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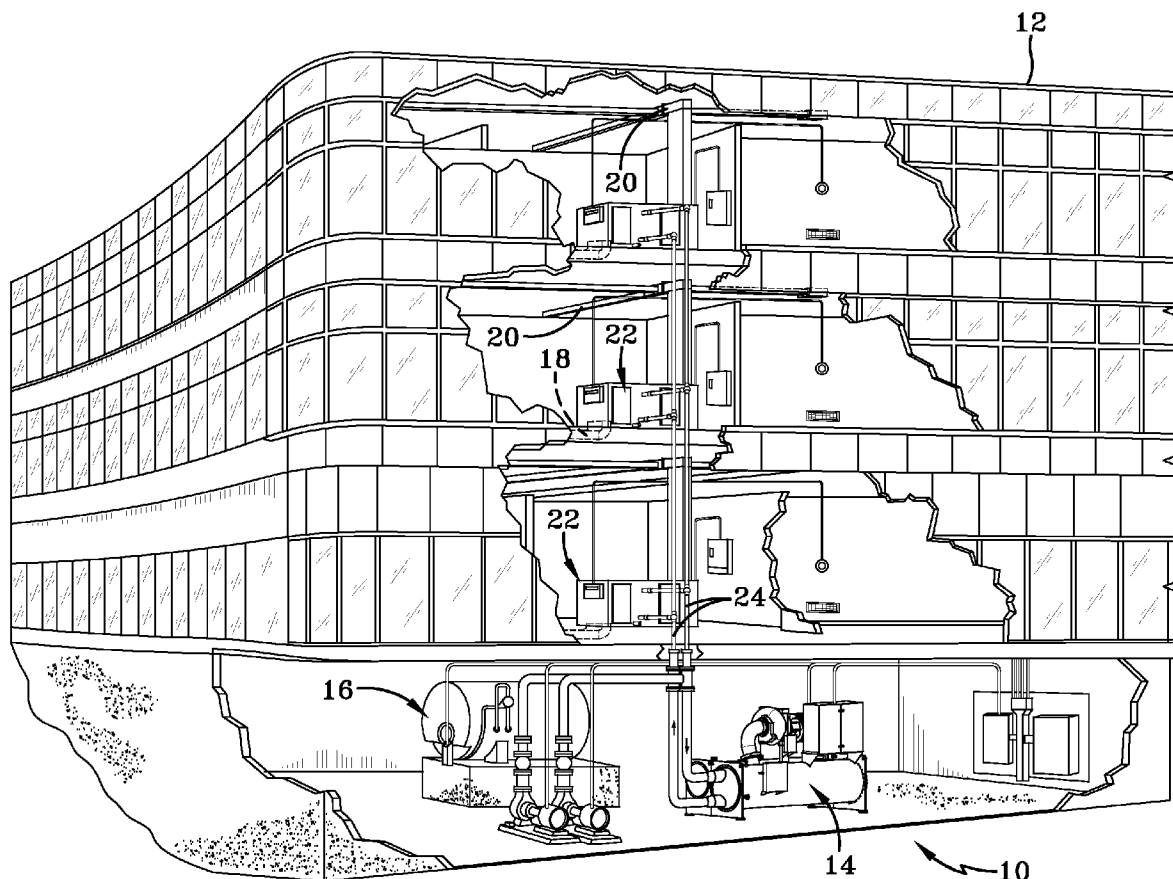
(19) **United States**(12) **Patent Application Publication**
SCHREIBER et al.(10) **Pub. No.: US 2009/0178790 A1**(43) **Pub. Date: Jul. 16, 2009**(54) **VAPOR COMPRESSION SYSTEM**(22) Filed: **Jan. 12, 2009**(75) Inventors: **Jeb SCHREIBER**, Emigsville, PA (US); **Jay A. KOHLER**, York, PA (US); **John C. HANSEN**, Spring Grove, PA (US); **Mustafa Kemal YANIK**, York, PA (US); **William F. MCQUADE**, New Cumberland, PA (US); **Justin KAUFFMAN**, York, PA (US); **Satheesh KULANKARA**, York, PA (US); **Soren Pierre POULSEN**, Rissle (DK); **Lee Li WANG**, Shanghai (CN)**Related U.S. Application Data**

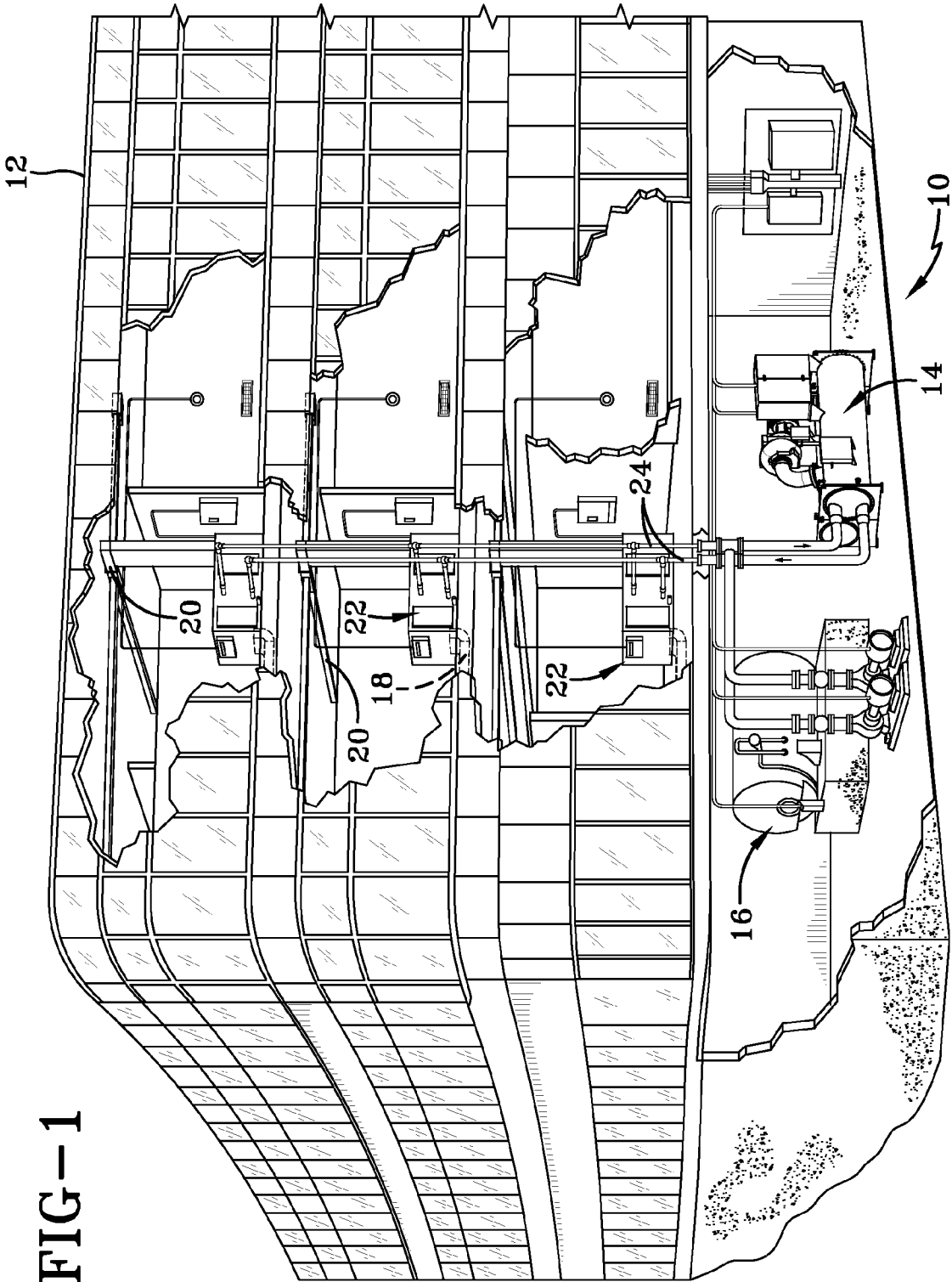
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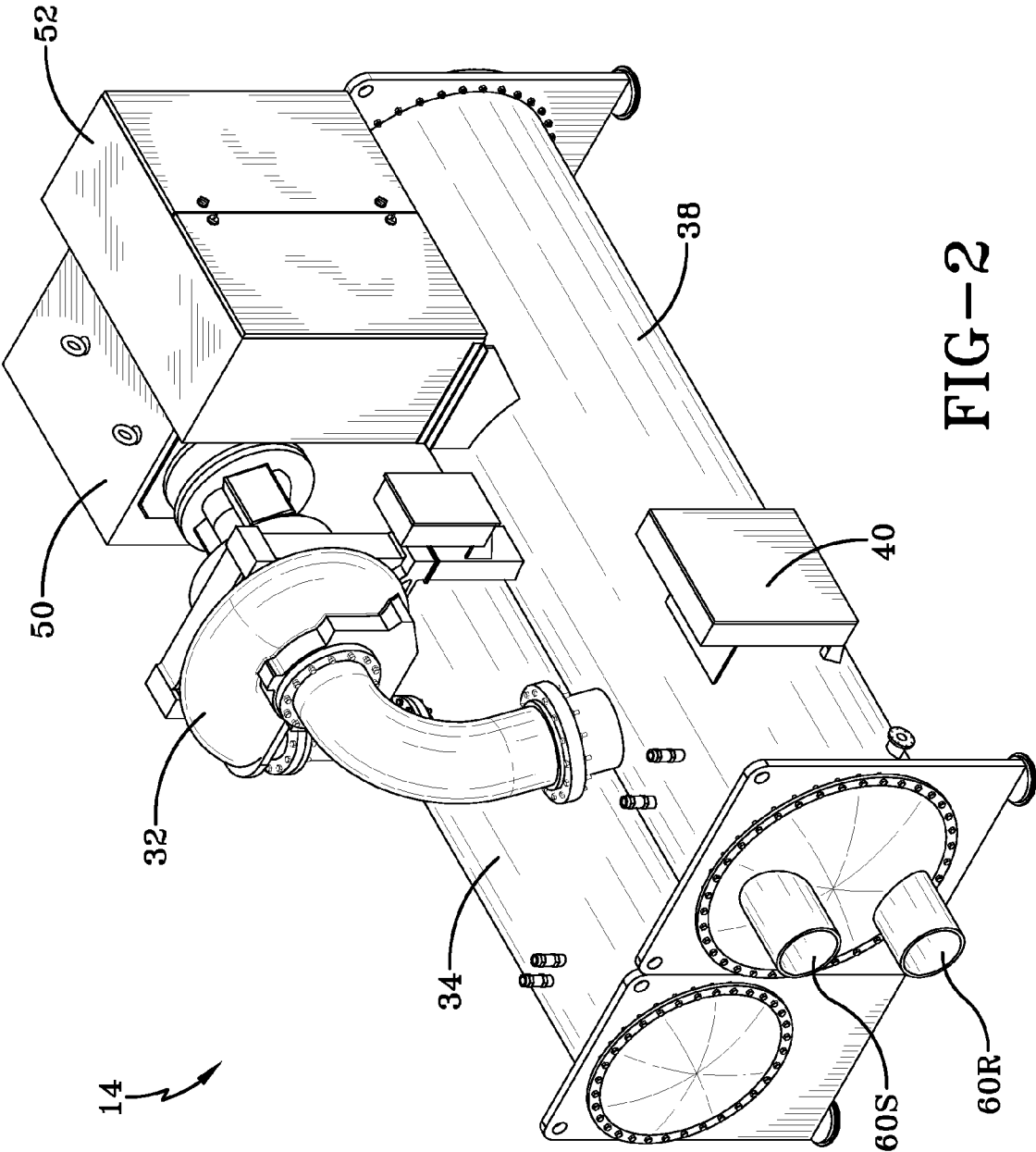
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(52) **U.S. Cl.** **165/158; 165/161; 165/104.21**(57) **ABSTRACT**

An evaporator for use in a vapor compression system is disclosed. The evaporator may include an enclosure that covers a substantial portion of a tube bundle in the evaporator. The enclosure substantially prevents refrigerant vapor, generated as a result of the heat transfer with the tube bundle, from flowing laterally between tubes of the tube bundle. Various configurations of a distributor for distributing refrigerant to at least a portion of a tube bundle in the evaporator provides increased performance of the evaporator.

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TECHNOLOGY COMPANY,
Holland, MI (US)(21) Appl. No.: **12/352,437**





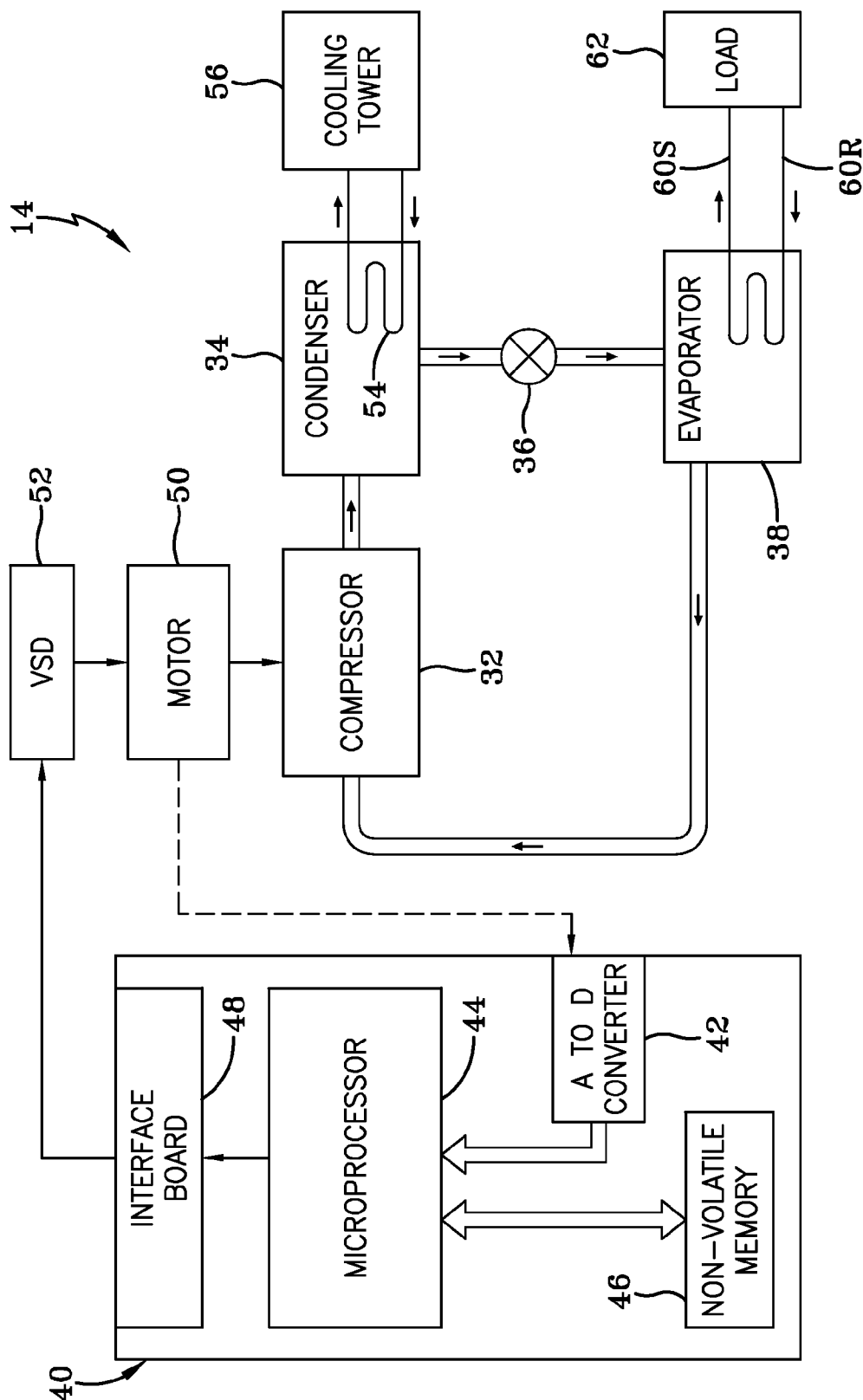


FIG-3

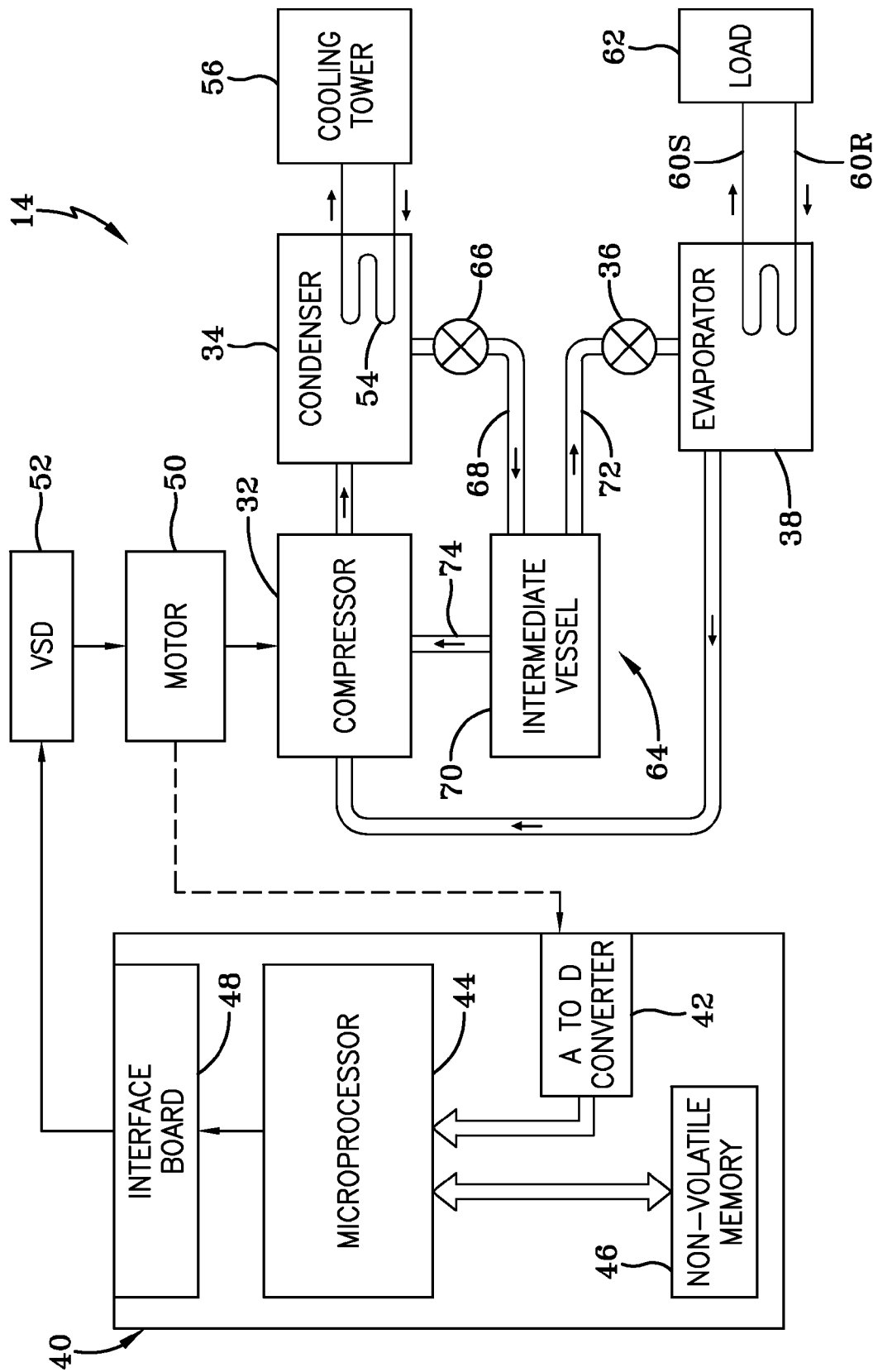
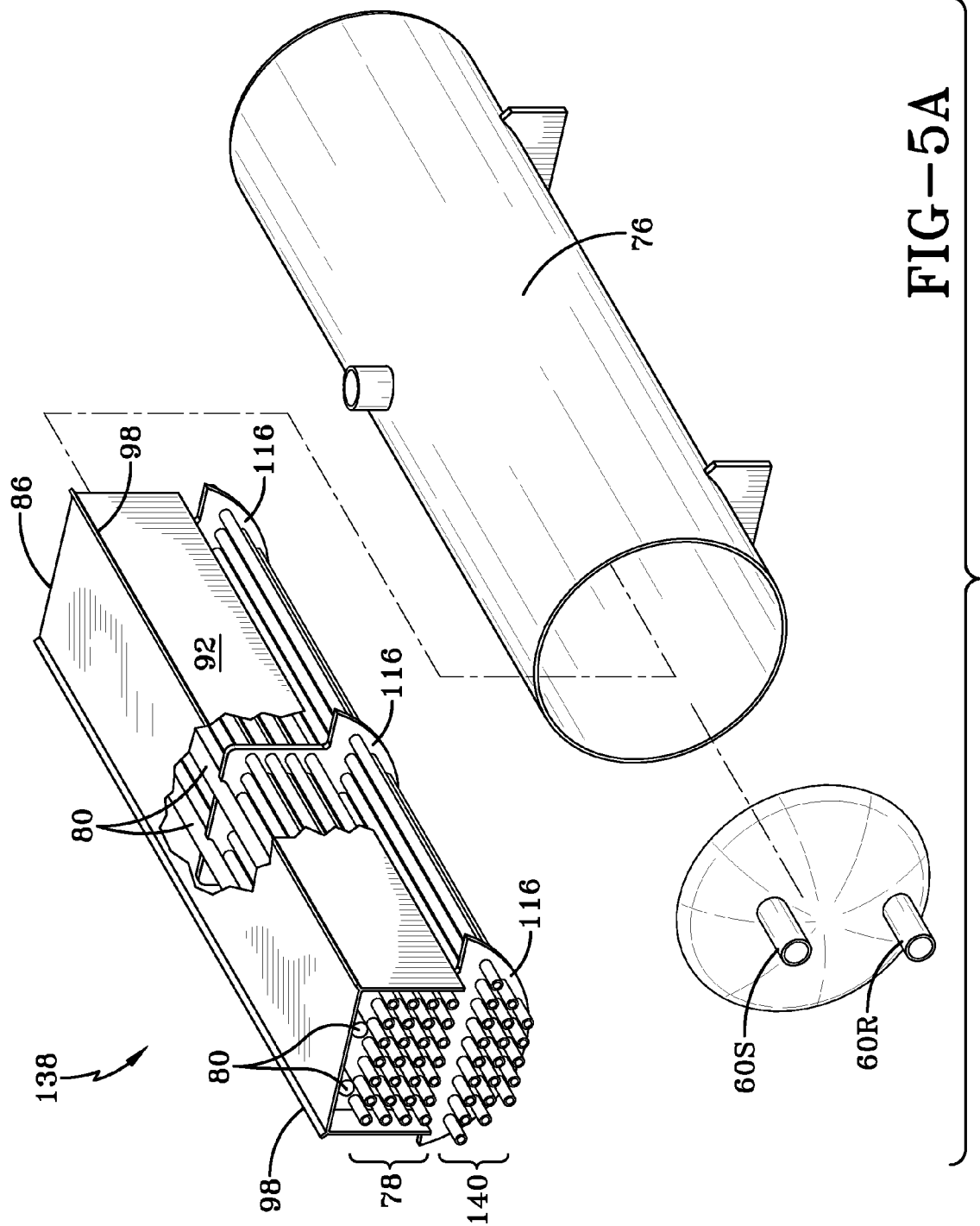
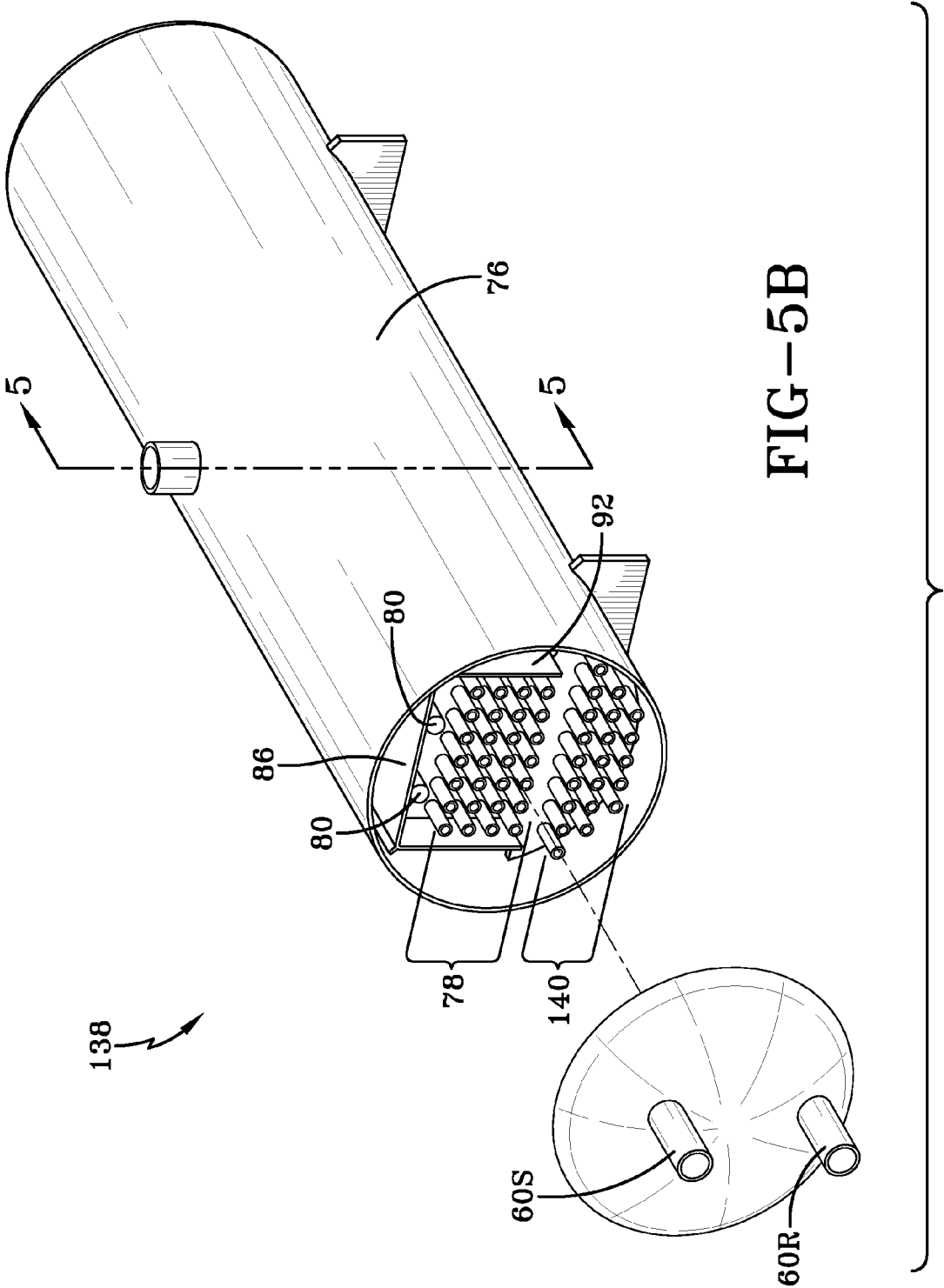


FIG-4





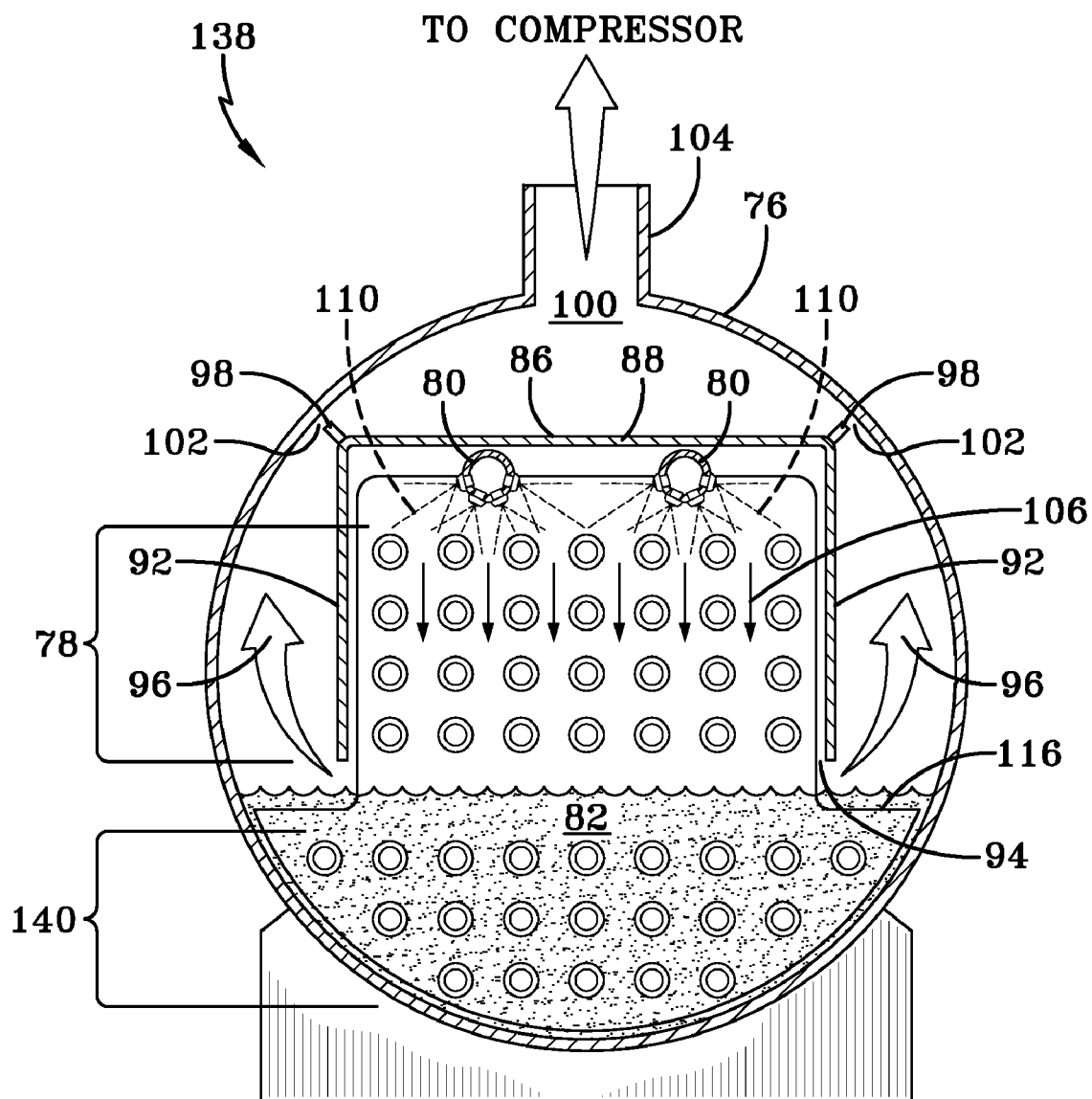
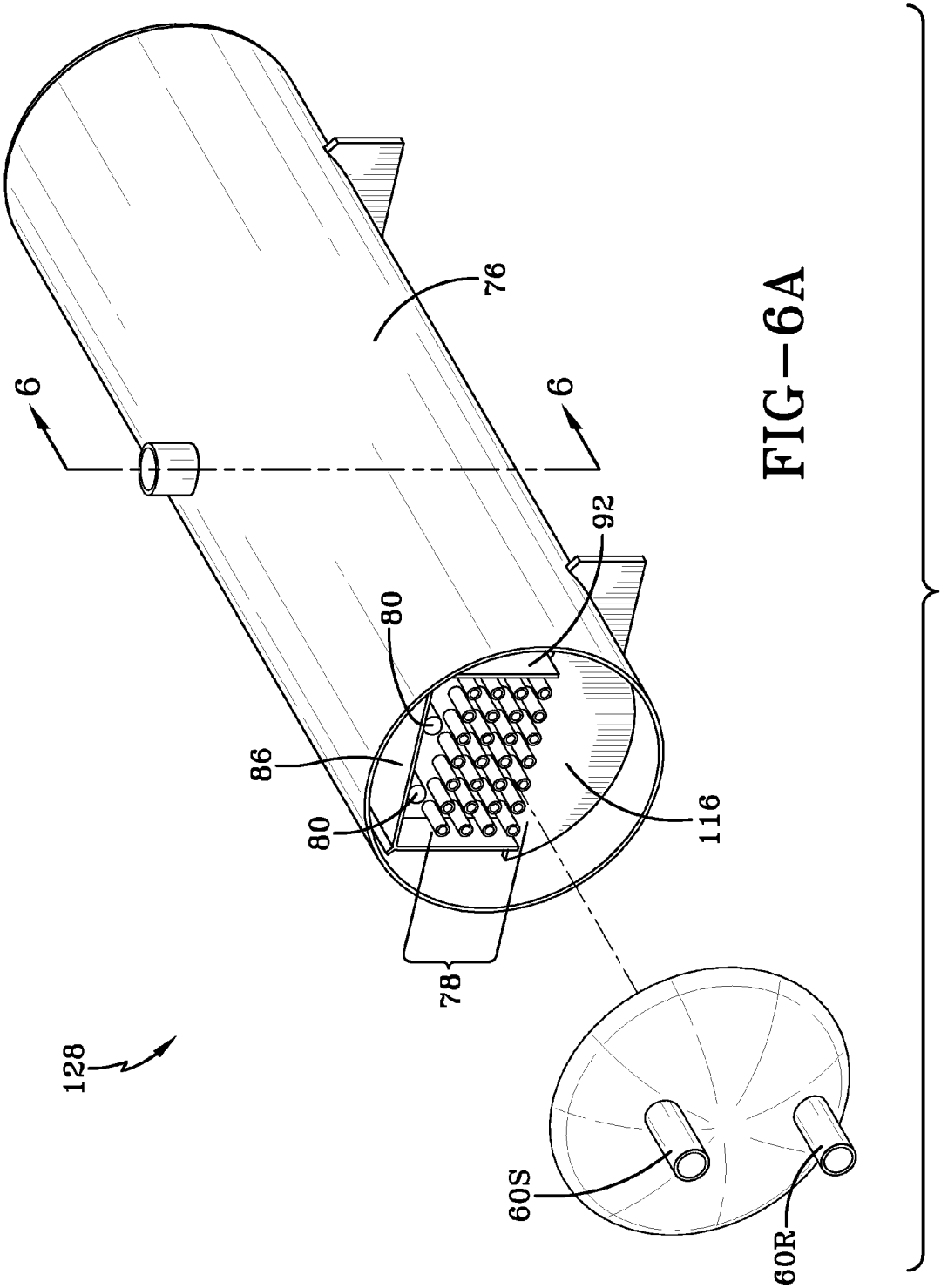
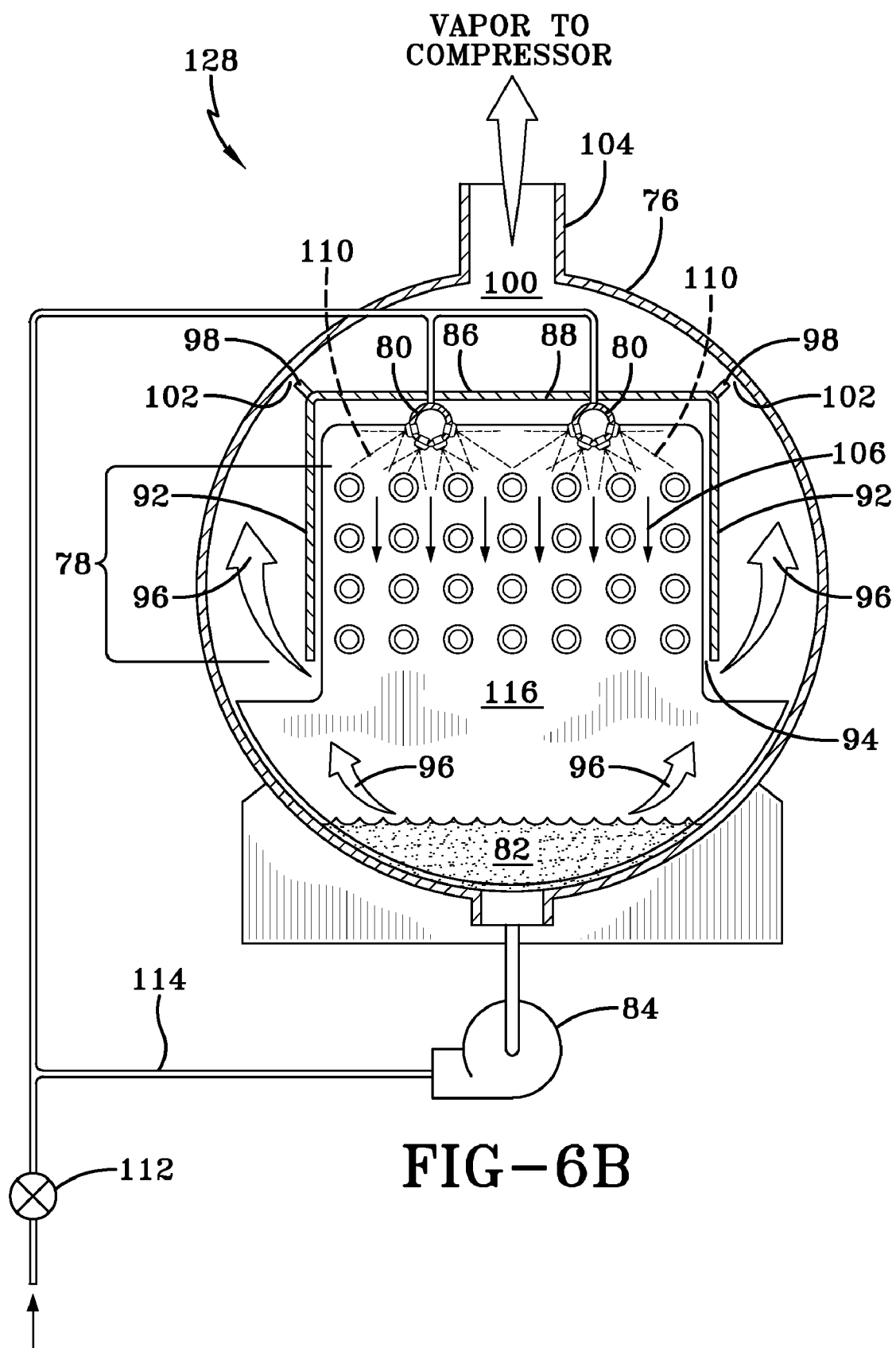


FIG-5C





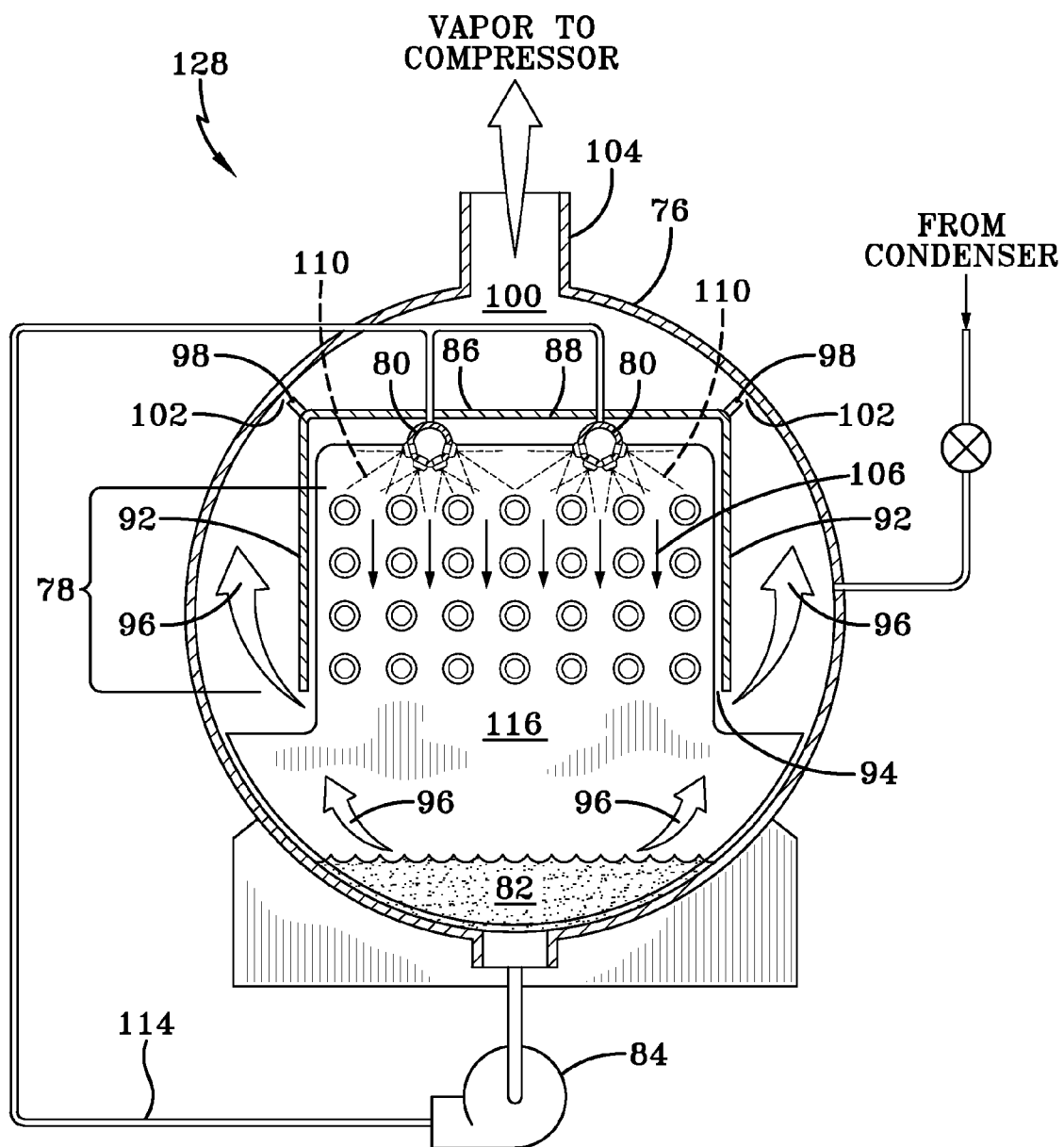


FIG-6C

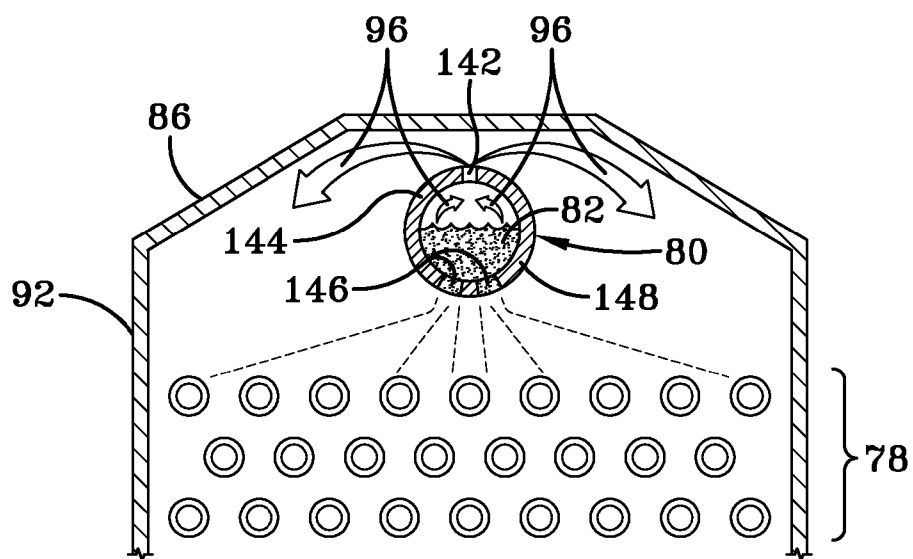


FIG-7A

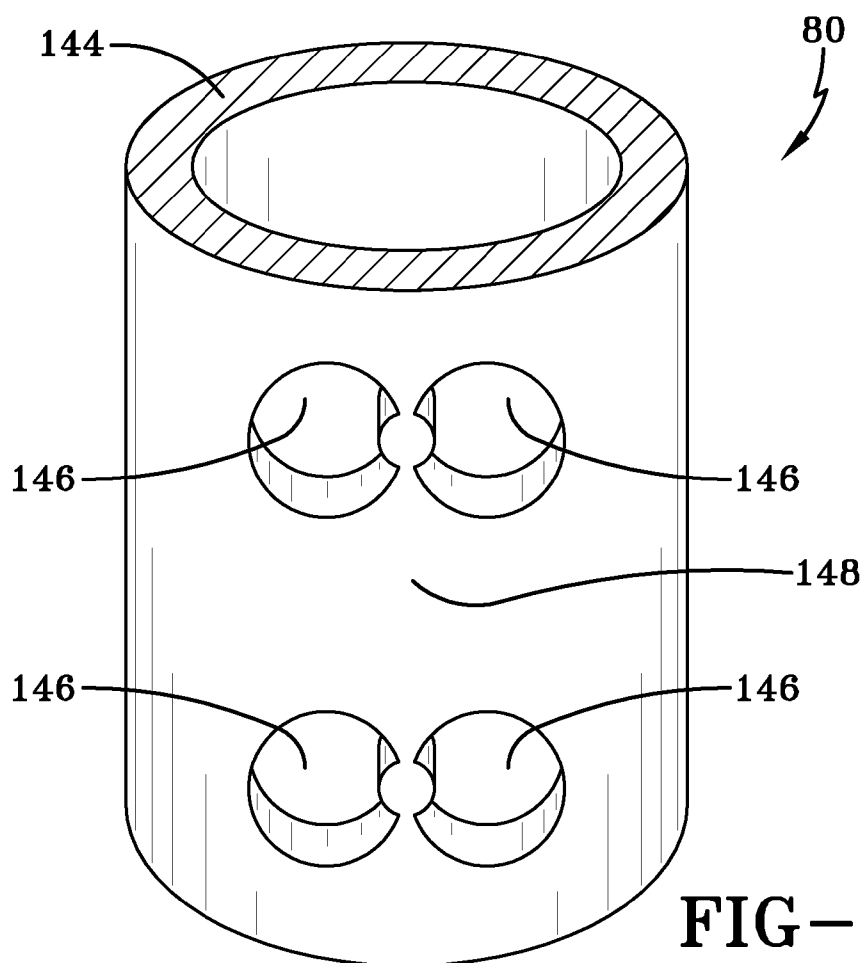


FIG-7B

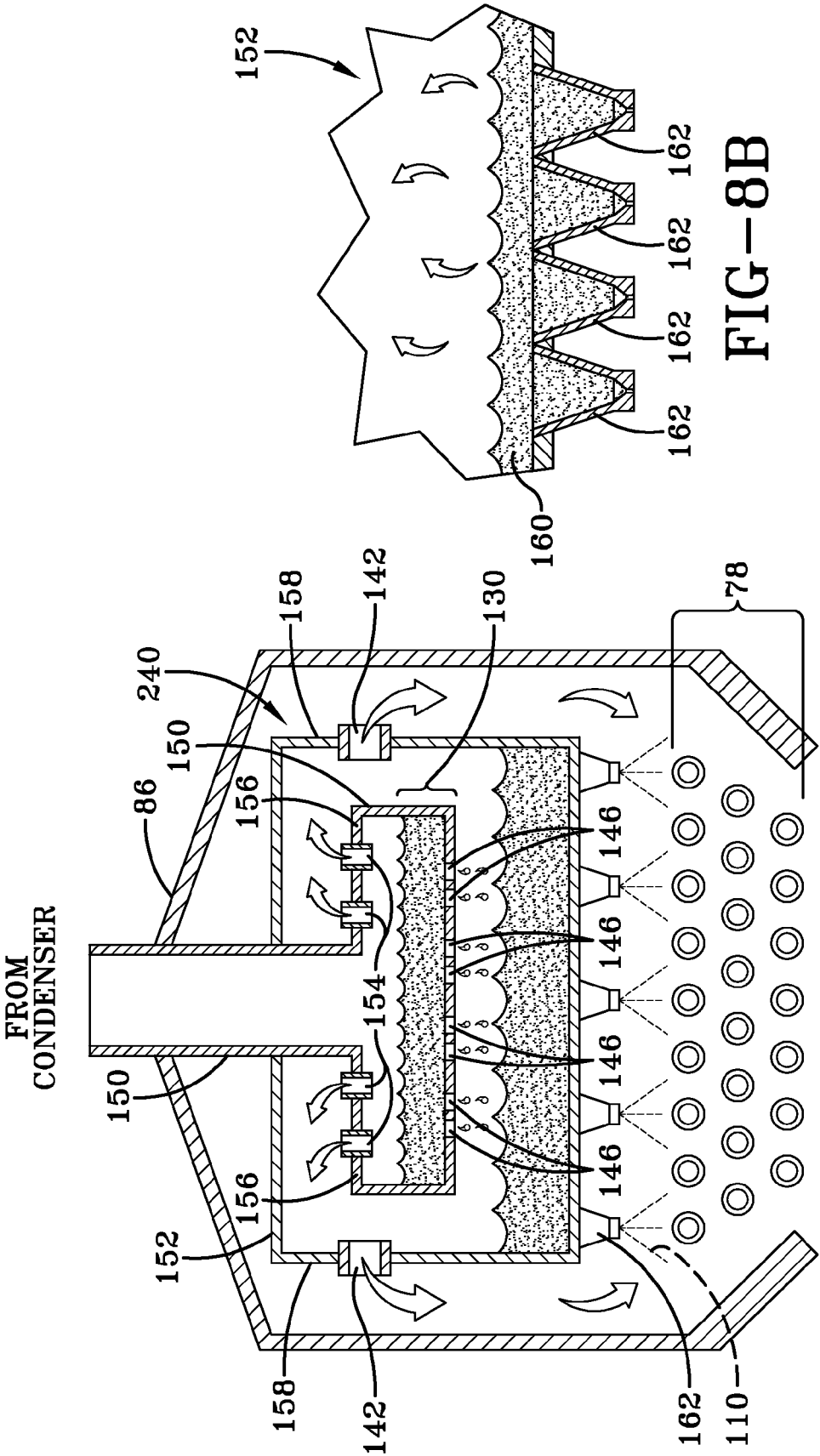


FIG-8A

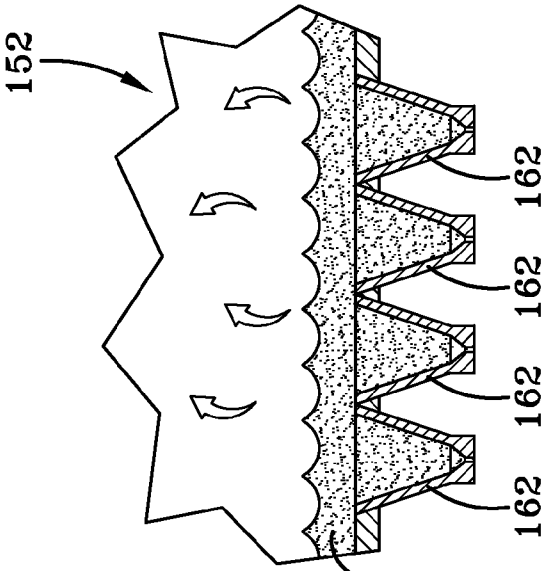
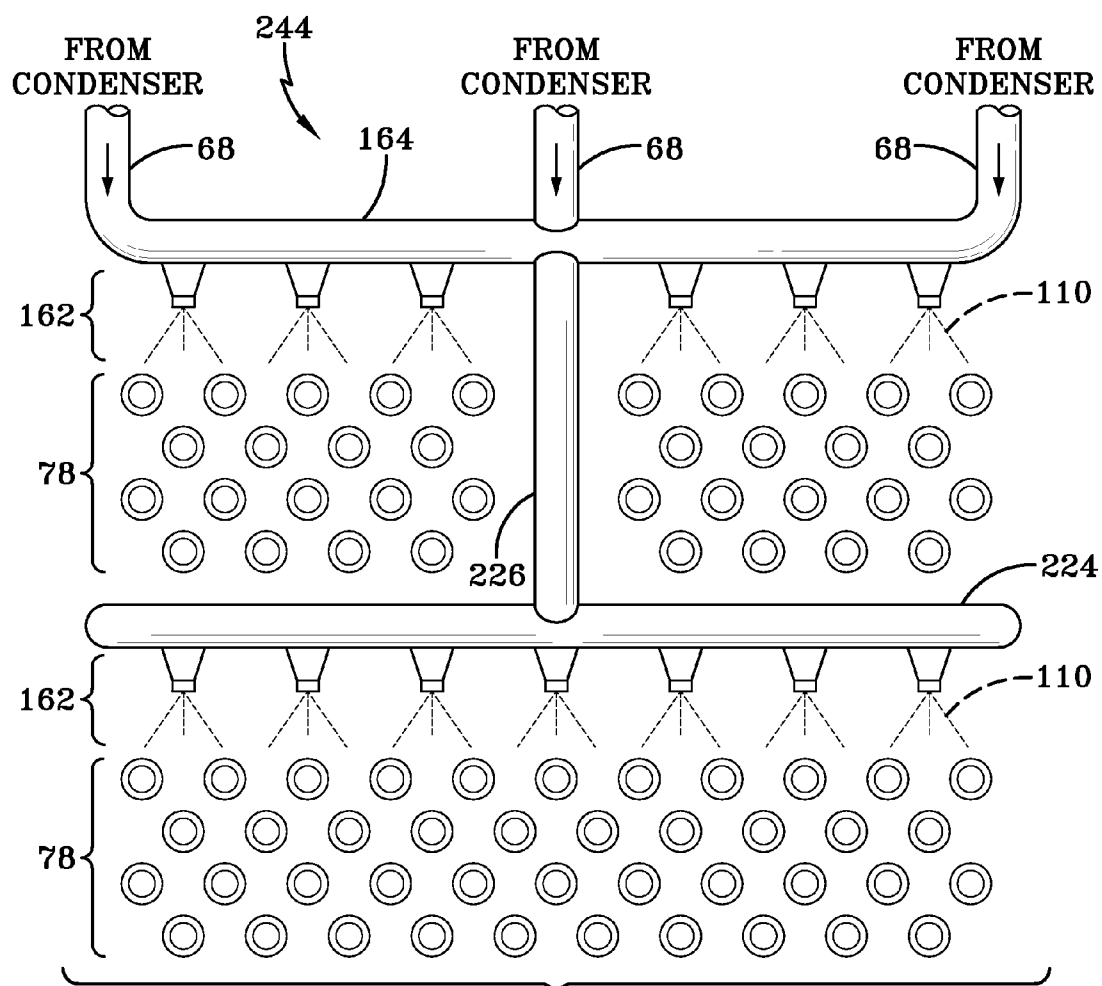
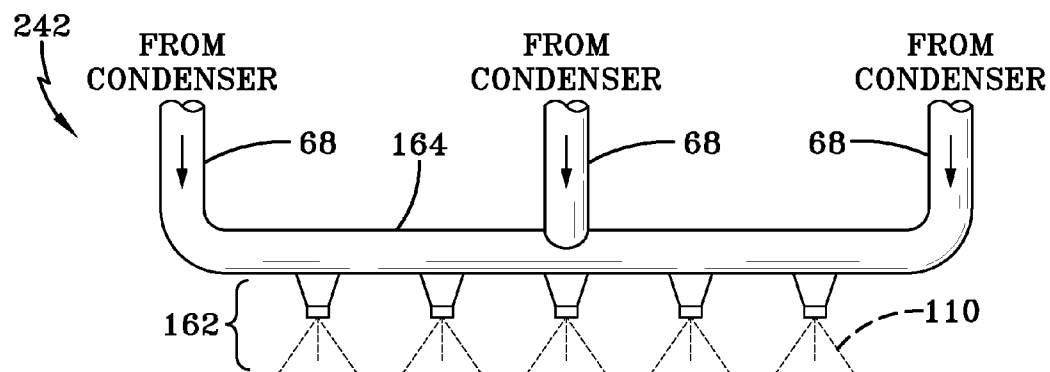


FIG-8B



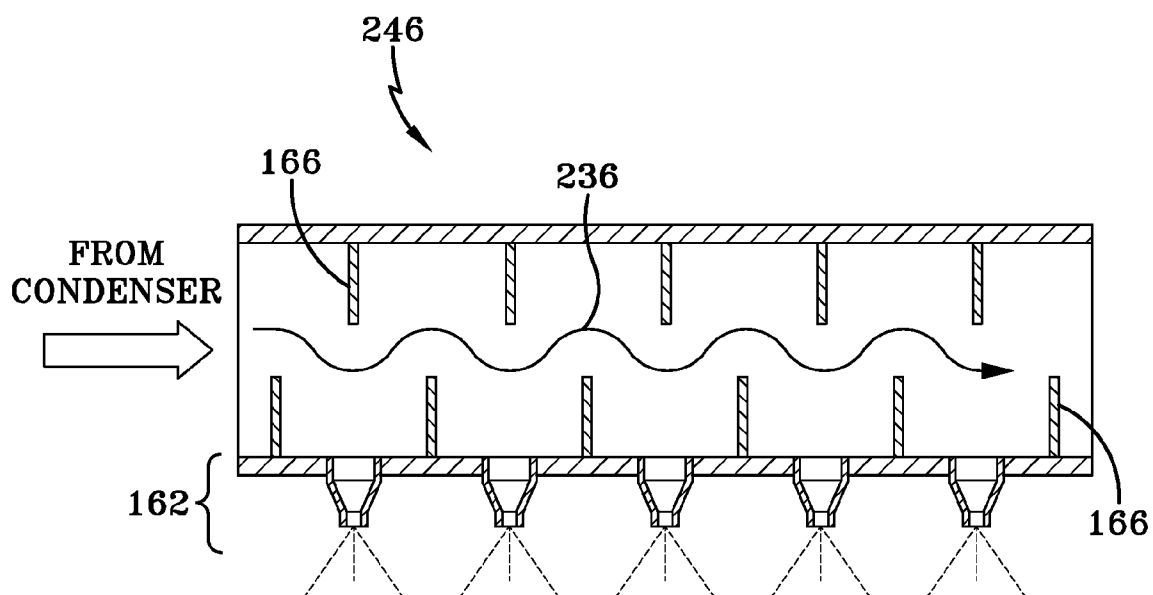


FIG-11

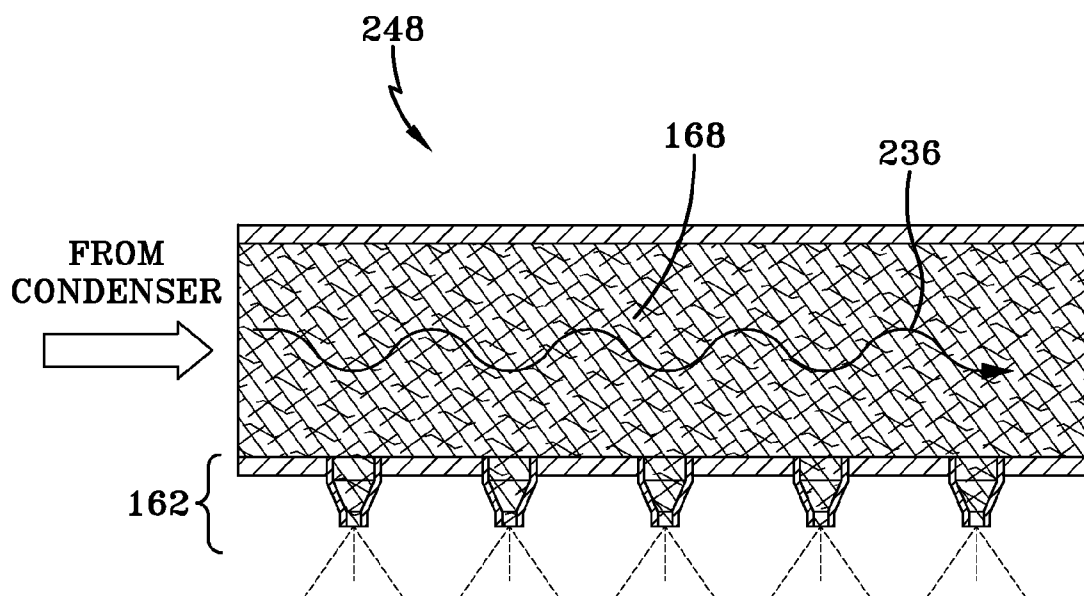


FIG-12

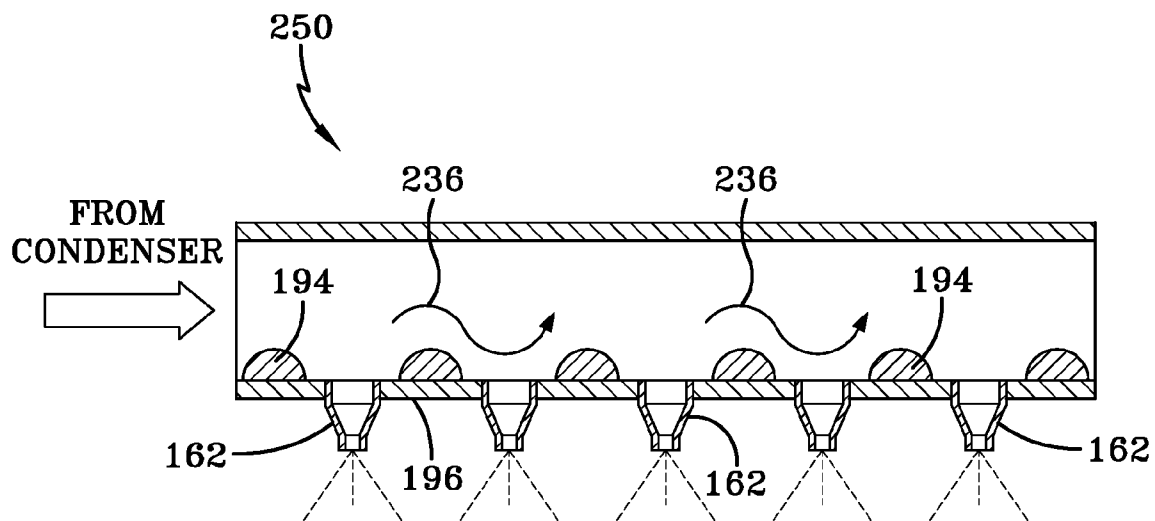


FIG-13

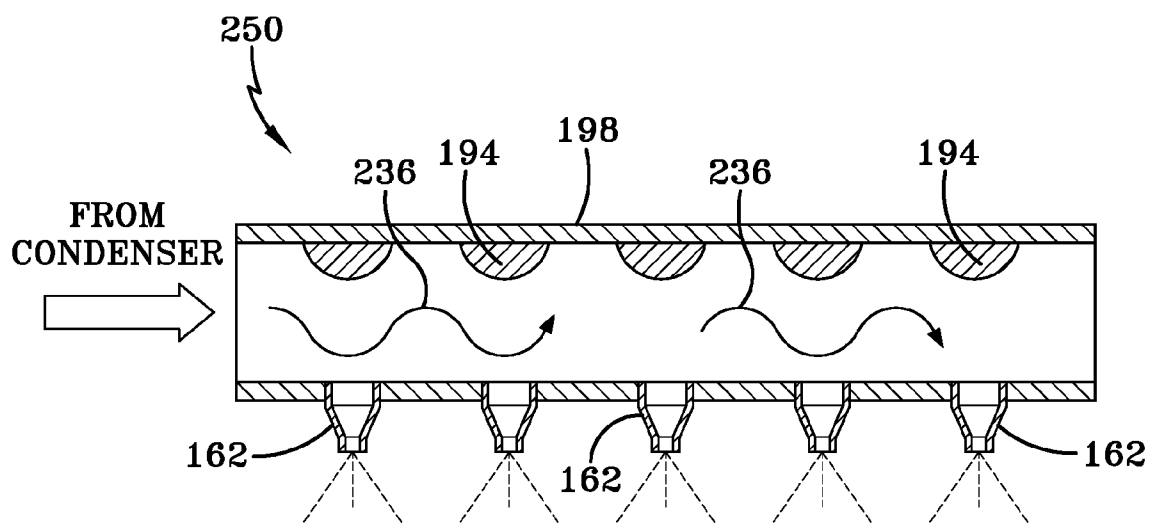


FIG-14

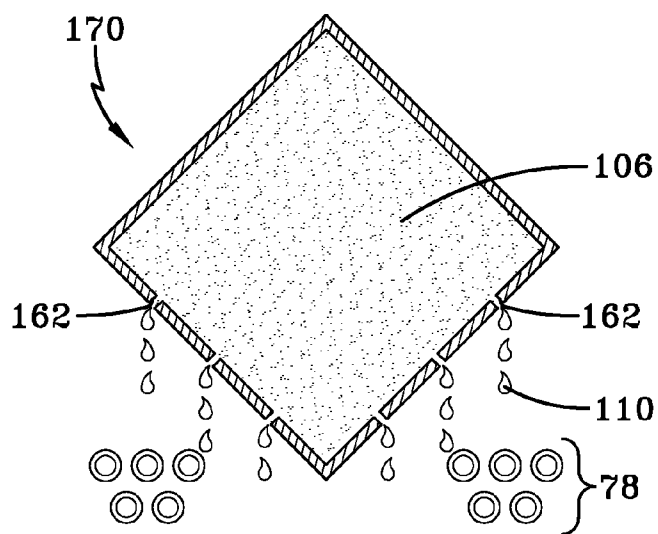


FIG-15

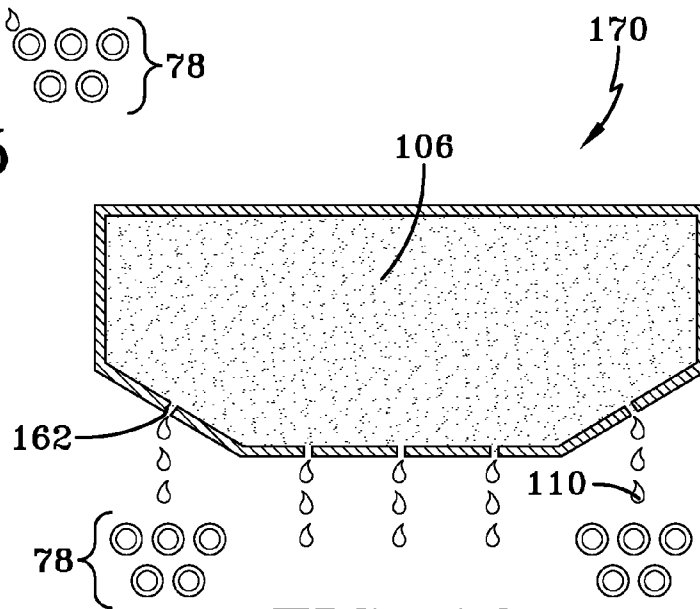


FIG-16

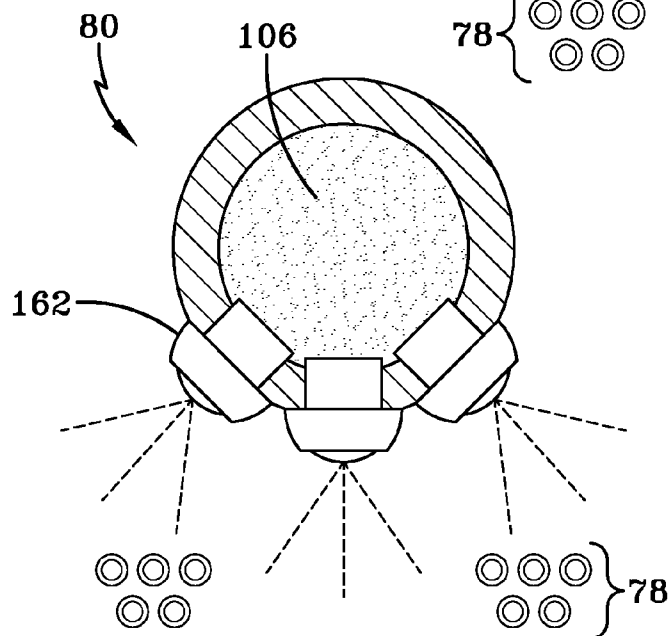


FIG-17

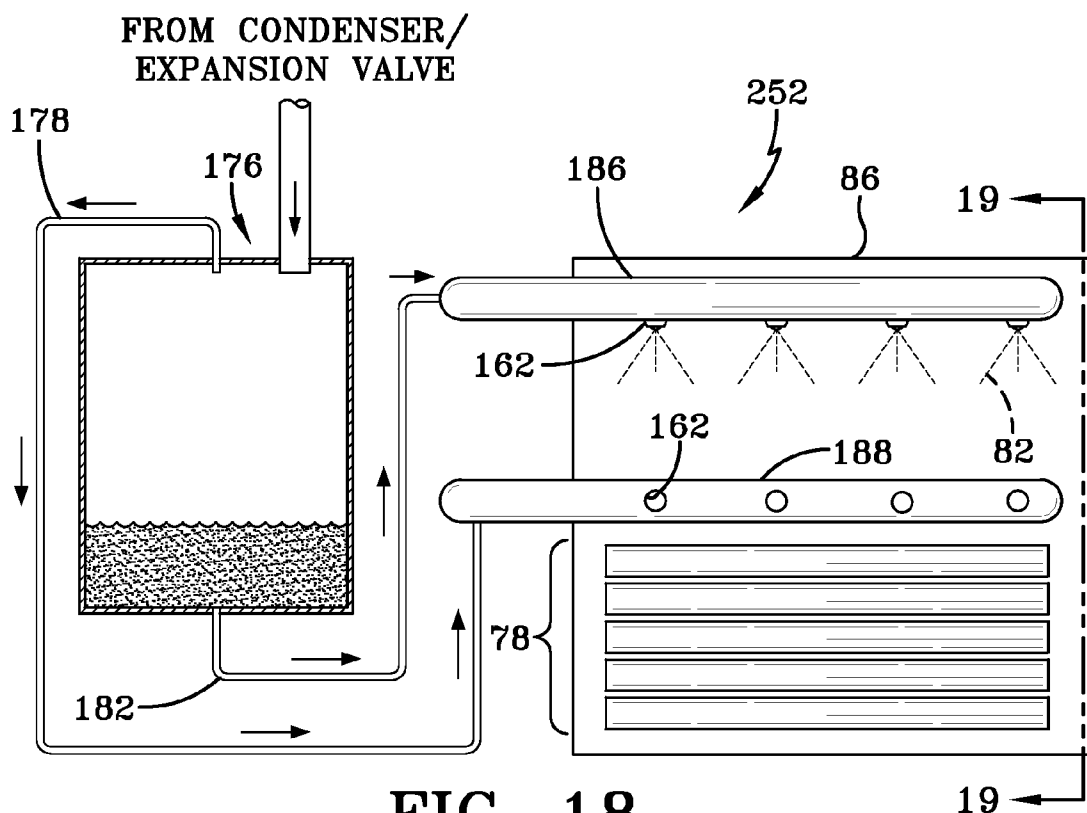


FIG-18

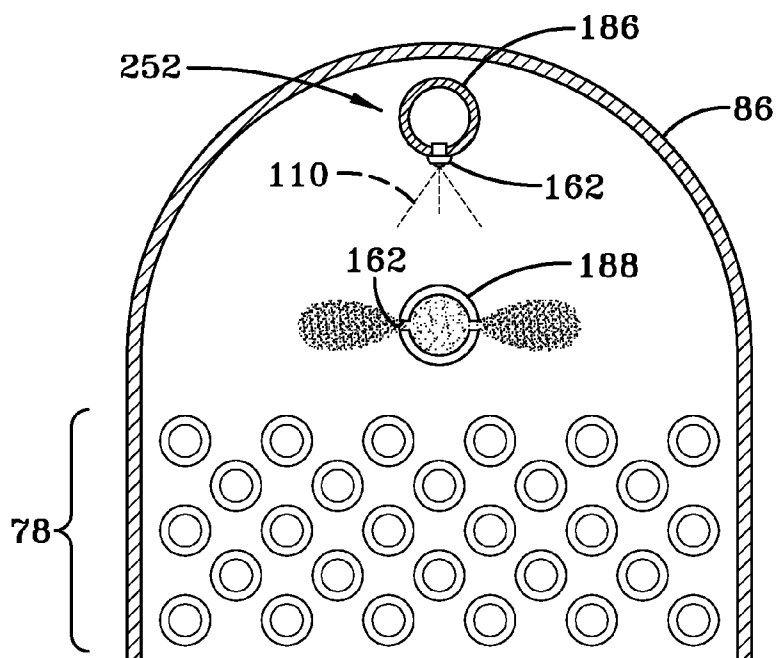
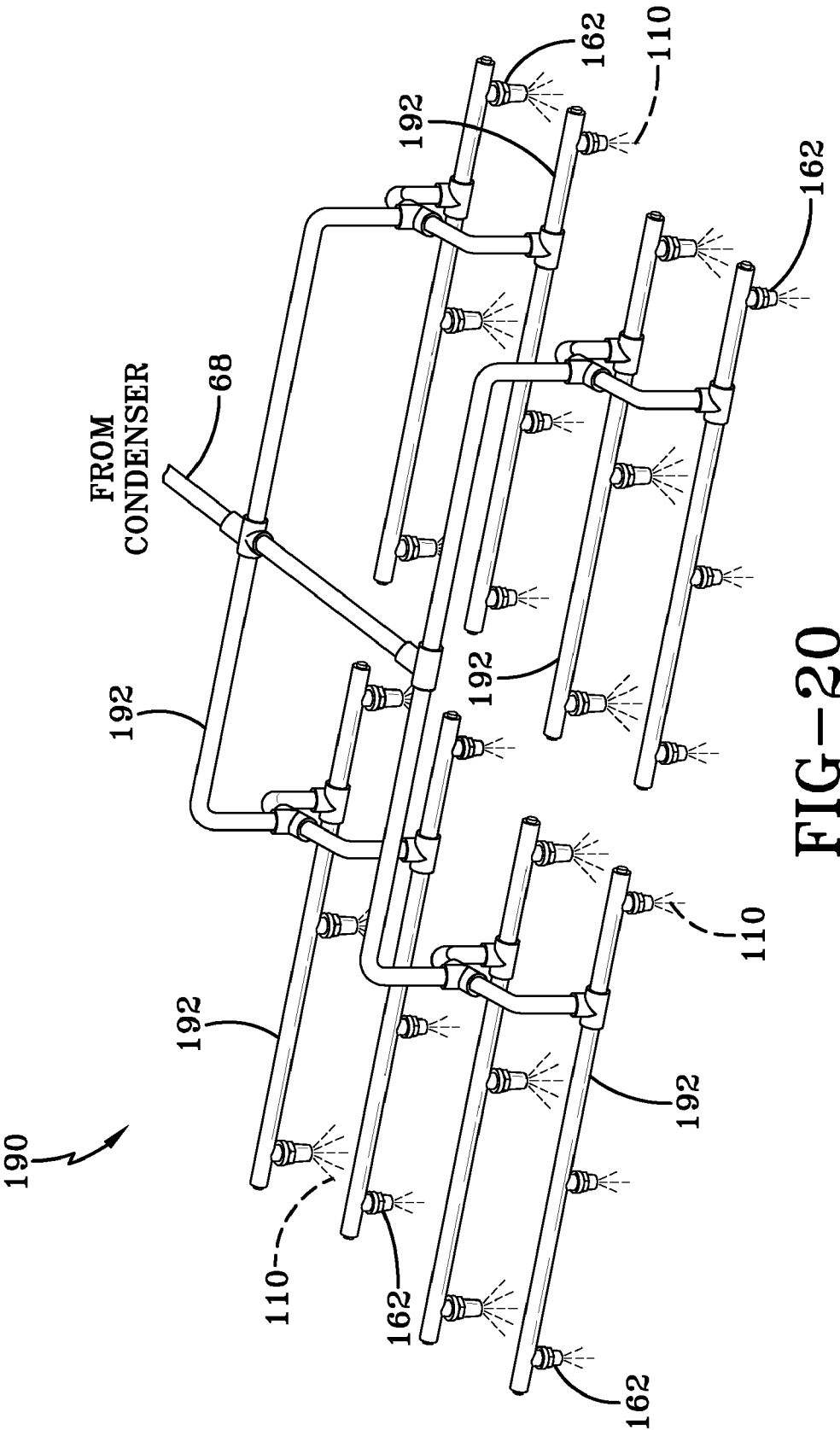


FIG-19



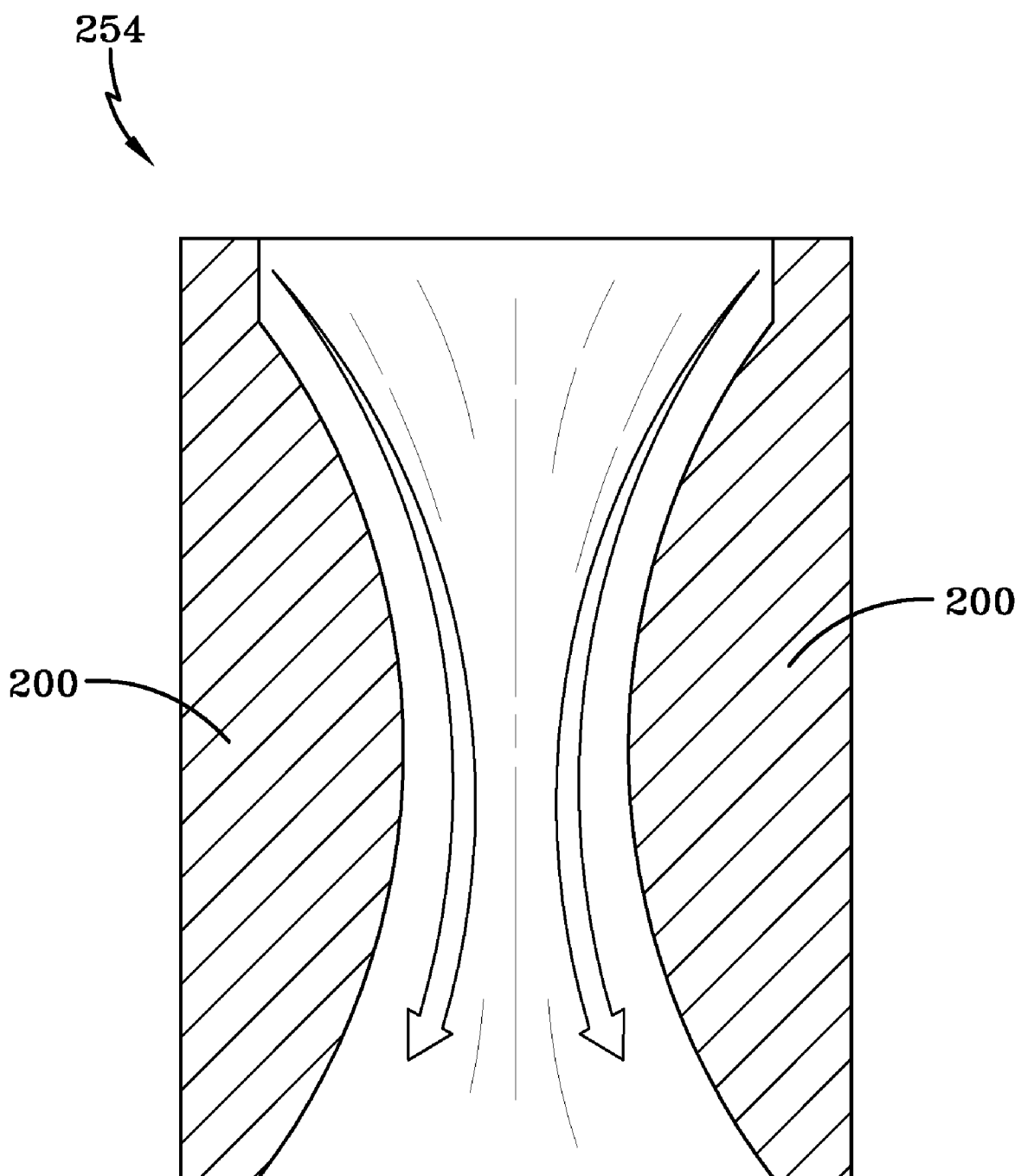


FIG-21

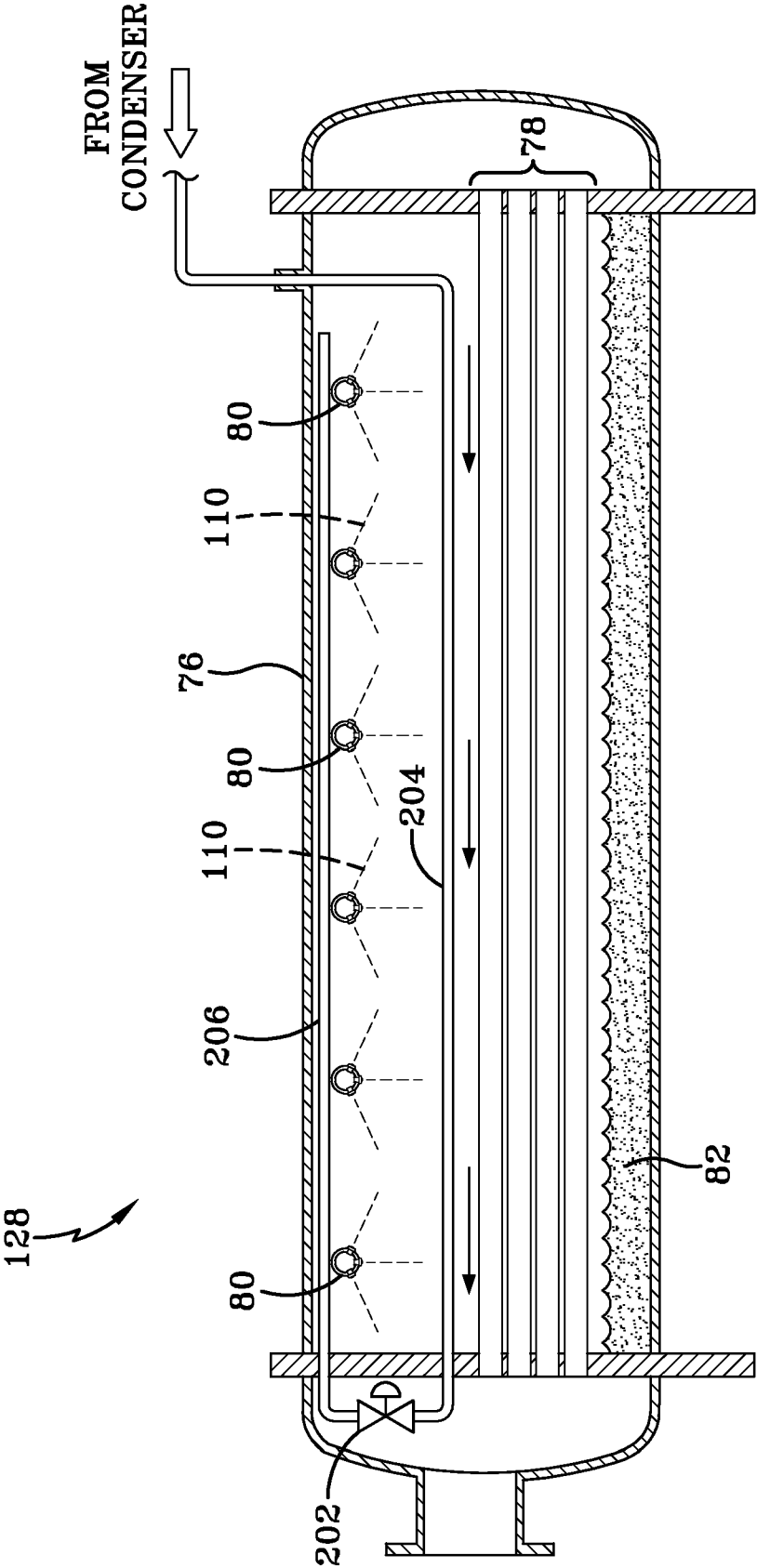
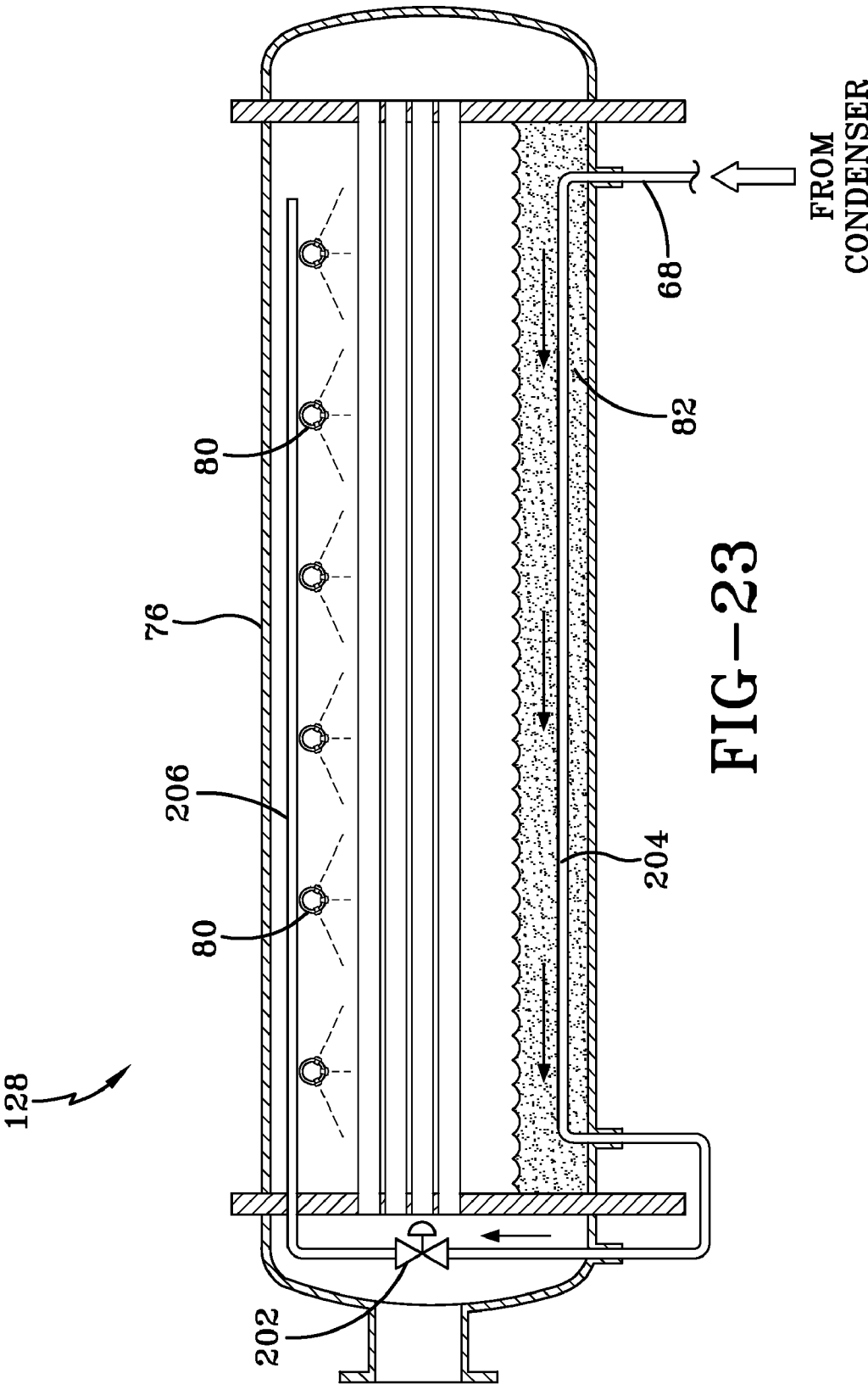


FIG-22



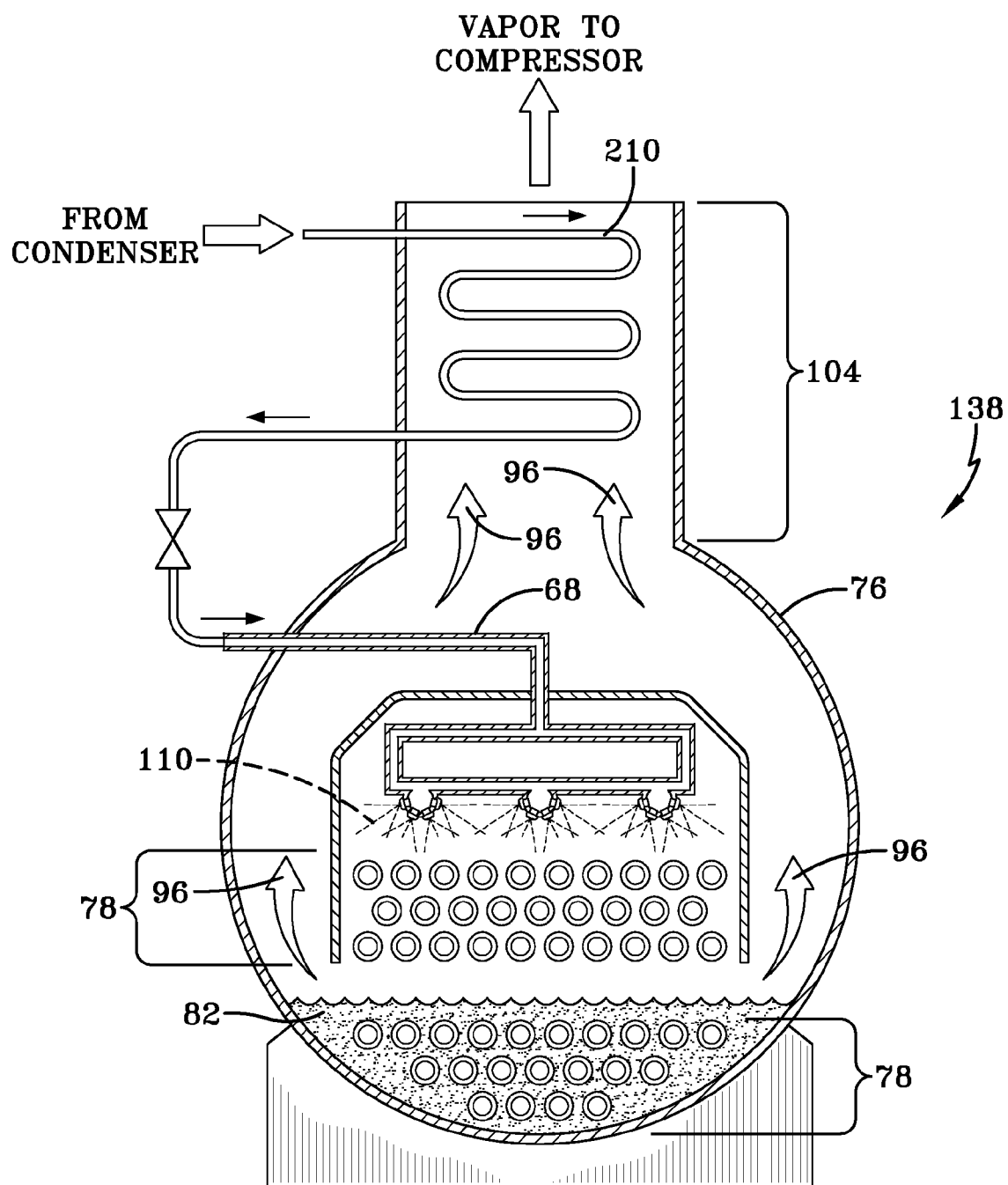


FIG-24

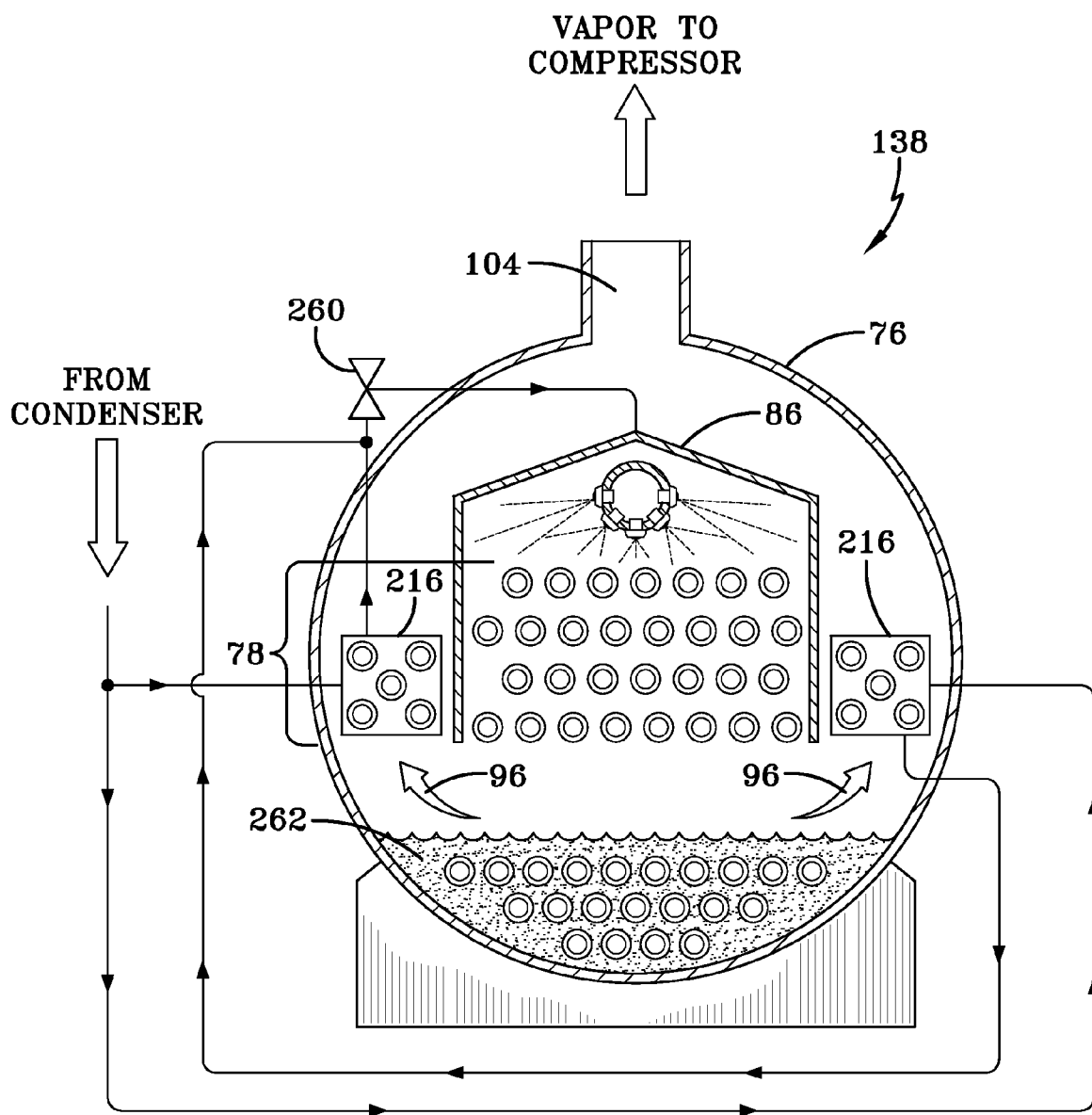


FIG-25

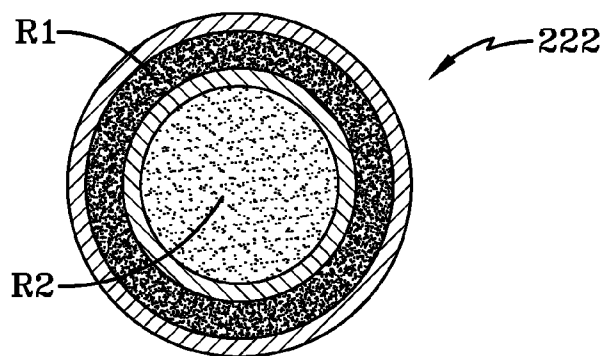


FIG-26A

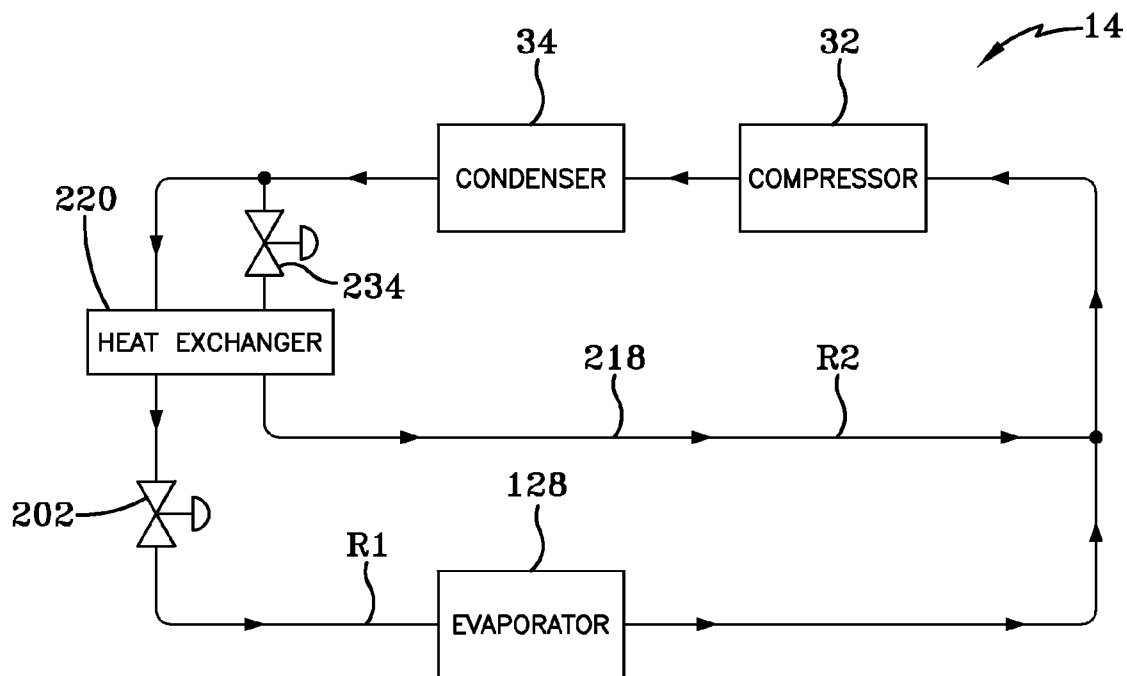


FIG-26B

VAPOR COMPRESSION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from and the benefit of U.S. Provisional Application No. 61/020,533, entitled FALLING FILM EVAPORATOR SYSTEMS, filed Jan. 11, 2008, which is hereby incorporated by reference.

BACKGROUND

[0002] The application relates generally to vapor compression systems in refrigeration, air conditioning and chilled liquid systems. The application relates more specifically to distribution systems and methods in vapor compression systems.

[0003] Conventional chilled liquid systems used in heating, ventilation and air conditioning systems include an evaporator to affect a transfer of thermal energy between the refrigerant of the system and another liquid to be cooled. One type of evaporator includes a shell with a plurality of tubes forming a tube bundle(s) through which the liquid to be cooled is circulated. The refrigerant is brought into contact with the outer or exterior surfaces of the tube bundle inside the shell, resulting in a transfer of thermal energy between the liquid to be cooled and the refrigerant. For example, refrigerant can be deposited onto the exterior surfaces of the tube bundle by spraying or other similar techniques in what is commonly referred to as a “falling film” evaporator. In a further example, the exterior surfaces of the tube bundle can be fully or partially immersed in liquid refrigerant in what is commonly referred to as a “flooded” evaporator. In yet another example, a portion of the tube bundle can have refrigerant deposited on the exterior surfaces and another portion of the tube bundle can be immersed in liquid refrigerant in what is commonly referred to as a “hybrid falling film” evaporator.

[0004] As a result of the thermal energy transfer with the liquid, the refrigerant is heated and converted to a vapor state, which is then returned to a compressor where the vapor is compressed, to begin another refrigerant cycle. The cooled liquid can be circulated to a plurality of heat exchangers located throughout a building. Warmer air from the building is passed over the heat exchangers where the cooled liquid is warmed, while cooling the air for the building. The liquid warmed by the building air is returned to the evaporator to repeat the process.

SUMMARY

[0005] The present invention relates to a heat exchanger for use in a vapor compression system having a shell, a tube bundle, a hood, and a distributor. The tube bundle has a plurality of tubes extending substantially horizontally in the shell and the hood covers the tube bundle. The distributor mixes vapor and liquid entering the distributor to form a mixed fluid. The distributor is positioned to apply the mixed fluid to the tube bundle.

[0006] The present invention also relates to a heat exchanger for use in a vapor compression system having a shell, a tube bundle, a hood, and a distributor. The tube bundle includes a plurality of tubes extending substantially horizontally in the shell. The hood covers the tube bundle, and the distributor includes a first distribution device positioned to

distribute vapor refrigerant. The distributor also includes a second distribution device positioned to apply liquid refrigerant to the tube bundle.

[0007] The present invention also relates to a heat exchanger for a vapor compression system including a shell, a tube bundle, a hood, a distributor, and an inlet connection. The heat exchanger also includes a refrigerant line connecting the inlet connection and the distributor. The tube bundle includes a plurality of tubes extending substantially horizontally in the shell. The hood covers the tube bundle and the refrigerant line is positioned to enable refrigerant in the refrigerant line to enter into a heat transfer relationship with refrigerant in the heat exchanger.

BRIEF DESCRIPTION OF THE FIGURES

[0008] FIG. 1 shows an exemplary embodiment for a heating, ventilation and air conditioning system.

[0009] FIG. 2 shows an isometric view of an exemplary vapor compression system.

[0010] FIGS. 3 and 4 schematically illustrate exemplary embodiments of the vapor compression system.

[0011] FIG. 5A shows an exploded, partial cutaway view of an exemplary evaporator.

[0012] FIG. 5B shows a top isometric view of the evaporator of FIG. 5A.

[0013] FIG. 5C shows a cross section of the evaporator taken along line 5-5 of FIG. 5B.

[0014] FIG. 6A shows a top isometric view of an exemplary evaporator.

[0015] FIGS. 6B and 6C show a cross section of the evaporator taken along line 6-6 of FIG. 6A.

[0016] FIG. 7A shows a partial cross section of an evaporator with an exemplary distributor.

[0017] FIG. 7B shows an enlarged partial bottom view of the distributor of FIG. 7A.

[0018] FIG. 8A shows a partial cross section of an evaporator with another exemplary distributor.

[0019] FIG. 8B shows an enlarged partial cross section of the distributor of FIG. 8A.

[0020] FIGS. 9 and 10 show elevation views of exemplary embodiments of distributors for an evaporator.

[0021] FIG. 11 shows a cross section of an exemplary baffled distributor for an evaporator.

[0022] FIG. 12 shows a cross section of an exemplary wire mesh distributor for an evaporator.

[0023] FIGS. 13 and 14 show cross sections of exemplary embodiments of distributors for an evaporator.

[0024] FIGS. 15, 16 and 17 show cross sections of exemplary embodiments of distributors for an evaporator.

[0025] FIG. 18 shows an exemplary distributor for an evaporator.

[0026] FIG. 19 shows a cross section of the distributor taken along line 19-19 of FIG. 18.

[0027] FIG. 20 shows another exemplary distributor for an evaporator.

[0028] FIG. 21 shows an exemplary embodiment of a venturi inlet for a distributor.

[0029] FIGS. 22 and 23 show cross sections of evaporators with exemplary distributors.

[0030] FIG. 24 shows a cross section of an evaporator with an exemplary distributor.

[0031] FIG. 25 shows a cross section of an evaporator with an exemplary distributor.

[0032] FIG. 26A shows a cross section of an exemplary heat exchanger.

[0033] FIG. 26B shows an exemplary vapor compression system with the heat exchanger of FIG. 26A.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[0034] FIG. 1 shows an exemplary environment for a heating, ventilation and air conditioning (HVAC) system 10 incorporating a chilled liquid system in a building 12 for a typical commercial setting. System 10 can include a vapor compression system 14 that can supply a chilled liquid, which may be used to cool building 12. System 10 can include a boiler 16 to supply heated liquid that may be used to heat building 12, and an air distribution system, which circulates air through building 12. The air distribution system can also include an air return duct 18, an air supply duct 20 and an air handler 22. Air handler 22 can include a heat exchanger that is connected to boiler 16 and vapor compression system 14 by conduits 24. The heat exchanger in air handler 22 may receive either heated liquid from boiler 16 or chilled liquid from vapor compression system 14, depending on the mode of operation of system 10. System 10 is shown with a separate air handler on each floor of building 12, but it is appreciated that the components may be shared between or among floors.

[0035] FIGS. 2 and 3 show an exemplary vapor compression system 14 that can be used in an HVAC system, such as HVAC system 10. Vapor compression system 14 can circulate a refrigerant through a compressor 32 driven by a motor 50, a condenser 34, expansion device(s) 36, and a liquid chiller or evaporator 38. Vapor compression system 14 can also include a control panel 40 that can include an analog to digital (A/D) converter 42, a microprocessor 44, a non-volatile memory 46, and an interface board 48. Some examples of fluids that may be used as refrigerants in vapor compression system 14 are hydrofluorocarbon (HFC) based refrigerants, for example, R-410A, R-407, R-134a, hydrofluoro olefin (HFO), “natural” refrigerants like ammonia (NH₃), R-717, carbon dioxide (CO₂), R-744, or hydrocarbon based refrigerants, water vapor or any other suitable type of refrigerant. In an exemplary embodiment, vapor compression system 14 may use one or more of each of VSDs 52, motors 50, compressors 32, condensers 34 and/or evaporators 38.

[0036] Motor 50 used with compressor 32 can be powered by a variable speed drive (VSD) 52 or can be powered directly from an alternating current (AC) or direct current (DC) power source. VSD 52, if used, receives AC power having a particular fixed line voltage and fixed line frequency from the AC power source and provides power having a variable voltage and frequency to motor 50. Motor 50 can include any type of electric motor that can be powered by a VSD or directly from an AC or DC power source. For example, motor 50 can be a switched reluctance motor, an induction motor, an electronically commutated permanent magnet motor or any other suitable motor type. In an alternate exemplary embodiment, other drive mechanisms such as steam or gas turbines or engines and associated components can be used to drive compressor 32.

[0037] Compressor 32 compresses a refrigerant vapor and delivers the vapor to condenser 34 through a discharge line. Compressor 32 can be a centrifugal compressor, screw compressor, reciprocating compressor, rotary compressor, swing link compressor, scroll compressor, turbine compressor, or any other suitable compressor. The refrigerant vapor deliv-

ered by compressor 32 to condenser 34 transfers heat to a fluid, for example, water or air. The refrigerant vapor condenses to a refrigerant liquid in condenser 34 as a result of the heat transfer with the fluid. The liquid refrigerant from condenser 34 flows through expansion device 36 to evaporator 38. In the exemplary embodiment shown in FIG. 3, condenser 34 is water cooled and includes a tube bundle 54 connected to a cooling tower 56.

[0038] The liquid refrigerant delivered to evaporator 38 absorbs heat from another fluid, which may or may not be the same type of fluid used for condenser 34, and undergoes a phase change to a refrigerant vapor. In the exemplary embodiment shown in FIG. 3, evaporator 38 includes a tube bundle having a supply line 60S and a return line 60R connected to a cooling load 62. A process fluid, for example, water, ethylene glycol, calcium chloride brine, sodium chloride brine, or any other suitable liquid, enters evaporator 38 via return line 60R and exits evaporator 38 via supply line 60S. Evaporator 38 chills the temperature of the process fluid in the tubes. The tube bundle in evaporator 38 can include a plurality of tubes and a plurality of tube bundles. The vapor refrigerant exits evaporator 38 and returns to compressor 32 by a suction line to complete the cycle.

[0039] FIG. 4, which is similar to FIG. 3, shows the refrigerant circuit with an intermediate circuit 64 that may be incorporated between condenser 34 and expansion device 36 to provide increased cooling capacity, efficiency and performance. Intermediate circuit 64 has an inlet line 68 that can be either connected directly to or can be in fluid communication with condenser 34. As shown, inlet line 68 includes an expansion device 66 positioned upstream of an intermediate vessel 70. Intermediate vessel 70 can be a flash tank, also referred to as a flash intercooler, in an exemplary embodiment. In an alternate exemplary embodiment, intermediate vessel 70 can be configured as a heat exchanger or a “surface economizer”. In the flash intercooler arrangement, a first expansion device 66 operates to lower the pressure of the liquid received from condenser 34. During the expansion process in a flash intercooler, a portion of the liquid is evaporated. Intermediate vessel 70 may be used to separate the evaporated vapor from the liquid received from the condenser. The evaporated liquid may be drawn by compressor 32 to a port at a pressure intermediate between suction and discharge or at an intermediate stage of compression, through a line 74. The liquid that is not evaporated is cooled by the expansion process, and collects at the bottom of intermediate vessel 70, where the liquid is recovered to flow to the evaporator 38, through a line 72 comprising a second expansion device 36.

[0040] In the “surface intercooler” arrangement, the implementation is slightly different, as known to those skilled in the art. Intermediate circuit 64 can operate in a similar matter to that described above, except that instead of receiving the entire amount of refrigerant from condenser 34, as shown in FIG. 4, intermediate circuit 64 receives only a portion of the refrigerant from condenser 34 and the remaining refrigerant proceeds directly to expansion device 36.

[0041] FIGS. 5A through 5C show an exemplary embodiment of an evaporator configured as a “hybrid falling film” evaporator. As shown in FIGS. 5A through 5C, an evaporator 138 includes a substantially cylindrical shell 76 with a plurality of tubes forming a tube bundle 78 extending substantially horizontally along the length of shell 76. At least one support 116 may be positioned inside shell 76 to support the plurality of tubes in tube bundle 78. A suitable fluid, such as

water, ethylene, ethylene glycol, or calcium chloride brine flows through the tubes of tube bundle 78. A distributor 80 positioned above tube bundle 78 distributes, deposits or applies refrigerant 110 from a plurality of positions onto the tubes in tube bundle 78. In one exemplary embodiment, the refrigerant deposited by distributor 80 can be entirely liquid refrigerant, although in another exemplary embodiment, the refrigerant deposited by distributor 80 can include both liquid refrigerant and vapor refrigerant.

[0042] Liquid refrigerant that flows around the tubes of tube bundle 78 without changing state collects in the lower portion of shell 76. The collected liquid refrigerant can form a pool or reservoir of liquid refrigerant 82. The deposition positions from distributor 80 can include any combination of longitudinal or lateral positions with respect to tube bundle 78. In another exemplary embodiment, deposition positions from distributor 80 are not limited to ones that deposit onto the upper tubes of tube bundle 78. Distributor 80 may include a plurality of nozzles supplied by a dispersion source of the refrigerant. In an exemplary embodiment, the dispersion source is a tube connecting a source of refrigerant, such as condenser 34. Nozzles include spraying nozzles, but also include machined openings that can guide or direct refrigerant onto the surfaces of the tubes. The nozzles may apply refrigerant in a predetermined pattern, such as a jet pattern, so that the upper row of tubes of tube bundle 78 are covered. The tubes of tube bundle 78 can be arranged to promote the flow of refrigerant in the form of a film around the tube surfaces, the liquid refrigerant coalescing to form droplets or in some instances, a curtain or sheet of liquid refrigerant at the bottom of the tube surfaces. The resulting sheeting promotes wetting of the tube surfaces which enhances the heat transfer efficiency between the fluid flowing inside the tubes of tube bundle 78 and the refrigerant flowing around the surfaces of the tubes of tube bundle 78.

[0043] In the pool of liquid refrigerant 82, a tube bundle 140 can be immersed or at least partially immersed, to provide additional thermal energy transfer between the refrigerant and the process fluid to evaporate the pool of liquid refrigerant 82. In an exemplary embodiment, tube bundle 78 can be positioned at least partially above (that is, at least partially overlying) tube bundle 140. In one exemplary embodiment, evaporator 138 incorporates a two pass system, in which the process fluid that is to be cooled first flows inside the tubes of tube bundle 140 and then is directed to flow inside the tubes of tube bundle 78 in the opposite direction to the flow in tube bundle 140. In the second pass of the two pass system, the temperature of the fluid flowing in tube bundle 78 is reduced, thus requiring a lesser amount of heat transfer with the refrigerant flowing over the surfaces of tube bundle 78 to obtain a desired temperature of the process fluid.

[0044] It is to be understood that although a two pass system is described in which the first pass is associated with tube bundle 140 and the second pass is associated with tube bundle 78, other arrangements are contemplated. For example, evaporator 138 can incorporate a one pass system where the process fluid flows through both tube bundle 140 and tube bundle 78 in the same direction. Alternatively, evaporator 138 can incorporate a three pass system in which two passes are associated with tube bundle 140 and the remaining pass associated with tube bundle 78, or in which one pass is associated with tube bundle 140 and the remaining two passes are associated with tube bundle 78. Further, evaporator 138 can incorporate an alternate two pass system in which one pass is

associated with both tube bundle 78 and tube bundle 140, and the second pass is associated with both tube bundle 78 and tube bundle 140. In one exemplary embodiment, tube bundle 78 is positioned at least partially above tube bundle 140, with a gap separating tube bundle 78 from tube bundle 140. In a further exemplary embodiment, hood 86 overlies tube bundle 78, with hood 86 extending toward and terminating near the gap. In summary, any number of passes in which each pass can be associated with one or both of tube bundle 78 and tube bundle 140 is contemplated.

[0045] An enclosure or hood 86 is positioned over tube bundle 78 to substantially prevent cross flow, that is, a lateral flow of vapor refrigerant or liquid and vapor refrigerant 106 between the tubes of tube bundle 78. Hood 86 is positioned over and laterally borders tubes of tube bundle 78. Hood 86 includes an upper end 88 positioned near the upper portion of shell 76. Distributor 80 can be positioned between hood 86 and tube bundle 78. In yet a further exemplary embodiment, distributor 80 may be positioned near, but exterior of, hood 86, so that distributor 80 is not positioned between hood 86 and tube bundle 78. However, even though distributor 80 is not positioned between hood 86 and tube bundle 78, the nozzles of distributor 80 are still configured to direct or apply refrigerant onto surfaces of the tubes. Upper end 88 of hood 86 is configured to substantially prevent the flow of applied refrigerant 110 and partially evaporated refrigerant, that is, liquid and/or vapor refrigerant 106 from flowing directly to outlet 104. Instead, applied refrigerant 110 and refrigerant 106 are constrained by hood 86, and, more specifically, are forced to travel downward between walls 92 before the refrigerant can exit through an open end 94 in the hood 86. Flow of vapor refrigerant 96 around hood 86 also includes evaporated refrigerant flowing away from the pool of liquid refrigerant 82.

[0046] It is to be understood that at least the above-identified, relative terms are non-limiting as to other exemplary embodiments in the disclosure. For example, hood 86 may be rotated with respect to the other evaporator components previously discussed, that is, hood 86, including walls 92, is not limited to a vertical orientation. Upon sufficient rotation of hood 86 about an axis substantially parallel to the tubes of tube bundle 78, hood 86 may no longer be considered "positioned over" nor to "laterally border" tubes of tube bundle 78. Similarly, "upper" end 88 of hood 86 may no longer be near "an upper portion" of shell 76, and other exemplary embodiments are not limited to such an arrangement between the hood and the shell. In an exemplary embodiment, hood 86 terminates after covering tube bundle 78, although in another exemplary embodiment, hood 86 further extends after covering tube bundle 78.

[0047] After hood 86 forces refrigerant 106 downward between walls 92 and through open end 94, the vapor refrigerant undergoes an abrupt change in direction before traveling in the space between shell 76 and walls 92 from the lower portion of shell 76 to the upper portion of shell 76. Combined with the effect of gravity, the abrupt directional change in flow results in a proportion of any entrained droplets of refrigerant colliding with either liquid refrigerant 82 or shell 76, thereby removing those droplets from the flow of vapor refrigerant 96. Also, refrigerant mist traveling along the length of hood 86 between walls 92 is coalesced into larger drops that are more easily separated by gravity, or maintained sufficiently near or in contact with tube bundle 78, to permit evaporation of the refrigerant mist by heat transfer with the tube bundle. As a

result of the increased drop size, the efficiency of liquid separation by gravity is improved, permitting an increased upward velocity of vapor refrigerant **96** flowing through the evaporator in the space between walls **92** and shell **76**. Vapor refrigerant **96**, whether flowing from open end **94** or from the pool of liquid refrigerant **82**, flows over a pair of extensions **98** protruding from walls **92** near upper end **88** and into a channel **100**. Vapor refrigerant **96** enters into channel **100** through slots **102**, which is the space between the ends of extensions **98** and shell **76**, before exiting evaporator **138** at an outlet **104**. In another exemplary embodiment, vapor refrigerant **96** can enter into channel **100** through openings or apertures formed in extensions **98**, instead of slots **102**. In yet another exemplary embodiment, slots **102** can be formed by the space between hood **86** and shell **76**, that is, hood **86** does not include extensions **98**.

[0048] Stated another way, once refrigerant **106** exits from hood **86**, vapor refrigerant **96** then flows from the lower portion of shell **76** to the upper portion of shell **76** along the prescribed passageway. In an exemplary embodiment, the passageways can be substantially symmetric between the surfaces of hood **86** and shell **76** prior to reaching outlet **104**. In an exemplary embodiment, baffles, such as extensions **98** are provided near the evaporator outlet to prevent a direct path of vapor refrigerant **96** to the compressor inlet.

[0049] In one exemplary embodiment, hood **86** includes opposed substantially parallel walls **92**. In another exemplary embodiment, walls **92** can extend substantially vertically and terminate at open end **94**, that is located substantially opposite upper end **88**. Upper end **88** and walls **92** are closely positioned near the tubes of tube bundle **78**, with walls **92** extending toward the lower portion of shell **76** so as to substantially laterally border the tubes of tube bundle **78**. In an exemplary embodiment, walls **92** may be spaced between about 0.02 inch (0.5 mm) and about 0.8 inch (20 mm) from the tubes in tube bundle **78**. In a further exemplary embodiment, walls **92** may be spaced between about 0.1 inch (3 mm) and about 0.2 inch (5 mm) from the tubes in tube bundle **78**. However, spacing between upper end **88** and the tubes of tube bundle **78** may be significantly greater than 0.2 inch (5 mm), in order to provide sufficient spacing to position distributor **80** between the tubes and the upper end of the hood. In an exemplary embodiment in which walls **92** of hood **86** are substantially parallel and shell **76** is cylindrical, walls **92** may also be symmetric about a central vertical plane of symmetry of the shell bisecting the space separating walls **92**. In other exemplary embodiments, walls **92** need not extend vertically past the lower tubes of tube bundle **78**, nor do walls **92** need to be planar, as walls **92** may be curved or have other non-planar shapes. Regardless of the specific construction, hood **86** is configured to channel refrigerant **106** within the confines of walls **92** through open end **94** of hood **86**.

[0050] FIGS. 6A through 6C show an exemplary embodiment of an evaporator configured as a “falling film” evaporator **128**. As shown in FIGS. 6A through 6C, evaporator **128** is similar to evaporator **138** shown in FIGS. 5A through 5C, except that evaporator **128** does not include tube bundle **140** in the pool of refrigerant **82** that collects in the lower portion of the shell. In an exemplary embodiment, hood **86** terminates after covering tube bundle **78**, although in another exemplary embodiment, hood **86** further extends toward pool of refrigerant **82** after covering tube bundle **78**. In yet a further exem-

plary embodiment, hood **86** terminates so that the hood does not totally cover the tube bundle, that is, substantially covers the tube bundle.

[0051] As shown in FIGS. 6B and 6C, a pump **84** can be used to recirculate the pool of liquid refrigerant **82** from the lower portion of the shell **76** via line **114** to distributor **80**. As further shown in FIG. 6B, line **114** can include a regulating device **112** that can be in fluid communication with a condenser (not shown). In another exemplary embodiment, an ejector (not shown) can be employed to draw liquid refrigerant **82** from the lower portion of shell **76** using the pressurized refrigerant from condenser **34**, which operates by virtue of the Bernoulli effect. The ejector combines the functions of a regulating device **112** and a pump **84**.

[0052] In an exemplary embodiment, one arrangement of tubes or tube bundles may be defined by a plurality of uniformly spaced tubes that are aligned vertically and horizontally, forming an outline that can be substantially rectangular. However, a stacking arrangement of tube bundles can be used where the tubes are neither vertically or horizontally aligned, as well as arrangements that are not uniformly spaced.

[0053] In another exemplary embodiment, different tube bundle constructions are contemplated. For example, finned tubes (not shown) can be used in a tube bundle, such as along the uppermost horizontal row or uppermost portion of the tube bundle. Besides the possibility of using finned tubes, tubes developed for more efficient operation for pool boiling applications, such as in “flooded” evaporators, may also be employed. Additionally, or in combination with the finned tubes, porous coatings can also be applied to the outer surface of the tubes of the tube bundles.

[0054] In a further exemplary embodiment, the cross-sectional profile of the evaporator shell may be non-circular.

[0055] In an exemplary embodiment, a portion of the hood may partially extend into the shell outlet.

[0056] In addition, it is possible to incorporate the expansion functionality of the expansion devices of system **14** into distributor **80**. In one exemplary embodiment, two expansion devices may be employed. One expansion device is exhibited in the spraying nozzles of distributor **80**. The other expansion device, for example, expansion device **36**, can provide a preliminary partial expansion of refrigerant, before that provided by the spraying nozzles positioned inside the evaporator. In an exemplary embodiment, the other expansion device, that is, the non-spraying nozzle expansion device, can be controlled by the level of liquid refrigerant **82** in the evaporator to account for variations in operating conditions, such as evaporating and condensing pressures, as well as partial cooling loads. In an alternative exemplary embodiment, expansion device can be controlled by the level of liquid refrigerant in the condenser, or in a further exemplary embodiment, a “flash economizer” vessel. In one exemplary embodiment, the majority of the expansion can occur in the nozzles, providing a greater pressure difference, while simultaneously permitting the nozzles to be of reduced size, therefore reducing the size and cost of the nozzles.

[0057] As shown in FIG. 7A, distributor **80** includes at least one aperture **142** formed in an upper section **144** of distributor **80** to permit vapor refrigerant to be separated from liquid refrigerant before the refrigerant is distributed over tube bundle **78**. Refrigerant may enter distributor **80** as a two-state refrigerant from a condenser or other source (not shown). The pressure of the refrigerant flow from the condenser or other source provides the necessary force for the refrigerant to flow

through distributor **80**. A pump may be used to provide additional force for refrigerant flow through distributor **80**. The inlet to the distributor (not shown) may be located or formed in the upper section **144** of distributor **80**, or at an end of the distributor (not shown). Apertures **142** permit vapor refrigerant to exit distributor **80** without being directly distributed over tube bundle **78**. FIG. 7A shows apertures **142** as being located at the uppermost portion of upper section **144**, however apertures **142** may be located on any suitable portion of upper section **144**. In an exemplary embodiment, apertures **142** may have any suitable shape for distributing vapor refrigerant. Liquid refrigerant is distributed on tube bundle **78** through openings **146** formed in the lower section **148** of distributor **80**. Openings **146** are shown in FIG. 7B as paired or double openings, however openings **146** may be single openings or three or more openings. In an exemplary embodiment, openings **146** may have any suitable shape for distributing liquid refrigerant onto tube bundle **78**.

[0058] FIGS. 8A and 8B show another embodiment of distributor **80** used in an evaporator. Distributor **240** can be positioned within hood **86**, and has an inner distributor **150** and an outer distributor **152**. Distributors **150** and **152** may also be referred to as compartments or chambers. At least one aperture **154** may be formed in an upper portion **156** of inner distributor **150** to permit vapor refrigerant to flow from inner distributor **150** into outer distributor **152**. While FIG. 8A shows apertures **154** having a tube inserted in upper portion **156**, aperture **154** may be integrally formed within upper portion **156**. Openings **146** may be formed or disposed in the bottom segment **130** of inner distributor **150** to allow liquid refrigerant to flow into outer distributor **152**.

[0059] Outer distributor **152** can have apertures **142** formed in lateral portions or walls **158** of outer distributor **152** to permit vapor refrigerant to flow from outer distributor **152** into the space under hood **86**. While FIG. 8A shows apertures **142** having a tube inserted in lateral portions **158**, apertures **142** may be integrally formed in lateral portions **158** of outer distributor **152**. Liquid refrigerant may collect in a bottom portion **160** of outer distributor **152** and flow through distribution devices **162** positioned in bottom portion **160** of outer distributor **152**. Distribution devices **162** permit the distribution of liquid refrigerant from outer distributor **152** onto tube bundle **78** for heat transfer between the refrigerant and the process fluid in tube bundle **78**. Distribution devices **162** may be nozzles, holes, openings, valves or any other suitable device. In another exemplary embodiment, distribution devices **162** may be integrally formed with outer distributor **152**. FIG. 8B shows an embodiment of outer distributor **152** with distribution devices **162** positioned with little or minimal space between adjacent neighboring flow distribution devices **162**. In an exemplary embodiment, outer distributor **152** may have a corrugated bottom to reduce the amount of refrigerant required to maintain a flow of liquid refrigerant to distribution devices **162**.

[0060] Referring now to FIGS. 9 and 10, exemplary embodiments for respective distributors **242** and **244** are shown. Distributors **242** and **244** may include multiple inlet lines **68**, also referred to as flow paths or flow portions, to receive refrigerant. Each inlet line **68** can be in fluid communication with each other, and each inlet line **68** can receive both liquid refrigerant and vapor refrigerant. Inlet lines **68** connect to line **164** that provides refrigerant to distribution devices **162**. Distribution devices **162** distribute refrigerant over tube bundle **78**. Distributors **242** and **244** may include a

separator (not shown) to separate vapor refrigerant and liquid refrigerant before refrigerant is provided to inlet lines **68** to be distributed onto tube bundle **78**. The vapor refrigerant from the separator may be provided to a compressor. Distributors **242** and **244** may also include various flow control components to regulate the flow of refrigerant in inlet lines **68**. The flow control components may include, but are not limited to, oscillating flow, pulse widths, or a pump to modulate the flow of refrigerant. Distribution devices **162** may be nozzles, valves, openings or any other suitable distribution device. In an exemplary embodiment, distribution devices **162** may be oscillating nozzles used to oscillate the refrigerant provided onto tube bundle **78**. In the exemplary embodiment shown in FIG. 10, line **164** is connected to second line **224** by a connection line **226** to provide refrigerant onto additional tubes of tube bundle **78**. Line **164** can be positioned above second line **224**.

[0061] FIGS. 11 and 12 show embodiments of distributors that can control refrigerant flow **236** and the supply of refrigerant to distribution devices **162**. In a distributor **246** shown in FIG. 11, a series of baffles **166** can be positioned in predetermined locations in distributor **246**. Baffles **166** are shown alternately protruding inwardly from opposite sides of distributor **246**. The alternate placement of baffles **166** provides a flow pattern for the refrigerant that provides more uniform refrigerant supply to distribution devices **162**. In distributor **248** shown in FIG. 12, a wire mesh **168** may be positioned in distributor **248** to control refrigerant flow **236** through distributor **248** and the supply of refrigerant to distribution devices **162**. Both baffles **166** and wire mesh **168** provide for refrigerant flow **236** that is a mixture of liquid refrigerant and vapor refrigerant before refrigerant is distributed to tube bundle **78** by distribution devices **162**.

[0062] FIGS. 13 and 14 show a distributor **250** having protrusions **194** for regulating refrigerant flow **236** through distributor **250**. As shown in FIG. 13, protrusions **194** can be positioned along the bottom surface **196** near distribution devices **162** to interrupt direct refrigerant flow to distribution devices **162**. As shown in FIG. 14, protrusions **194** can be positioned along the top surface **198** opposite distribution devices **162**. Protrusions **194** provide for refrigerant flow **236** that is a mixture of liquid refrigerant and vapor refrigerant. In another exemplary embodiment, protrusions **194** may be positioned on both top surface **198** and bottom surface **196** in distributor **250** to control refrigerant flow **236**.

[0063] FIGS. 15 and 16 show enclosures or housings **170** for a distributor. Enclosures **170** can have a predetermined shape, such as, a rectangular, diamond, and/or square shape for improving refrigerant flow to tube bundle **78**. Any suitable shape may be used for enclosures **170**, so long as refrigerant flow can be maintained through enclosure **170**. Inlets (not shown) may be located at an upper portion of enclosure **170** or at the ends of enclosure **170**. Distribution devices **162**, such as holes or openings, can be formed or located on a bottom portion of enclosure **170** to allow refrigerant **110** to flow onto tube bundles **78**. Other exemplary embodiments of enclosures **170** may include openings (not shown) in the upper portion of enclosure **170** to allow for the flow of vapor refrigerant from enclosure **170**. FIG. 17 shows an embodiment of distributor **80** for distributing refrigerant onto tube bundles **78**. Distribution devices **162** are positioned in predetermined locations on distributor **80**. Distributor **80** may include more or less than the three flow distribution devices shown in FIG. 17. In an exemplary embodiment, distribution devices **162**

may be formed by a cutting tool, such as a cutting tool with a rotating blade, or may be formed by other methods, such as a press. In a further exemplary embodiment, distribution devices 162 may be formed in enclosure 170 prior to the enclosure being formed into a final shape.

[0064] FIGS. 18 and 19 show an embodiment for a distributor 252 connected to a separator 176 for separating liquid refrigerant from vapor refrigerant before the refrigerant enters distributor 252. Separator 176 receives two-phase refrigerant and separates the refrigerant into vapor refrigerant and liquid refrigerant. A vapor line 178 exits from an upper portion of separator 176 and provides vapor refrigerant to a vapor refrigerant line 188 in distributor 252. Vapor refrigerant line 188 distributes vapor refrigerant onto tube bundle 78 in distributor 252. A liquid line 182 exits from a lower portion of separator 176 and provides liquid refrigerant to a liquid refrigerant line 186 in distributor 252. Liquid refrigerant line 186 distributes liquid refrigerant onto tube bundles 78. Liquid refrigerant is distributed above the vapor refrigerant in distributor 252. Vapor refrigerant and liquid refrigerant are distributed concurrently over tube bundle 78 to improve the heat transfer, or cooling, of tube bundle 78. The vapor refrigerant reduces the film thickness of liquid refrigerant on tube bundle 78 and provides a more uniform distribution of refrigerant to tube bundle 78, resulting in more efficient heat transfer with tube bundle 78. Distribution devices 162 are connected to liquid refrigerant line 186 and vapor refrigerant line 188 and used to distribute both the liquid refrigerant and vapor refrigerant onto tube bundle 78. Distribution devices 162 may be nozzles, openings or any other suitable distribution device, and may be positioned in any suitable position.

[0065] Referring now to FIG. 20, a multiple branch distributor 190 may be used to distribute refrigerant over tube bundles (not shown). Inlet line 68 receives refrigerant, which then flows through distribution lines 192 to distribution devices 162. Distribution lines 192 may be positioned laterally in relation to each other to provide refrigerant distribution to a greater surface area of the tube bundle. Applied refrigerant 110 is distributed onto the tube bundle by distribution device 162.

[0066] FIG. 21 shows an exemplary embodiment of an inlet 254 that may be used with a distributor. Inlet 254 can operate to mix liquid and vapor refrigerant that is entering the distributor with a tapered opening 200, such as a venturi or multiple venturi to control the flow of refrigerant. Refrigerant enters inlet 254 through a wider opening at a first flow rate. Tapered opening 200 of inlet 254 then narrows the passageway for the refrigerant from the opening in inlet 254. The narrowed opening or passageway results in an increase in the flow rate of the refrigerant to a second flow rate. The second flow rate permits vapor and liquid refrigerant to mix, resulting in a mixed refrigerant of both liquid refrigerant and vapor refrigerant. The mixed refrigerant then exits inlet 254 into the distributor through a wider opening at a third and slower flow rate than the second flow rate.

[0067] FIGS. 22 and 23 show distributors in evaporators 128 for distributing applied refrigerant 110 onto tube bundles 78. As shown in FIG. 22, refrigerant enters inlet line 68 through the top of shell 76 and flows through a tube 204 before passing through an expansion valve 202. Tube 204 is positioned in the vapor section of evaporator 128. Refrigerant travelling through tube 204 is cooled so that at least a portion of vapor refrigerant in tube 204 can condense to liquid refrigerant and be distributed by tube 206 to distributors 80. In

addition, at least a portion of liquid refrigerant that may be entrained with vapor refrigerant in the vapor section of evaporator 128 can be evaporated as a result of the heat transfer with the refrigerant in tube 204. As shown in FIG. 23, inlet line 68 may enter into pool of liquid refrigerant 82 located at the bottom of evaporator 128. The liquid refrigerant can enter into a heat transfer relationship with the refrigerant in tube 204, condensing at least a portion of vapor refrigerant in tube 204 before entering expansion valve 202 and tube 206. In addition, liquid refrigerant in pool of liquid refrigerant 82 may be evaporated as a result of the heat transfer with the refrigerant in tube 204. In another exemplary embodiment, tube 204 may also pass through both the pool of liquid refrigerant 82 and the vapor section of evaporator 128.

[0068] FIG. 24 shows an embodiment of a distributor with a heat exchanger 210 in outlet 104. Heat exchanger 210 may be positioned between evaporator 138 and a compressor (not shown). Refrigerant from the condenser can flow through heat exchanger 210 and an expansion device before reaching inlet line 68. A heat exchange relationship occurs between vapor refrigerant 96 leaving evaporator 138 and the refrigerant in heat exchanger 210. Refrigerant in heat exchanger 210 is cooled, and at least a portion of vapor refrigerant in heat exchanger 210 can be condensed. Vapor refrigerant 96 is heated by heat exchanger 210 and at least a portion of liquid refrigerant that may be entrained with vapor refrigerant 96 is evaporated.

[0069] In another embodiment shown in FIG. 25, heat exchangers 216 are positioned between hood 86 and shell 76 to remove at least a portion of entrained liquid that may be present in vapor refrigerant. Refrigerant from the condenser can flow through heat exchangers 216 before reaching expansion device 260. Refrigerant in heat exchangers 216 are cooled, and at least a portion of vapor refrigerant in heat exchangers 216 can be condensed. Refrigerant then flows through expansion device 260 before being distributed over tube bundle 78 and collecting at the bottom 262 of evaporator 138. Vapor refrigerant 96 flows over heat exchanger 216 before exiting through outlet 104 into the compressor and at least a portion of liquid refrigerant that may be entrained with vapor refrigerant 96 is evaporated.

[0070] As shown in FIG. 26A, a heat exchanger 220 can exhibit a tube-in-tube, or pipe-in-pipe configuration. A line carrying refrigerant R2 may be positioned within a line carrying refrigerant R1. In another exemplary embodiment, the line carrying refrigerant R1 may be positioned within the line carrying refrigerant R2. The pipe-in-pipe configuration provides for heat exchange between refrigerant R1 and refrigerant R2, where the temperature of refrigerant R1 is further lowered before entering evaporator 128. By lowering the temperature of refrigerant R1 entering evaporator 128, the amount of vapor refrigerant in refrigerant R1 is reduced before entering evaporator 128, which can result in more efficient heat transfer in evaporator 128 since most, if not all, of the refrigerant entering evaporator 128 can be evaporated.

[0071] FIG. 26B shows an exemplary embodiment of vapor compression system 14. Heat exchanger 220 can reduce the amount of vapor refrigerant provided to evaporator 128. Refrigerant exits condenser 34 and flows through either expansion device 234 before entering heat exchanger 220 or directly into heat exchanger 220. Expansion device 234 reduces the pressure of the refrigerant leaving condenser 34 and entering heat exchanger 220. From expansion device 234, the refrigerant enters heat exchanger 220 and is heated by the

other refrigerant that did not flow through expansion device 234. Refrigerant R1 in heat exchanger 220 (see FIG. 26A) is cooled by transferring heat with refrigerant R2 in heat exchanger 220 (see FIG. 26A). From heat exchanger 220, refrigerant R1 flows to expansion device 202 and evaporator 128, and refrigerant R2 flows through line 218 to compressor 32.

[0072] While only certain features and embodiments of the invention have been shown and described, many modifications and changes may occur to those skilled in the art (for example, variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters (for example, 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 (that is, 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.

What is claimed is:

1. A heat exchanger for use in a vapor compression system comprising:

- a shell;
- a tube bundle;
- a hood;
- a distributor; and
- the tube bundle comprising a plurality of tubes extending substantially horizontally in the shell;
- the hood covers the tube bundle; and
- the distributor is configured to mix vapor and liquid entering the distributor to form a mixed fluid, the distributor being positioned and configured to apply the mixed fluid to the tube bundle.

2. The heat exchanger of claim 1, wherein the distributor comprises a plurality of baffles configured and positioned to provide a flow path in the distributor to mix liquid and vapor.

3. The heat exchanger of claim 2, wherein the plurality of baffles are alternately positioned on opposed surfaces of the distributor.

4. The heat exchanger of claim 1, wherein the distributor comprises a wire mesh configured and positioned to provide a flow path in the distributor to mix liquid and vapor.

5. The heat exchanger of claim 1, wherein the distributor comprises a plurality of protrusions configured and positioned to provide a flow path in the distributor to mix liquid and vapor.

6. The heat exchanger of claim 5, wherein the distributor comprises a plurality of openings positioned and configured

to apply the mixed fluid to the tube bundle and the plurality of protrusions are positioned near the plurality of openings.

7. The heat exchanger of claim 5, wherein the distributor comprises a plurality of openings positioned and configured to apply the mixed fluid to the tube bundle and the plurality of protrusions are positioned opposite the plurality of openings.

8. A heat exchanger for use in a vapor compression system comprising:

- a shell;
- a tube bundle;
- a hood;
- a distributor;
- the tube bundle comprises a plurality of tubes extending substantially horizontally in the shell;
- the hood covers the tube bundle; and
- the distributor comprising a first distribution device configured and positioned to distribute vapor refrigerant and a second distribution device configured and positioned to apply liquid refrigerant to the tube bundle.

9. The heat exchanger of claim 8, wherein the distributor is configured to separate liquid refrigerant from vapor refrigerant in a flow of refrigerant entering the distributor.

10. The heat exchanger of claim 9, wherein the first distribution device is integral with the second distribution device.

11. The heat exchanger of claim 10, wherein the first distribution device comprises at least one opening and the second distribution device comprises at least one opening.

12. The heat exchanger of claim 9, wherein the distributor comprises a first chamber, the first distribution device comprises at least one opening in the first chamber and the second distribution device comprises at least one opening in the first chamber.

13. The heat exchanger of claim 12, wherein the distributor comprises a second chamber positioned in the first chamber, the second chamber being configured and positioned to receive the flow of refrigerant entering the distributor, and the first distribution device comprises a least one opening in the second chamber and the second distribution device comprises a least one opening in the second chamber.

14. The heat exchanger of claim 8, wherein the distributor is configured and positioned to receive liquid refrigerant by a liquid refrigerant line and vapor refrigerant by a vapor refrigerant line.

15. The heat exchanger of claim 14, wherein the second distribution device is positioned above the first distribution device, the second distribution device being connected to the liquid refrigerant line and the first distribution device being connected to the vapor refrigerant line.

16. The heat exchanger of claim 15, wherein the first distribution device is configured to distribute vapor refrigerant transverse to the liquid refrigerant applied by the second distribution device.

17. A heat exchanger for a vapor compression system comprising:

- a shell;
- a tube bundle;
- a hood;
- a distributor;
- an inlet connection;
- a refrigerant line connecting the inlet connection and the distributor;
- the tube bundle comprising a plurality of tubes extending substantially horizontally in the shell;
- the hood covers the tube bundle; and
- the refrigerant line is configured and positioned to enable refrigerant in the refrigerant line to enter into a heat

transfer relationship with refrigerant in the heat exchanger.

18. The heat exchanger of claim **17**, wherein the refrigerant line is configured and positioned in the shell to be surrounded by vapor refrigerant in the shell.

19. The heat exchanger of claim **17**, wherein the refrigerant line is configured and positioned in the shell to be surrounded by liquid refrigerant in the shell.

20. The heat exchanger of claim **17**, further comprises an outlet connection and at least a portion of the refrigerant line is positioned in the outlet connection.

21. The heat exchanger of claim **18**, wherein the refrigerant line comprises a second plurality of tubes, the second plurality of tubes being positioned near the hood.

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