle.

19. The HVAC&R system of claim 17, comprising the refrigerant, and wherein the refrigerant is a low pressure refrigerant.

20. The HVAC&R system of claim 17, comprising a condenser disposed along the refrigerant loop and a refrigerant pump disposed along the refrigerant loop and disposed between the condenser and the evaporator.

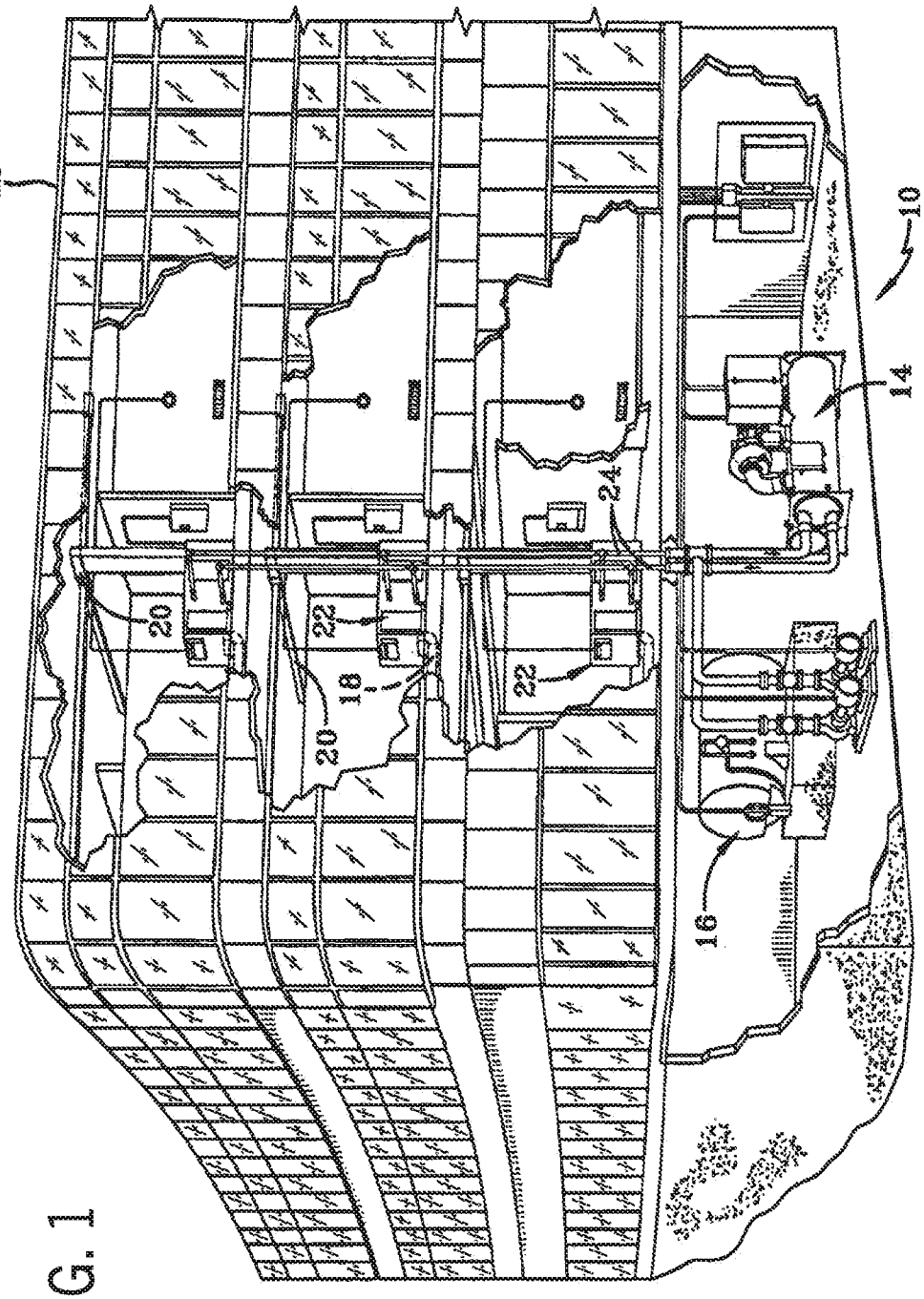


FIG. 1

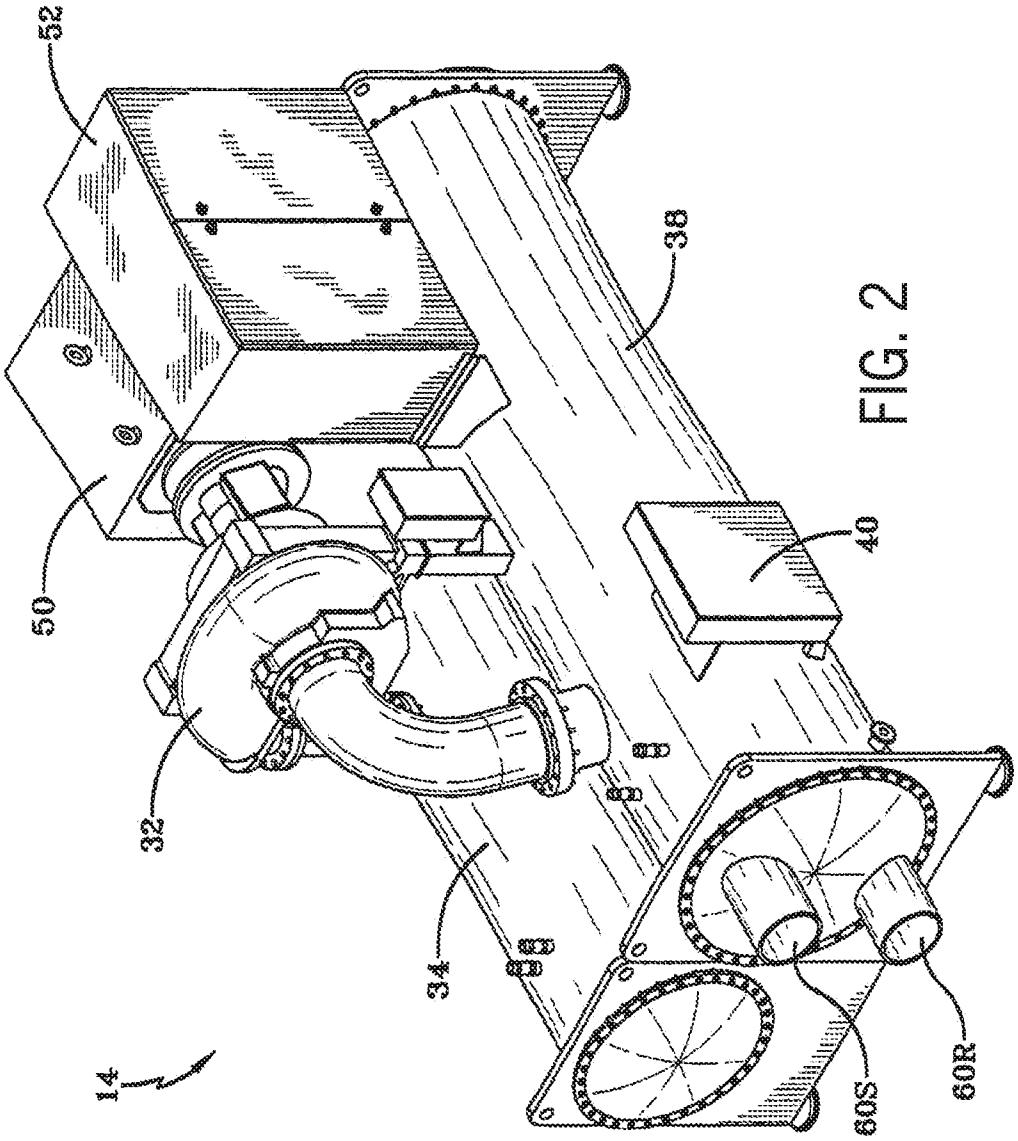


FIG. 2

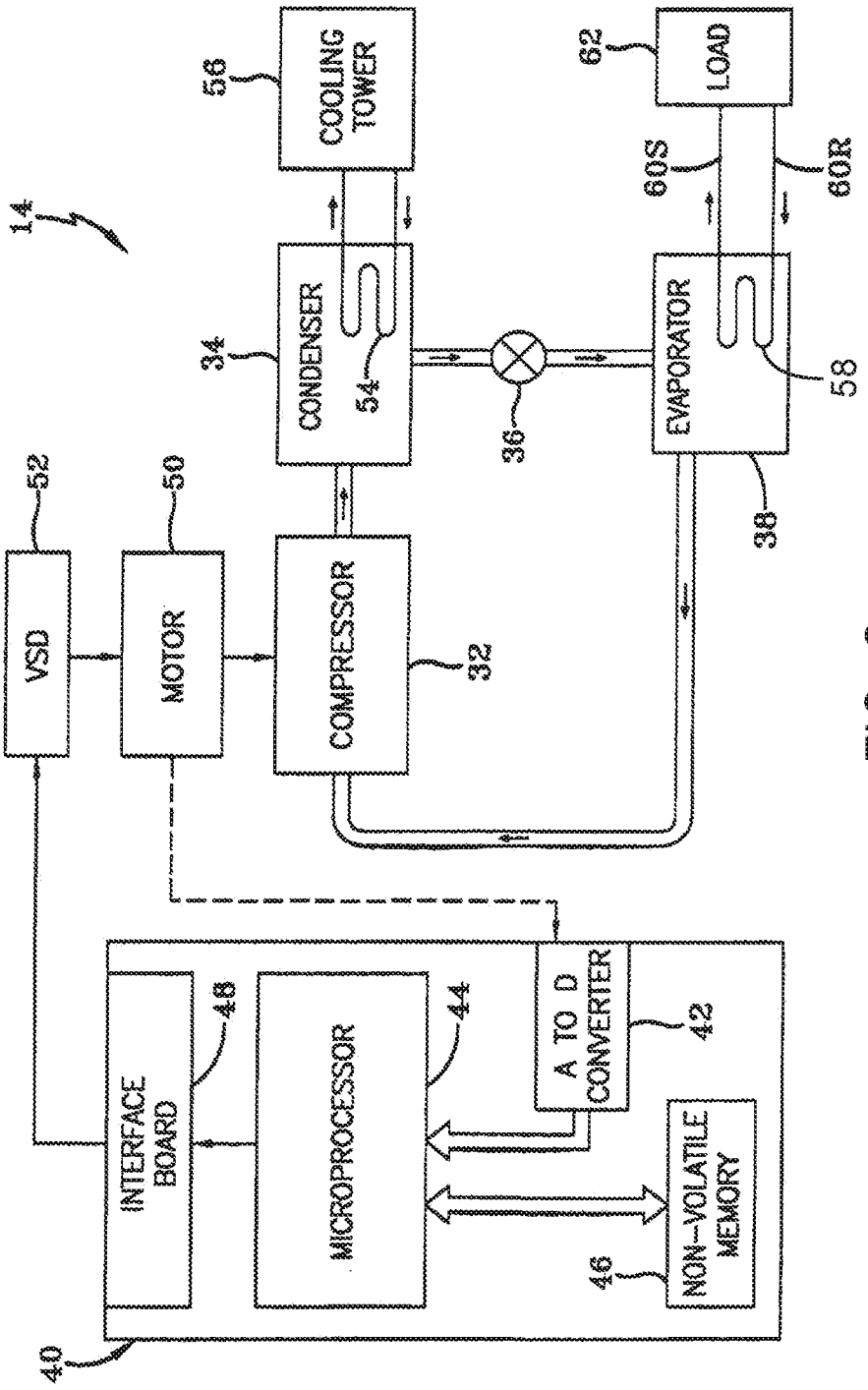

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FIG. 3

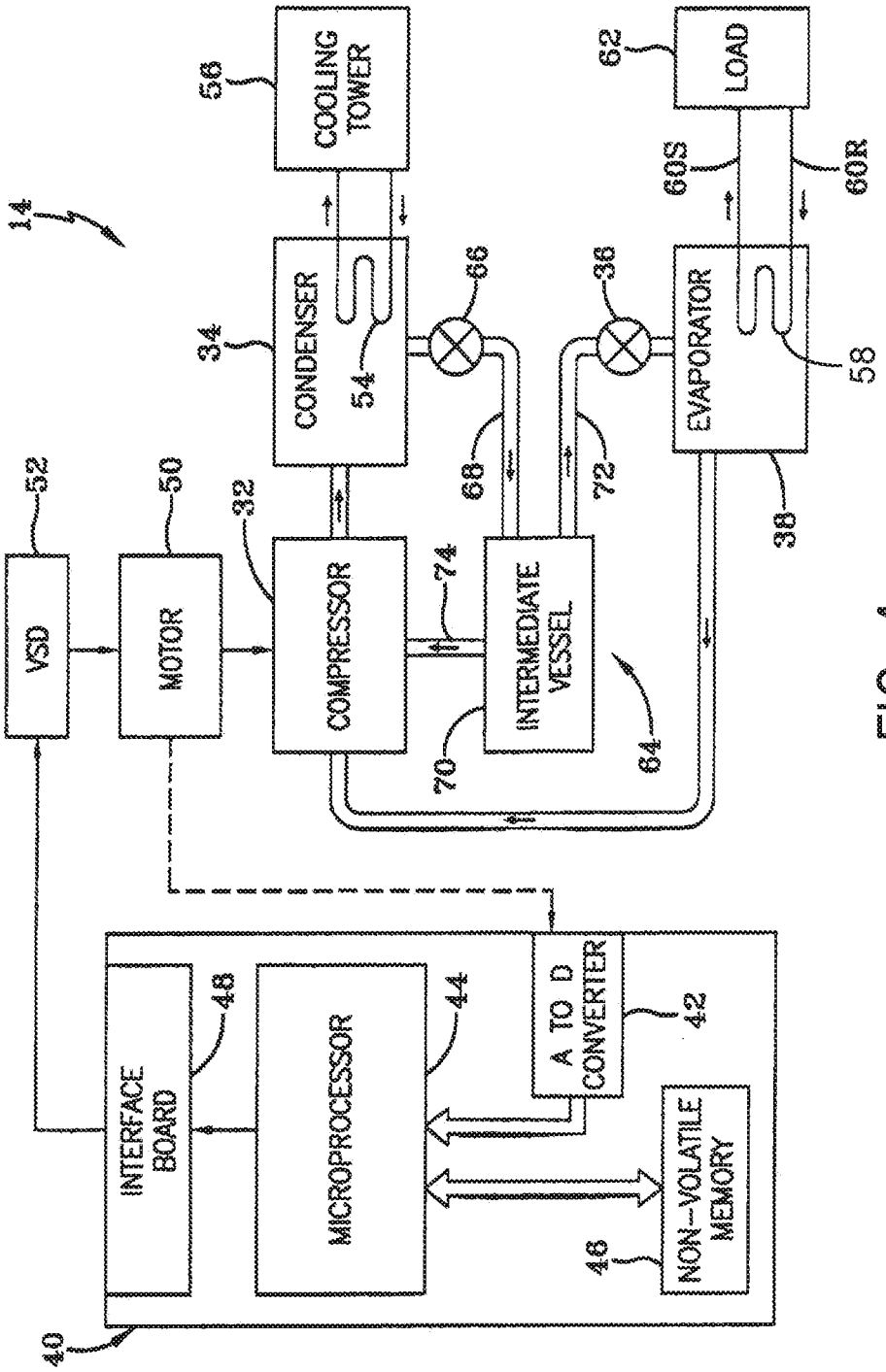

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FIG. 4

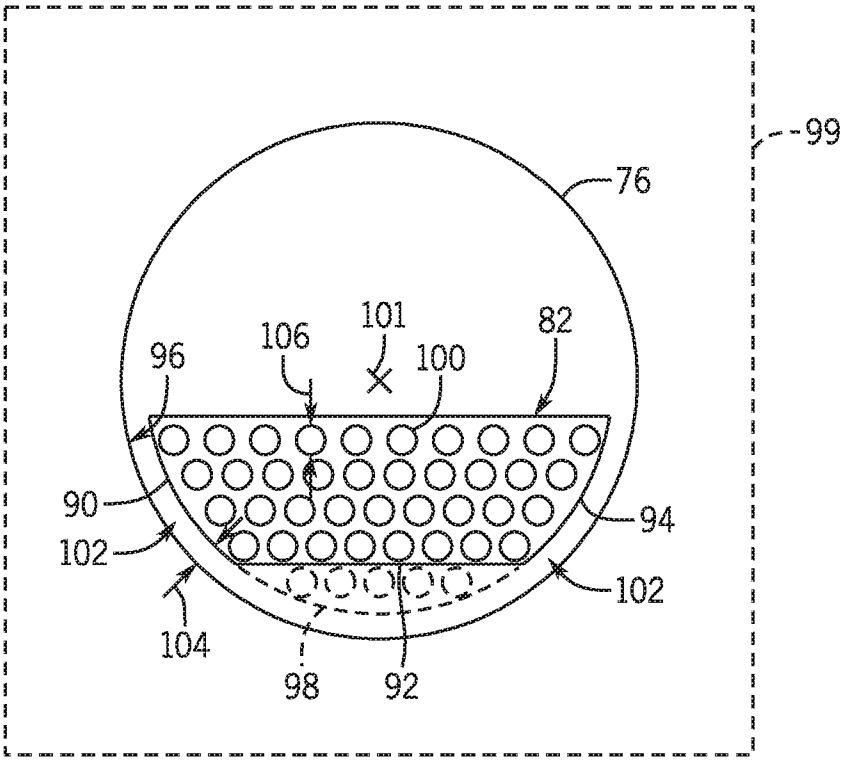

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FIG. 5

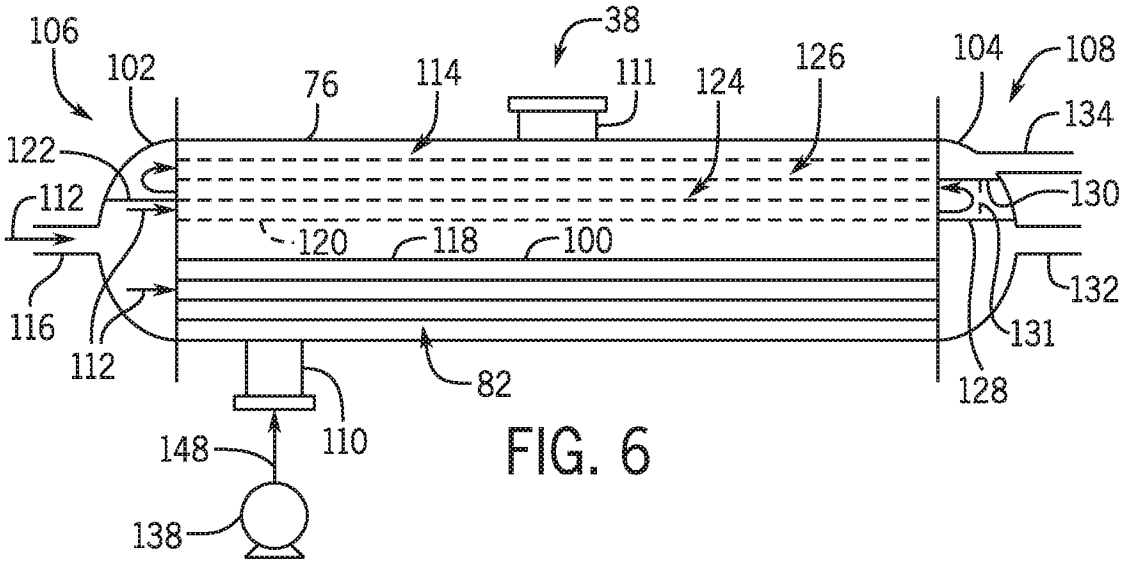

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FIG. 6

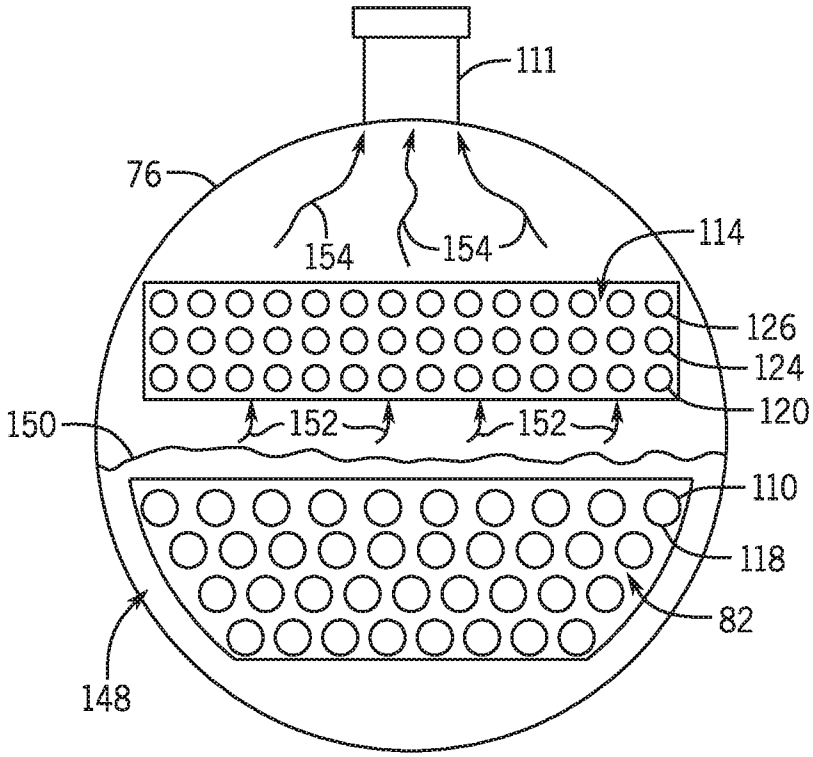


FIG. 7

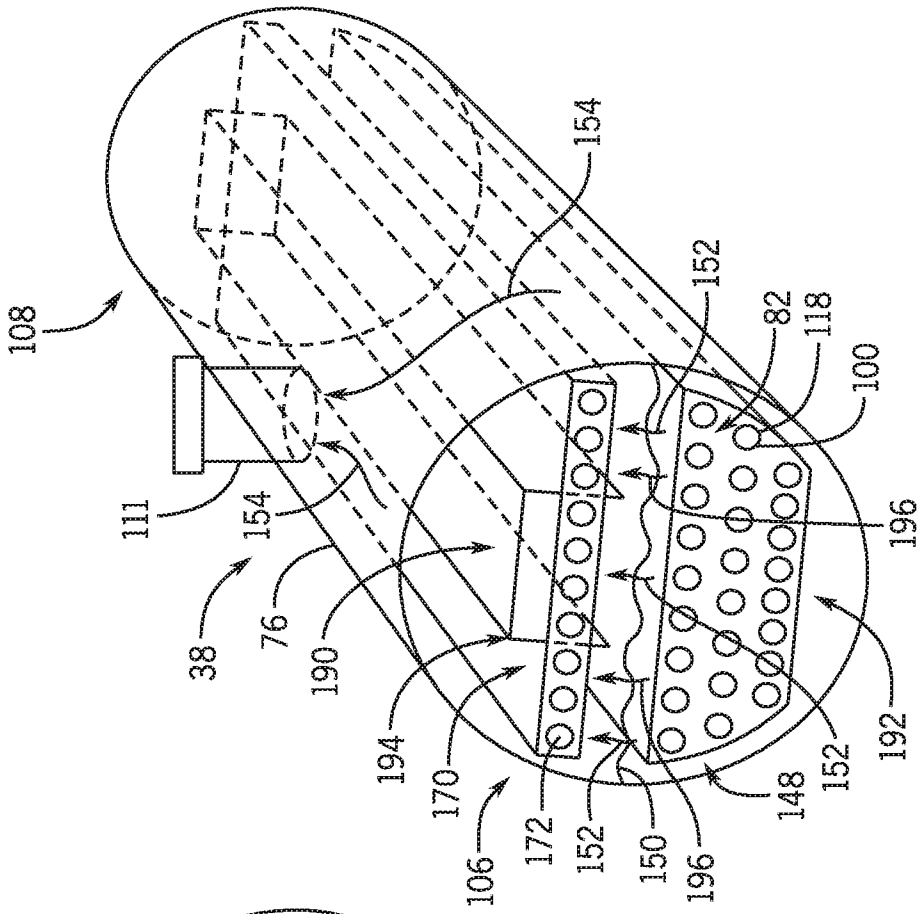

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FIG. 9

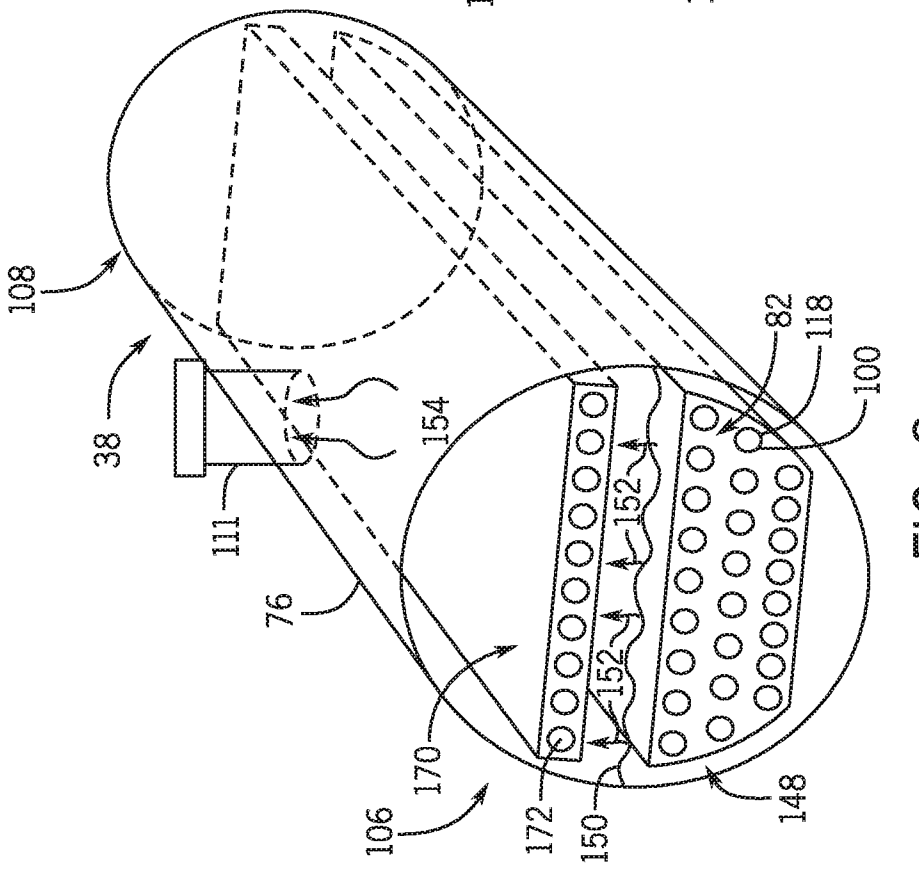

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FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/012557

A. CLASSIFICATION OF SUBJECT MATTER
INV. F25B39/02 F28D7/16
ADD. F28D21/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25B F28D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

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Y	page 1, line 23 - page 35; figures 1-3 page 3, line 6 - page 7, line 29	4,12
X	US 2011/056664 A1 (DE LARMINAT PAUL [FR] ET AL) 10 March 2011 (2011-03-10) paragraphs [0002] - [0004], [0025]; figures 5A, 5B, 5C, 6A paragraphs [0032] - [0041]	1-20
X	US 2011/017432 A1 (KULANKARA SATHEESH [US] ET AL) 27 January 2011 (2011-01-27) paragraphs [0002] - [0009]; figures 1,5,6,7,8 paragraphs [0035] - [0042]	1-20

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 March 2017	05/04/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Weisser, Meinrad

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INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	WO 2014/179576 A2 (UNITED TECHNOLOGIES CORP [US]) 6 November 2014 (2014-11-06) page 9, line 20 - page 11, line 8; figures 3,4	4,12
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Information on patent family members

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