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(54) ABSORPTION CHILLER AND SYSTEM INCORPORATING THE SAME

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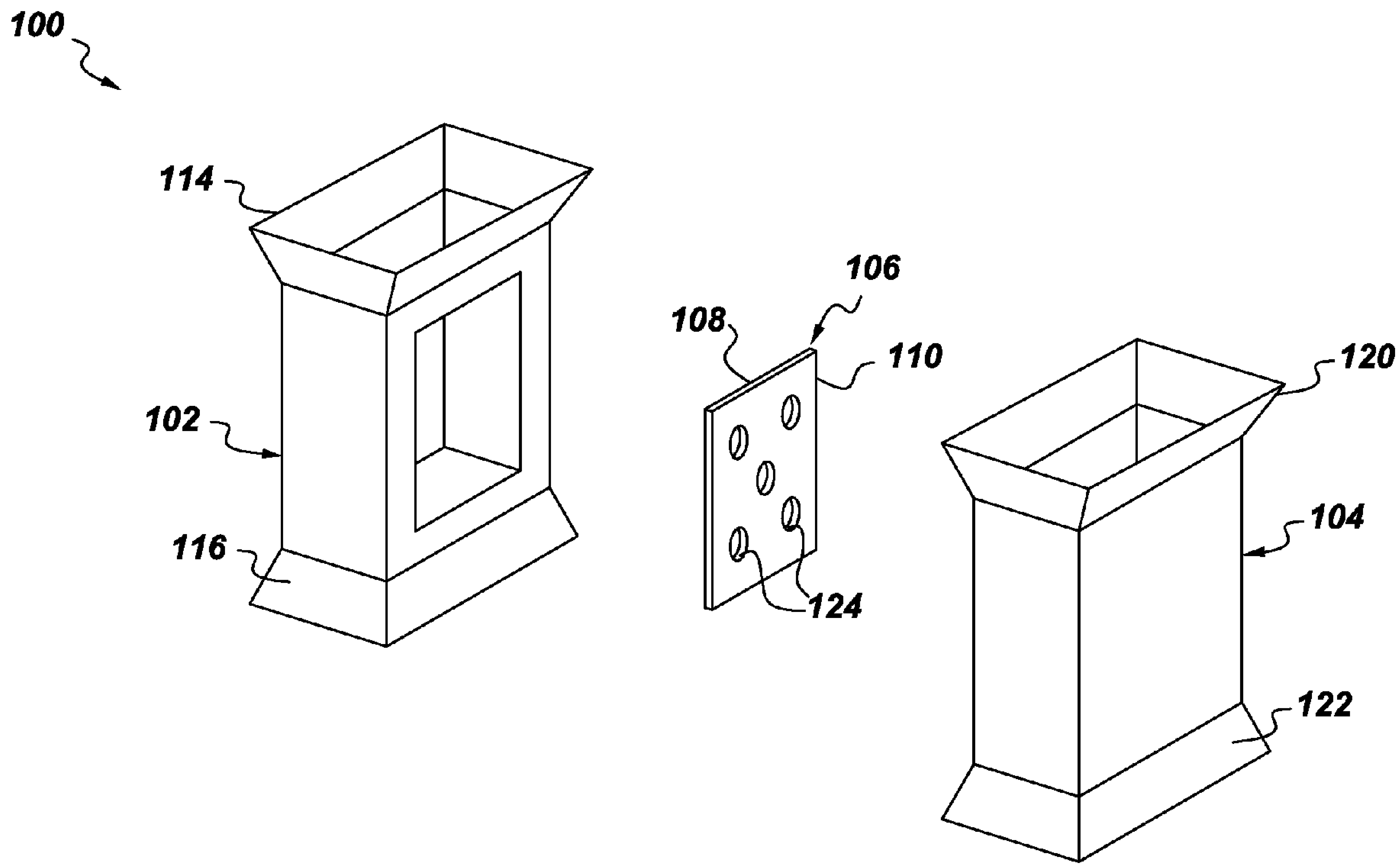
(57) **ABSTRACT**

A device, such as an absorption chiller sub-system, is provided. The absorption chiller sub-system can include an evaporator and an absorber. The evaporator can be configured to receive a liquid first working fluid and to produce first working fluid vapor. The absorber can be configured to receive and combine first working fluid vapor and a second working fluid, for example, so as to release thermal energy. A divider having opposing first and second sides in respective fluid communication with the evaporator and the absorber can also be included. The divider can be configured to allow first working fluid vapor to pass therethrough between the first and second sides and to inhibit movement of liquid first working fluid therethrough between the first and second sides. Associated systems and methods are also provided.



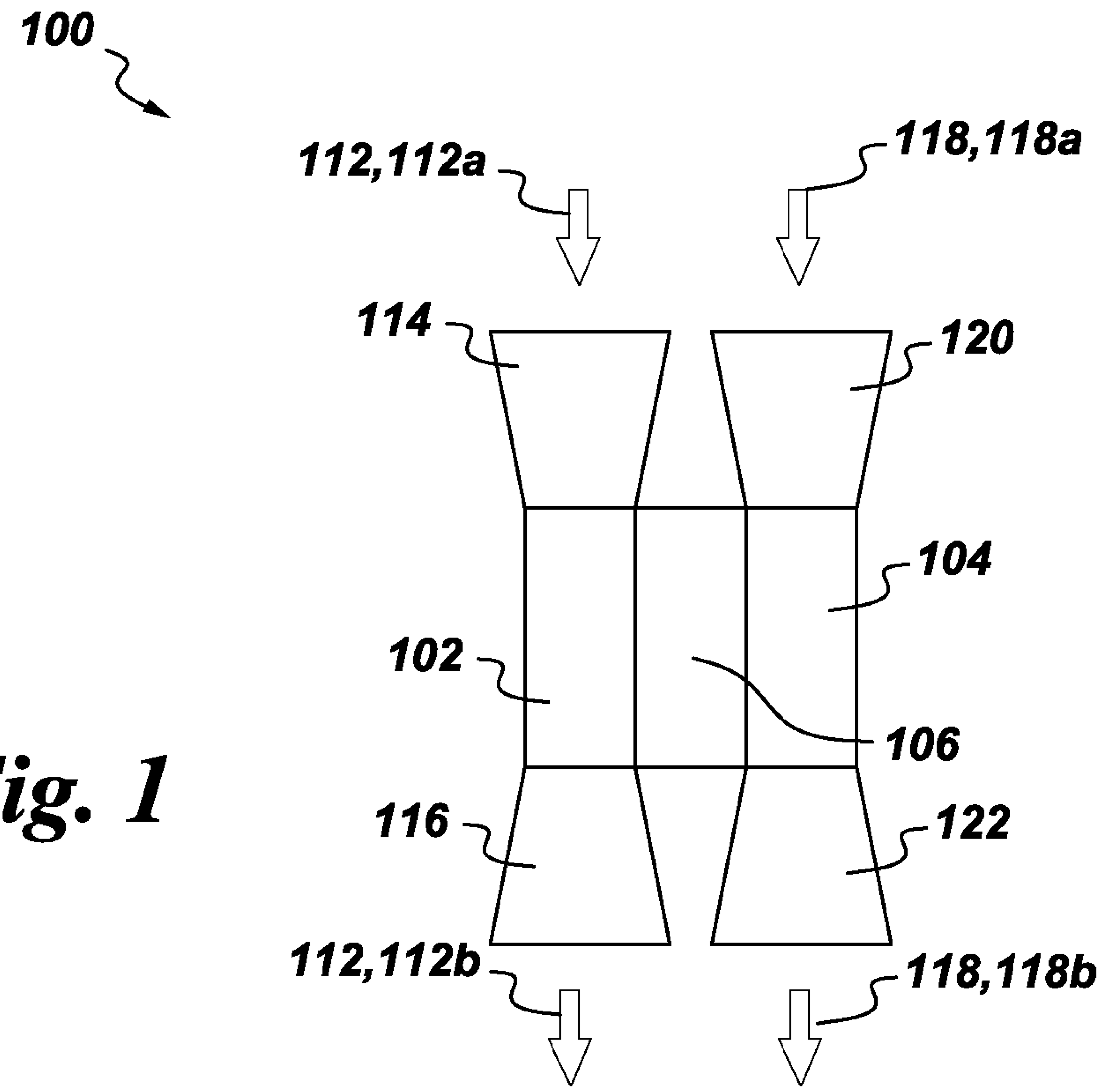

100
112,112a
118,118a
114
120
104
102
106
116
122
112,112b
118,118b

Fig. 1

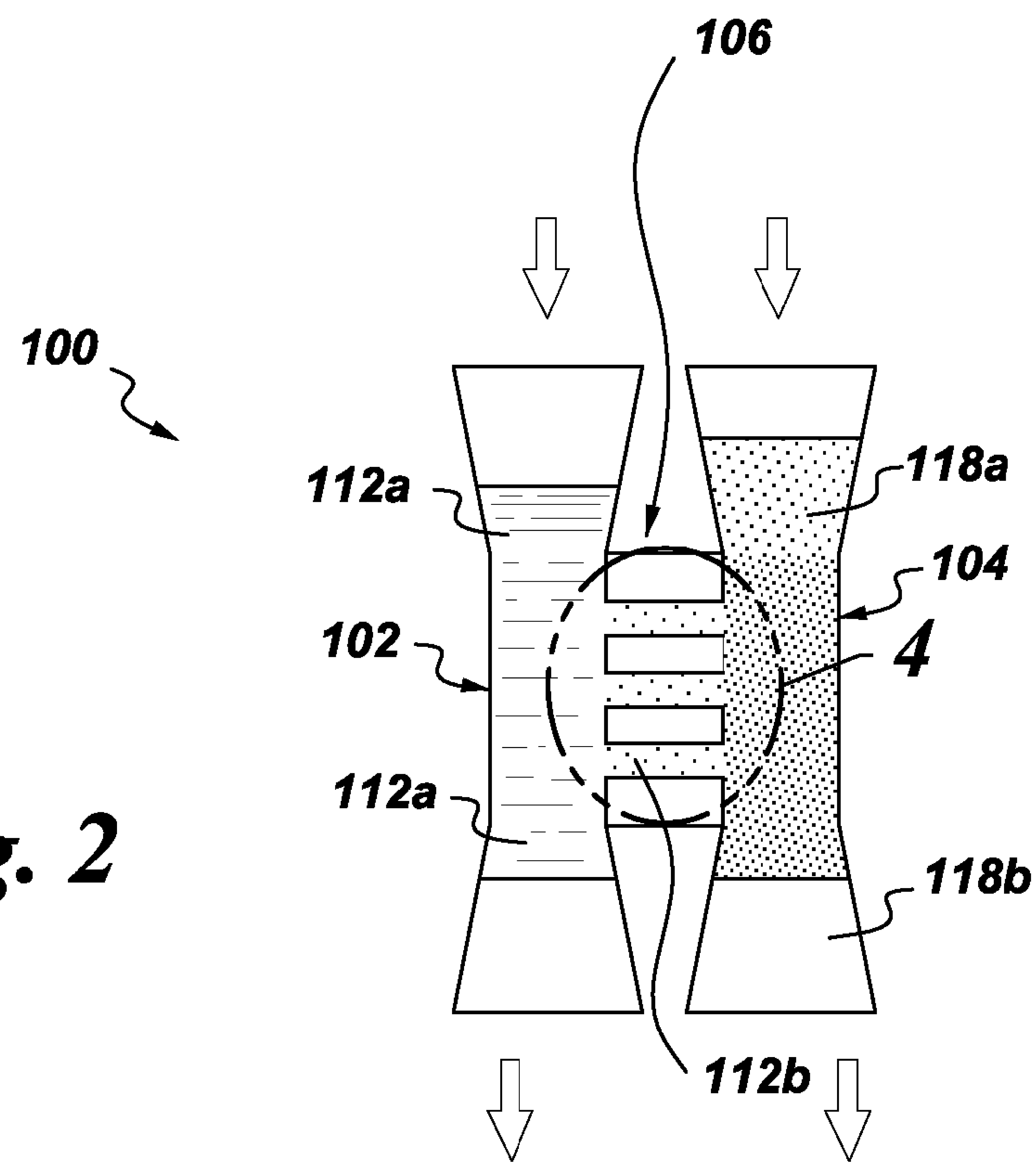

106
100
112a
118a
104
102
4
112a
118b
112b

Fig. 2

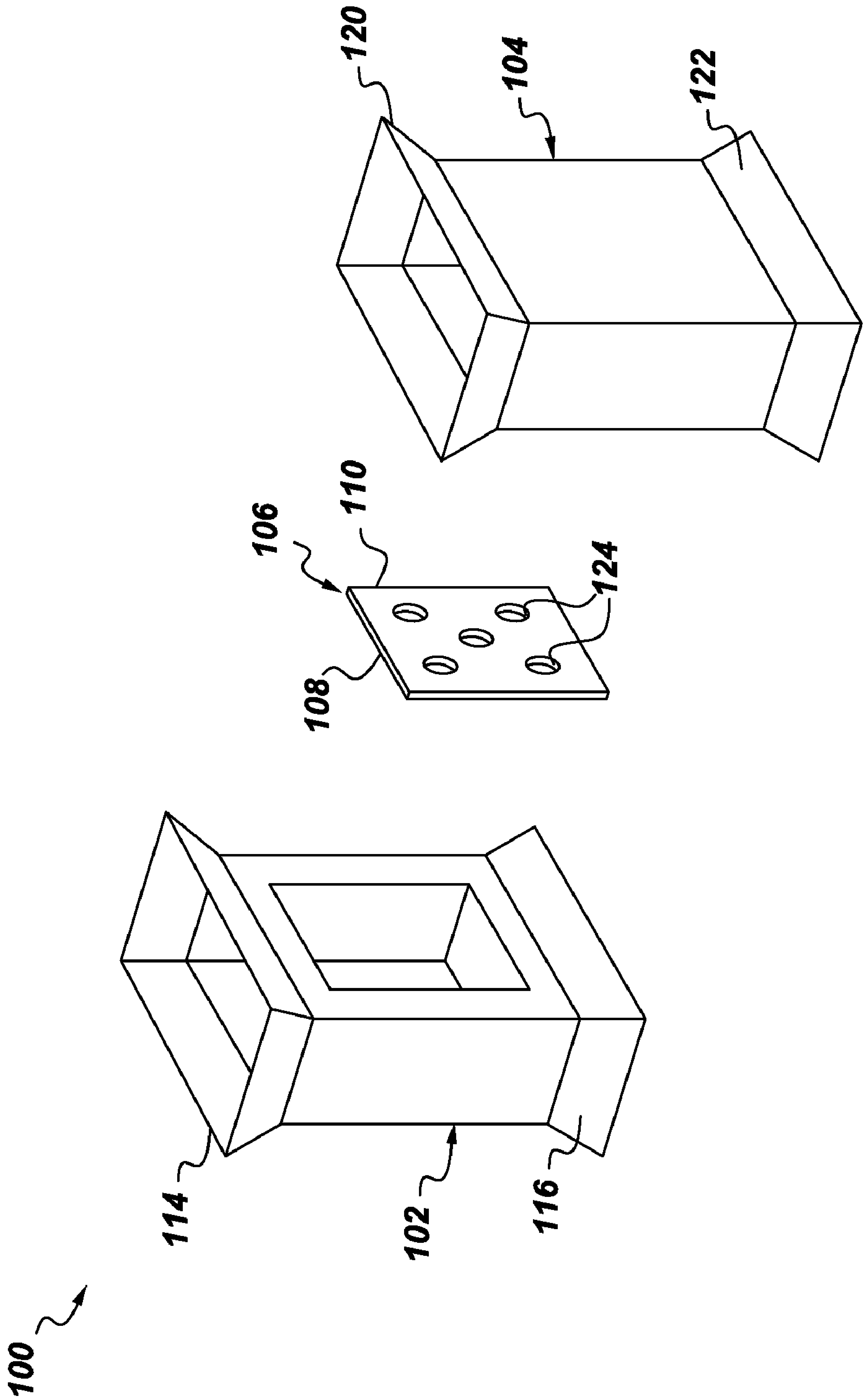


Fig. 3

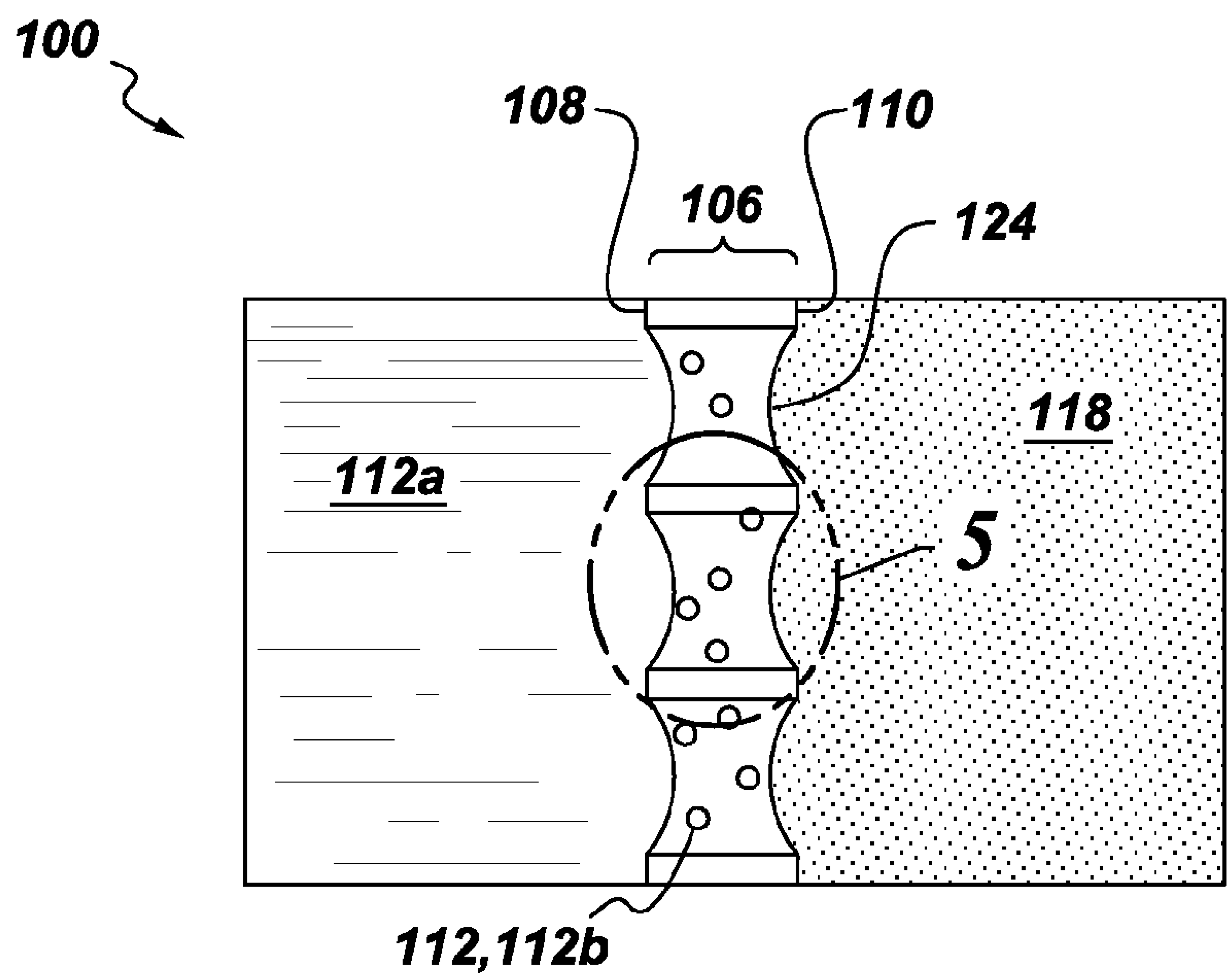

100
108
110
106
124
118
112a
5
112,112b

Fig. 4

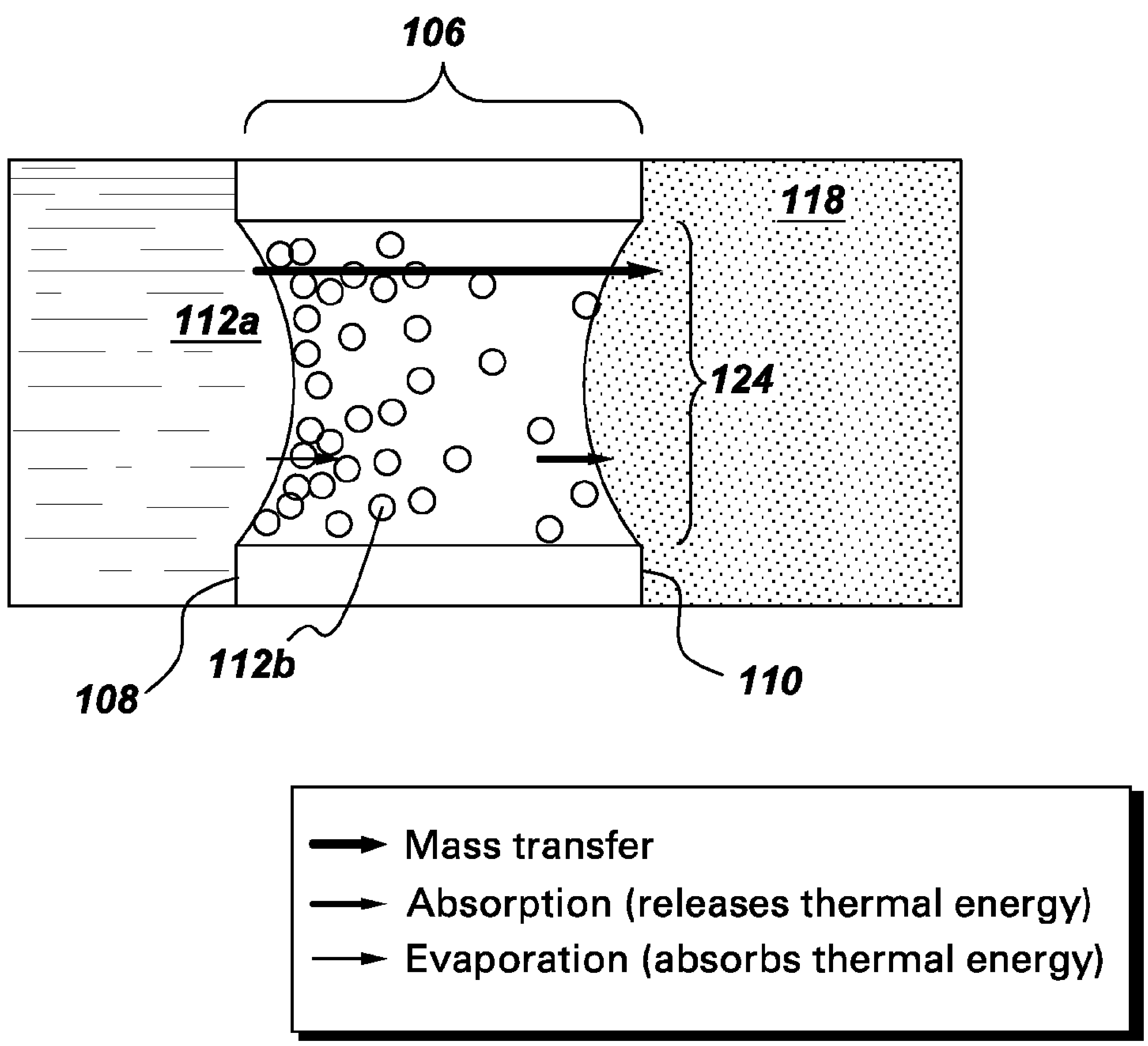

106
118
112a
124
108
112b
110
Mass transfer
Absorption (releases thermal energy)
Evaporation (absorbs thermal energy)

Fig. 5

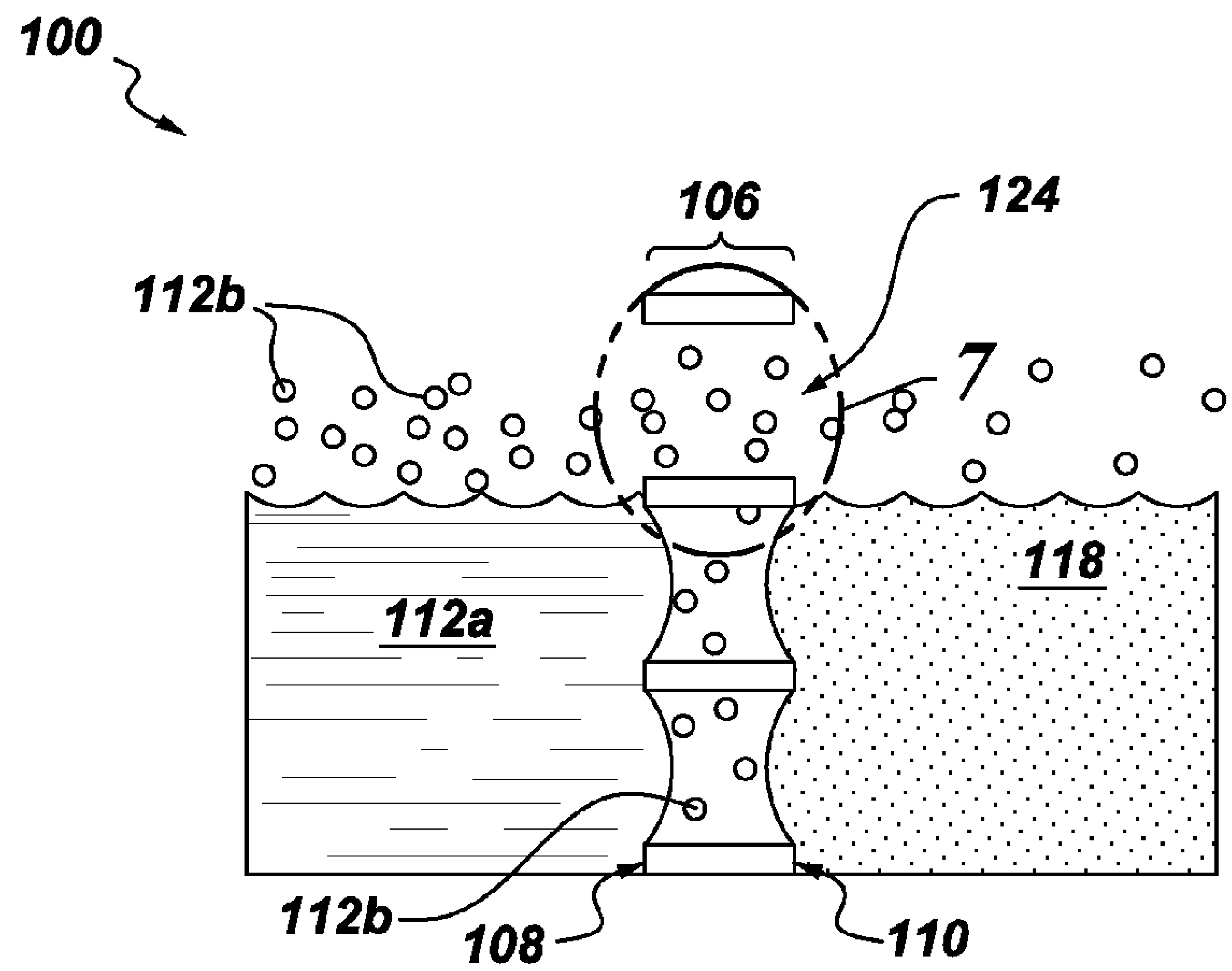

100
106
124
112b
7
118
112a
112b
108
110

Fig. 6

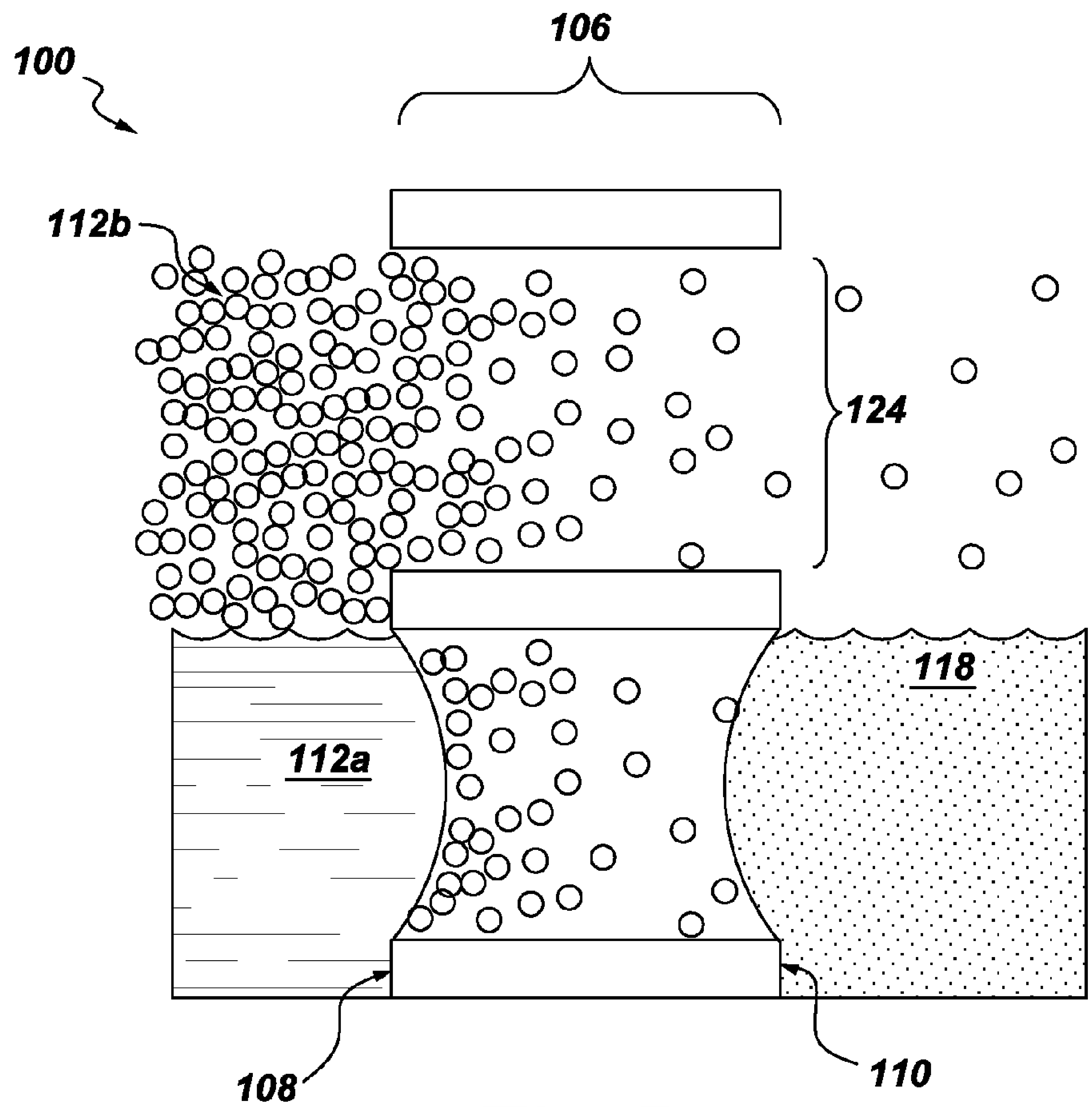

106
100
112b
124
118
112a
108
110

Fig. 7

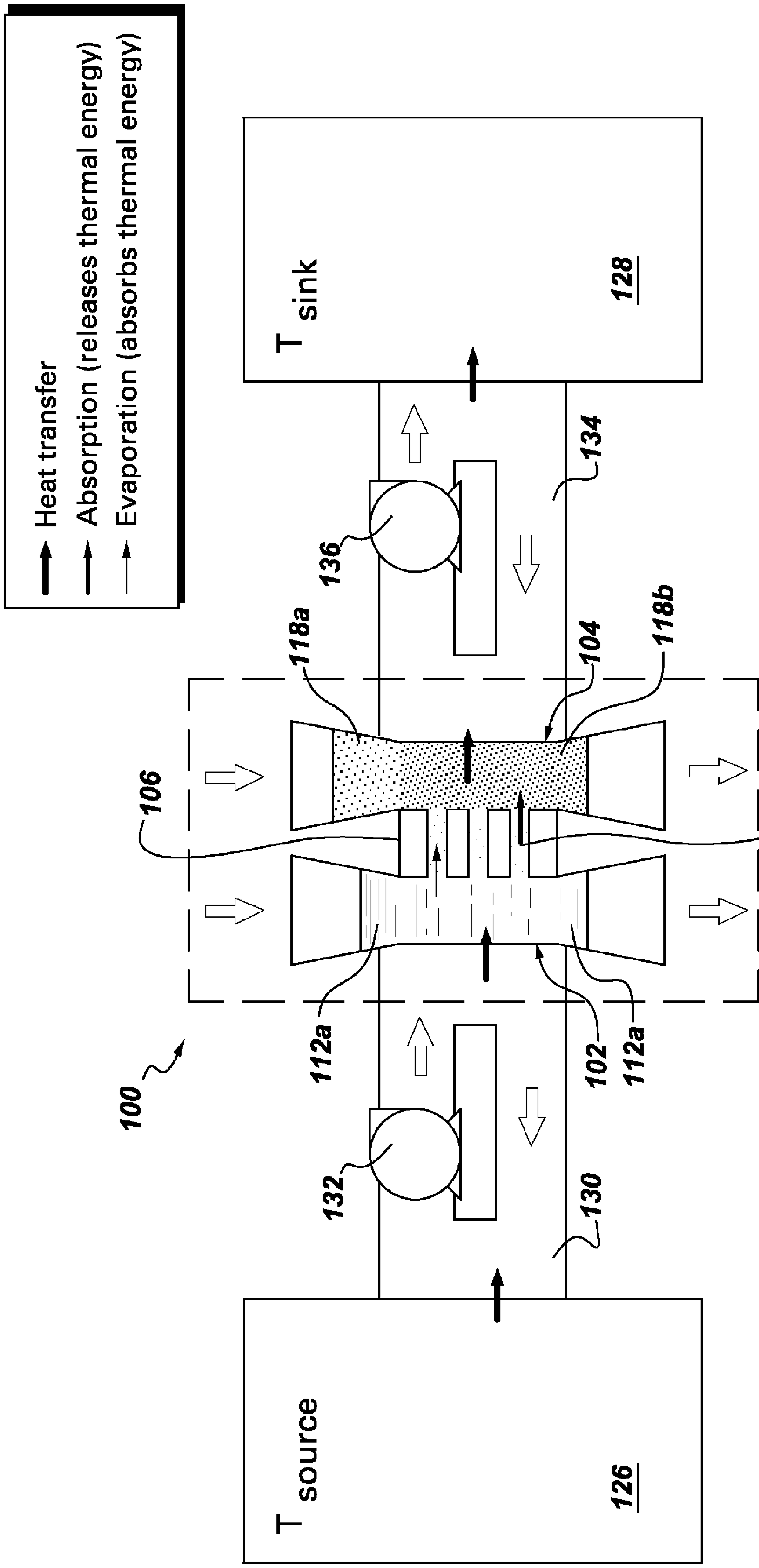
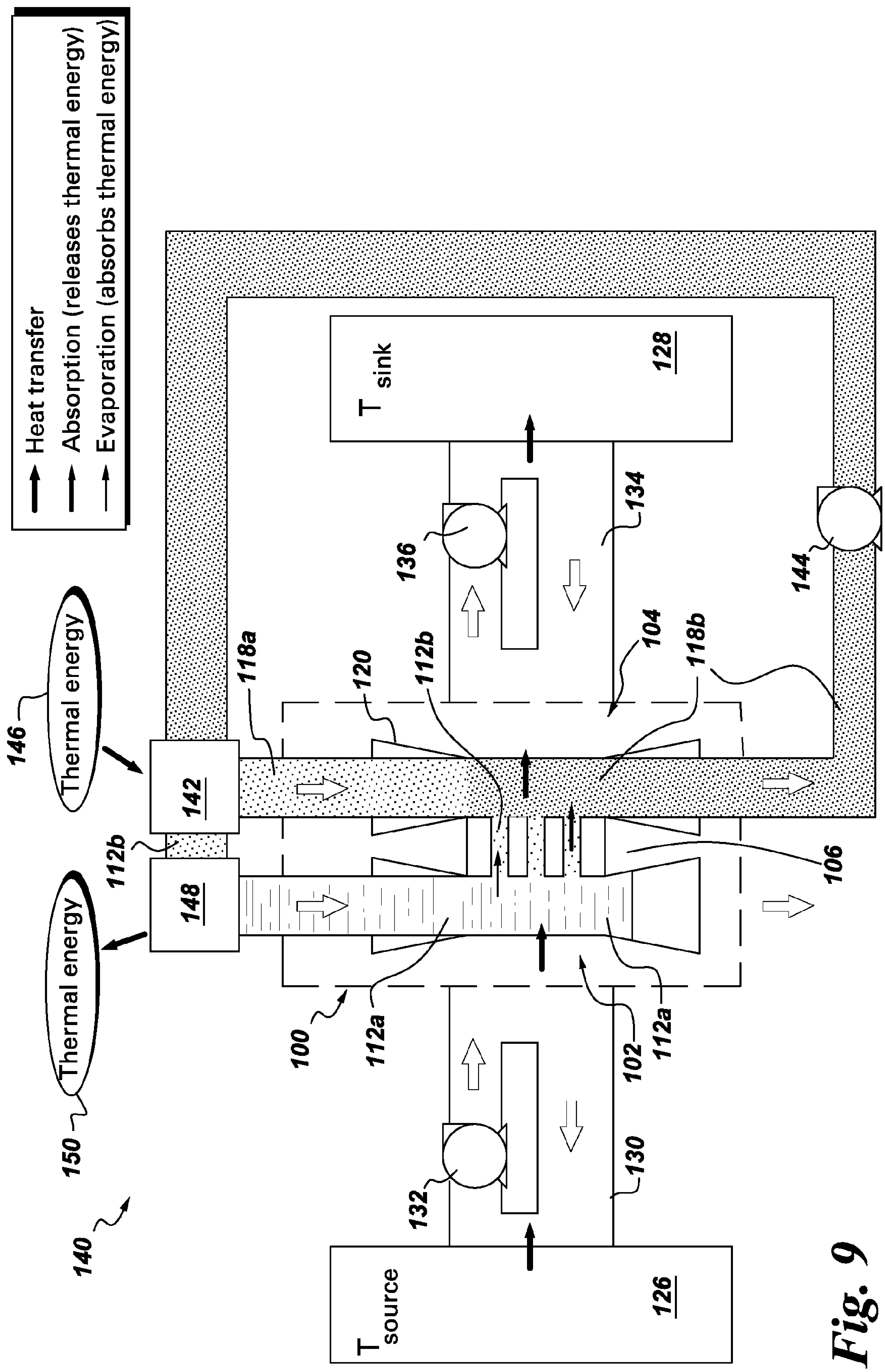
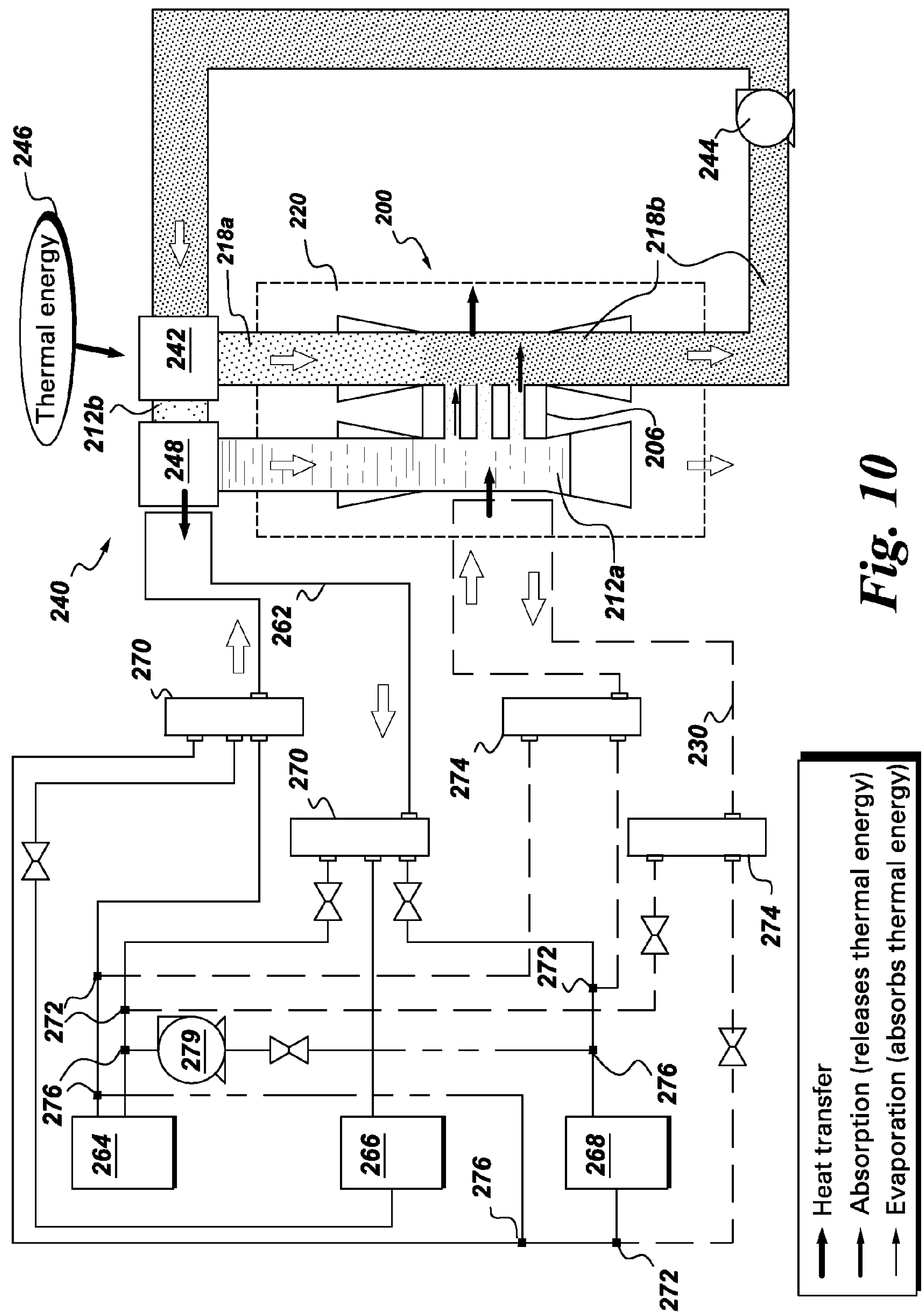

Heat transfer
Absorption (releases thermal energy)
Evaporation (absorbs thermal energy)
T sink
128
134
136
118a
104
118b
106
112b
100
112a
102
112a
132
130
T source
126

Fig. 8



Heat transfer
Absorption (releases thermal energy)
Evaporation (absorbs thermal energy)
Thermal energy
146
142
Thermal energy
150
148
112b
140
118a
120
112b
104
118b
106
100
112a
102
112a
134
136
144
128
T_{sink}
T_{source}
126
132
130

Fig. 9



246
Thermal energy
242
248
212b
218a
220
200
218b
244
206
212a
240
262
270
270
274
274
230
272
272
272
272
276
276
276
279
264
266
268
Heat transfer
Absorption (releases thermal energy)
Evaporation (absorbs thermal energy)

Fig. 10

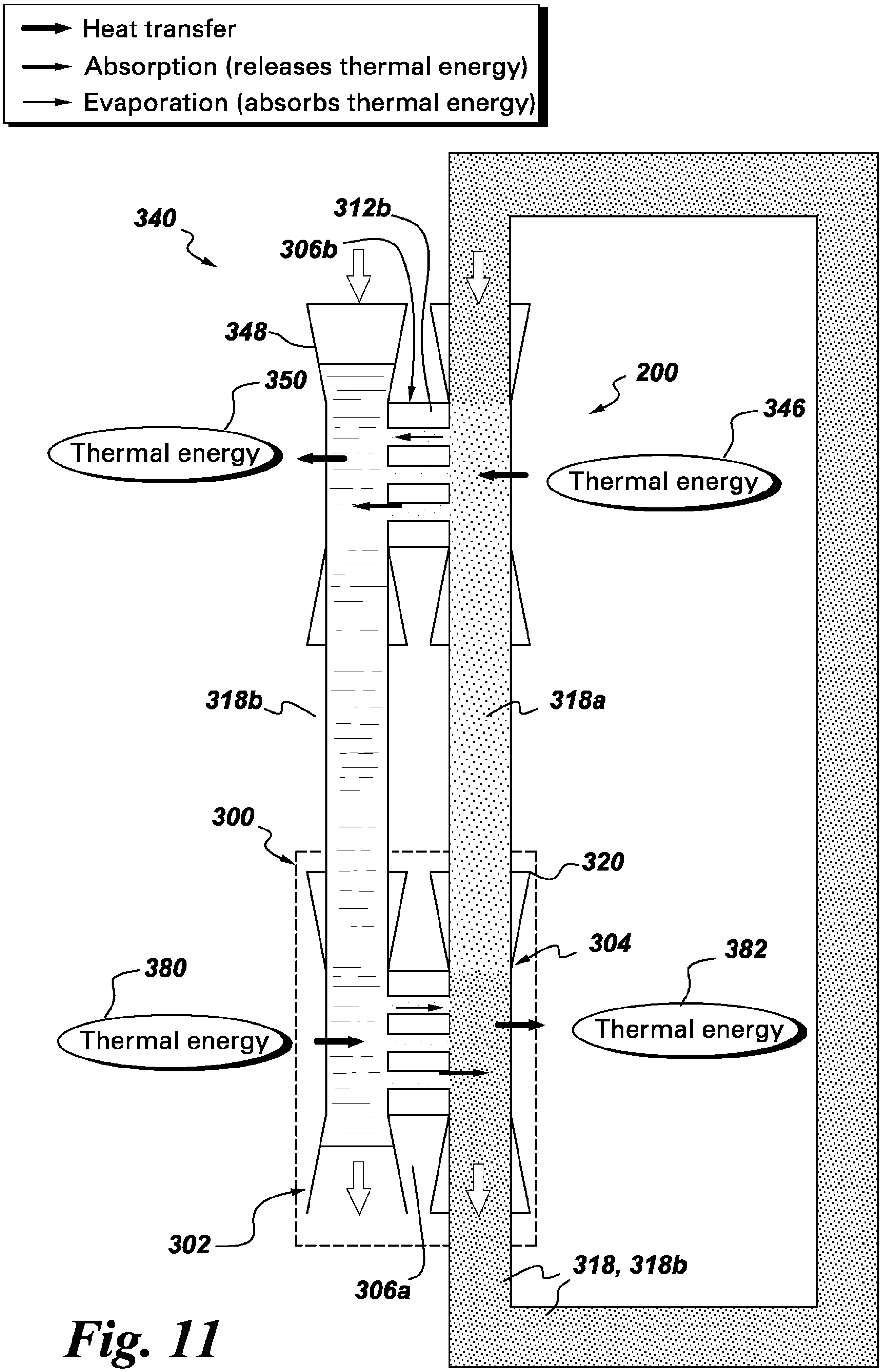

Heat transfer
Absorption (releases thermal energy)
Evaporation (absorbs thermal energy)
340
312b
306b
348
350
Thermal energy
200
346
Thermal energy
318b
318a
300
320
304
382
380
Thermal energy
Thermal energy
302
306a
318, 318b

Fig. 11

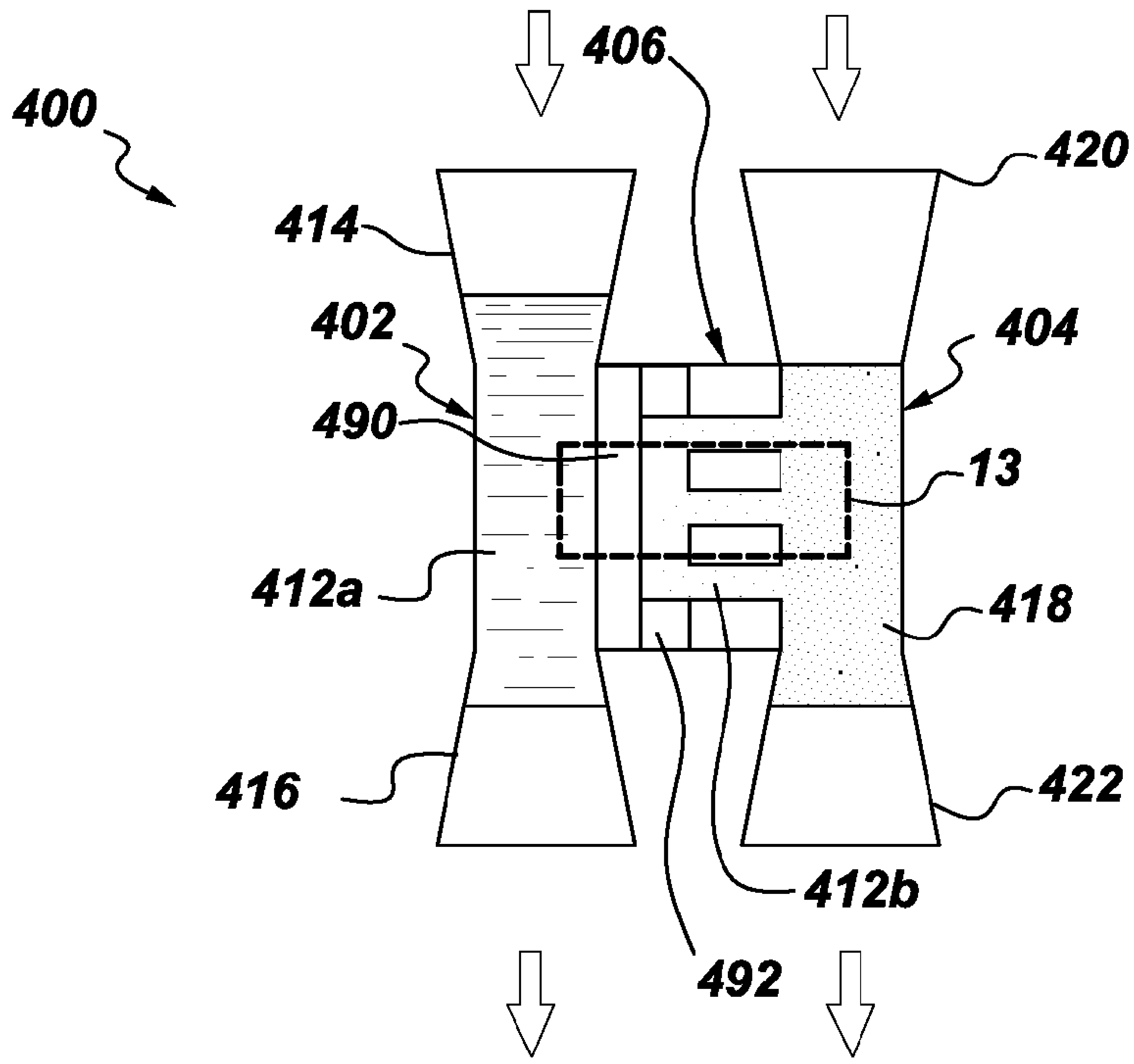

400
414
402
490
412a
416
406
420
404
13
418
422
412b
492

Fig. 12

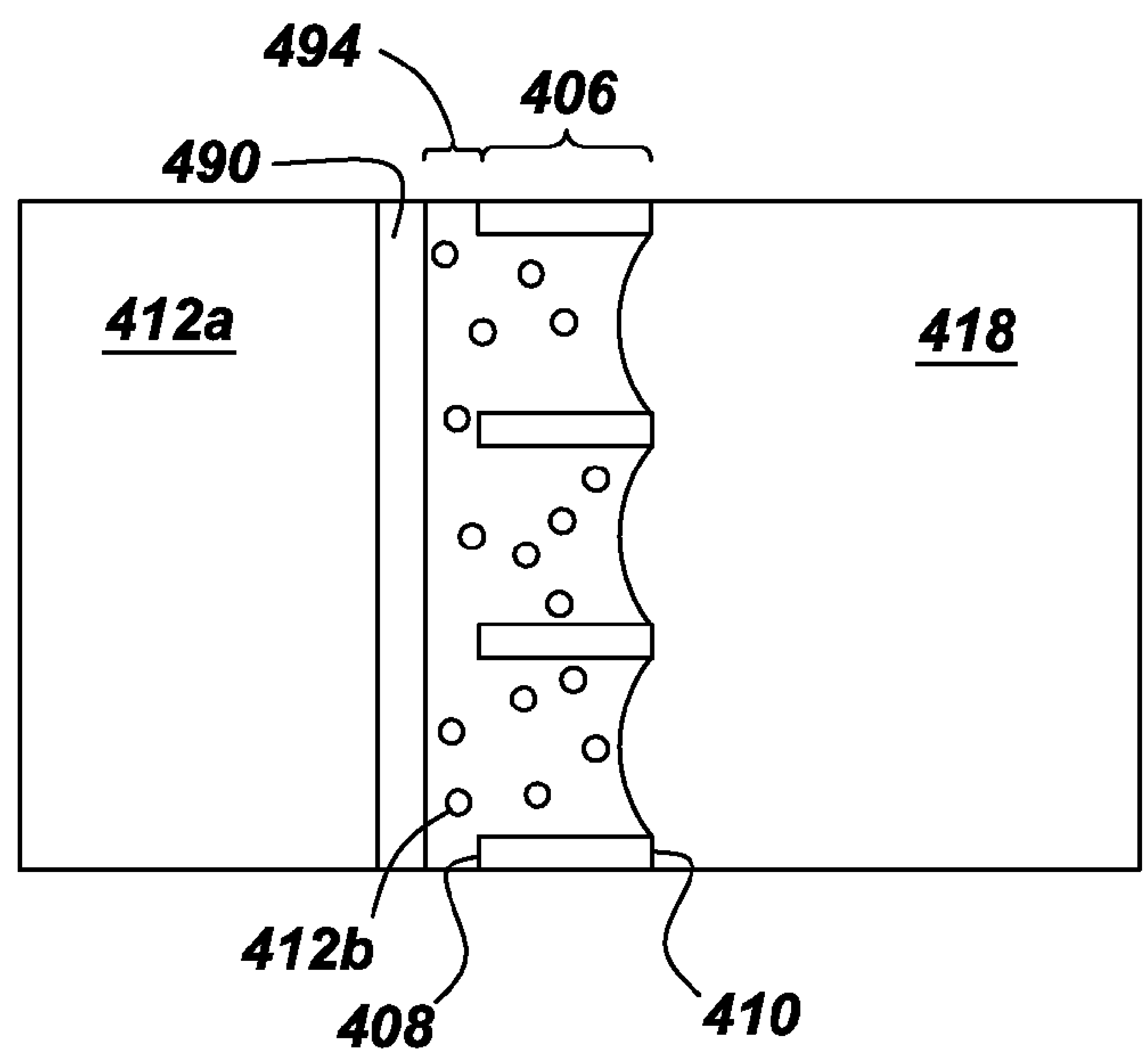

494
406
490
412a
418
412b
408
410

Fig. 13

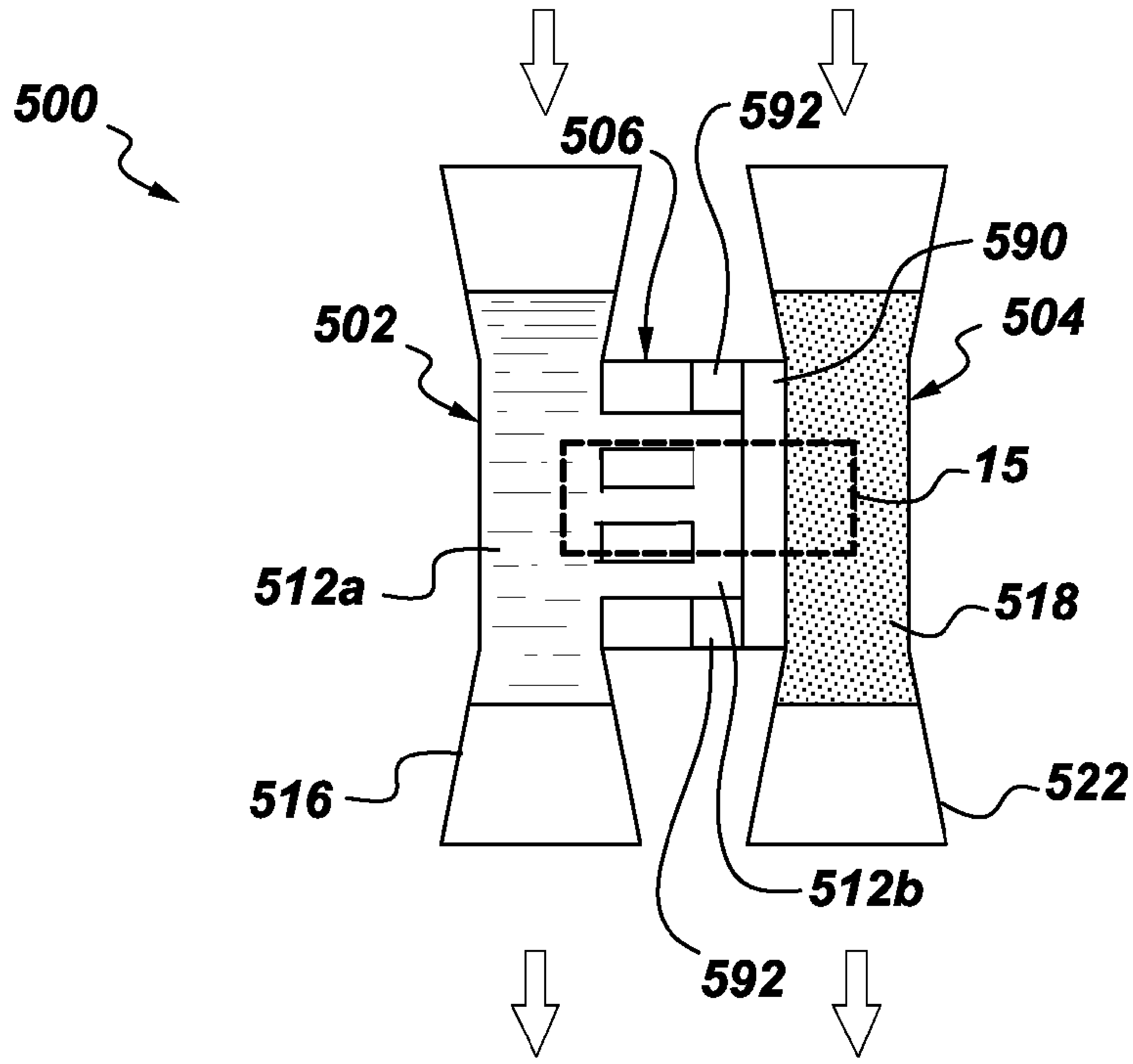

500
506
592
590
502
504
15
512a
518
516
522
512b
592

Fig. 14

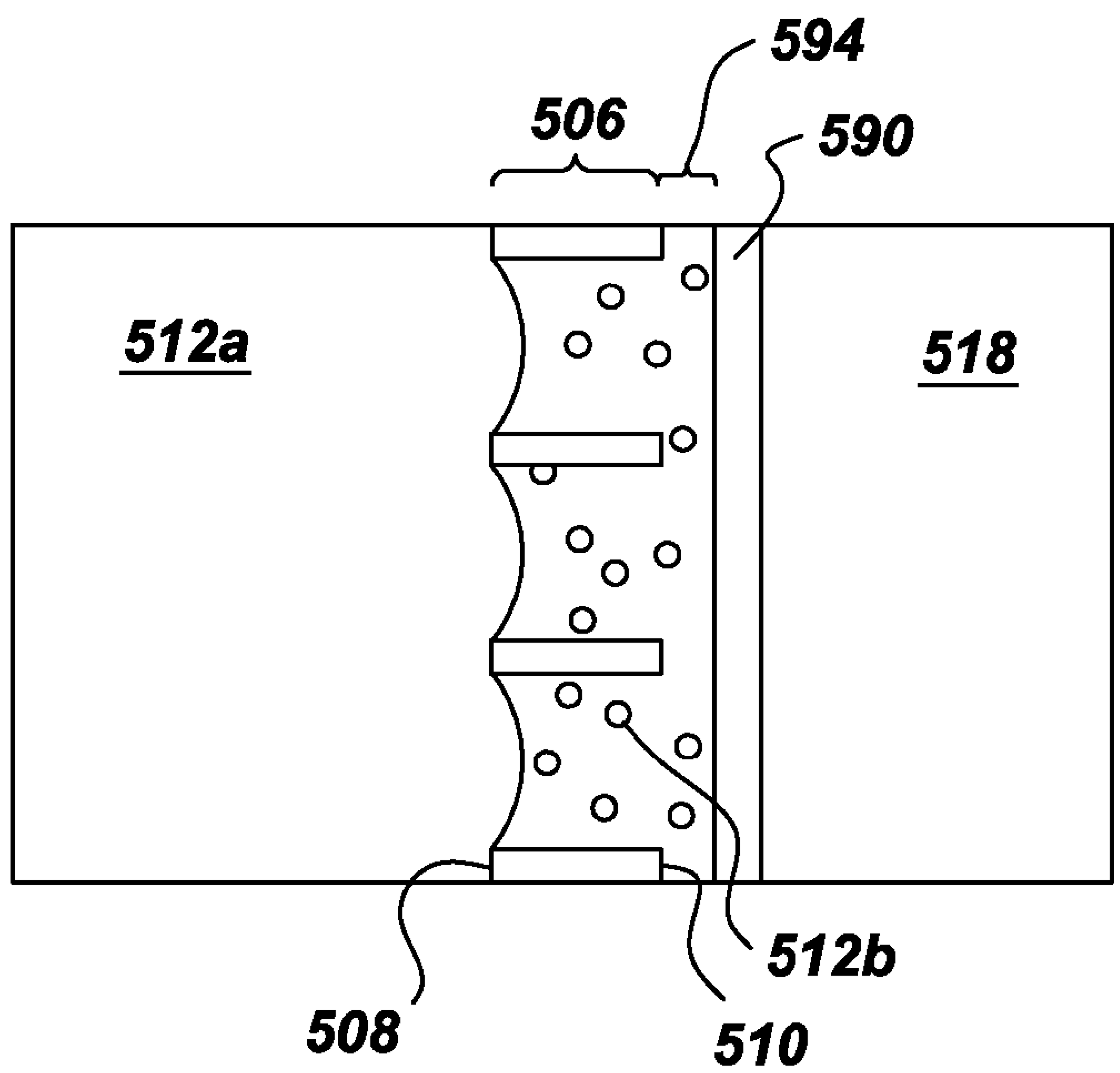

594
506
590
512a
518
508
510
512b

Fig. 15

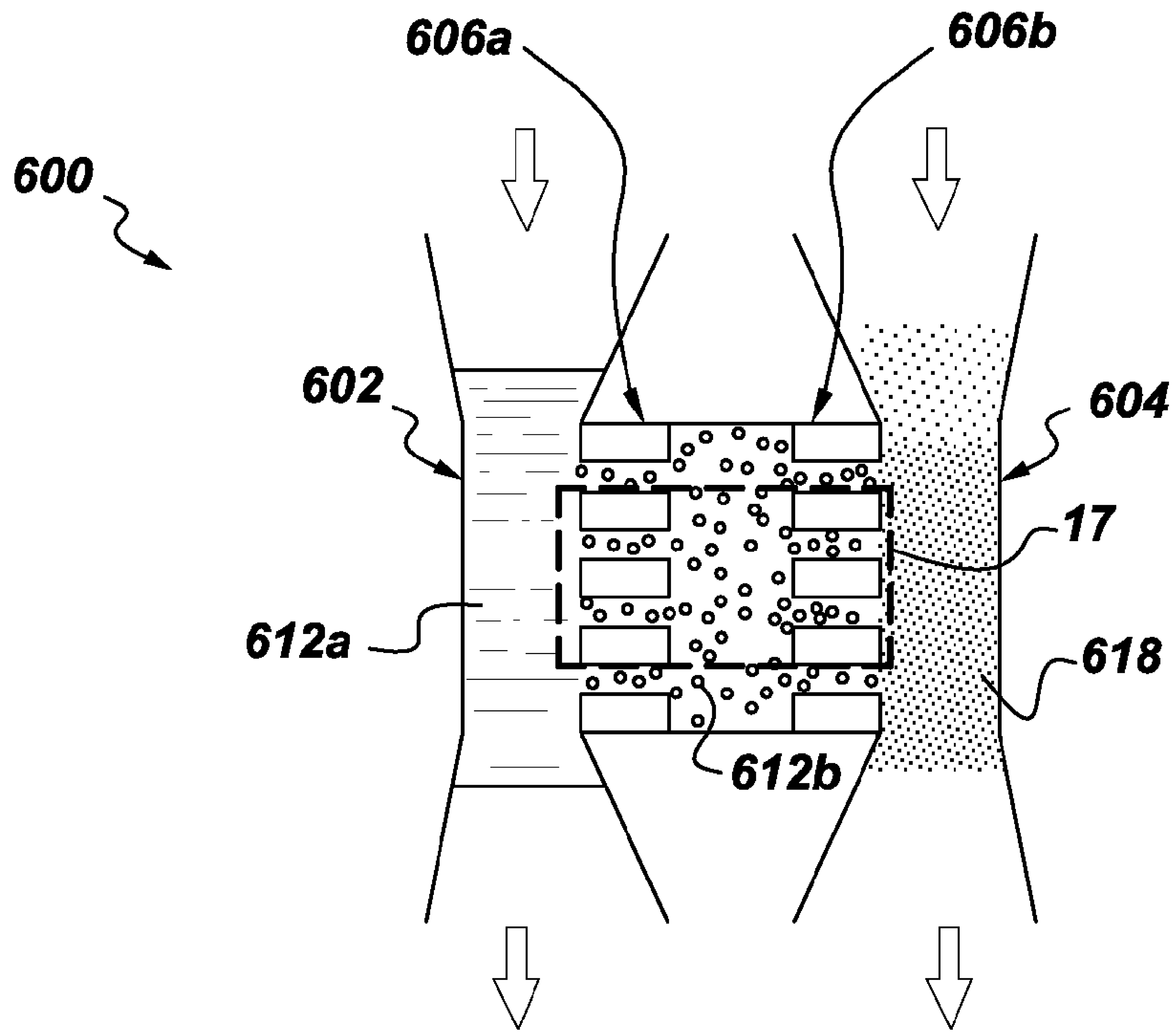

606a
606b
600
602
604
17
612a
618
612b

Fig. 16

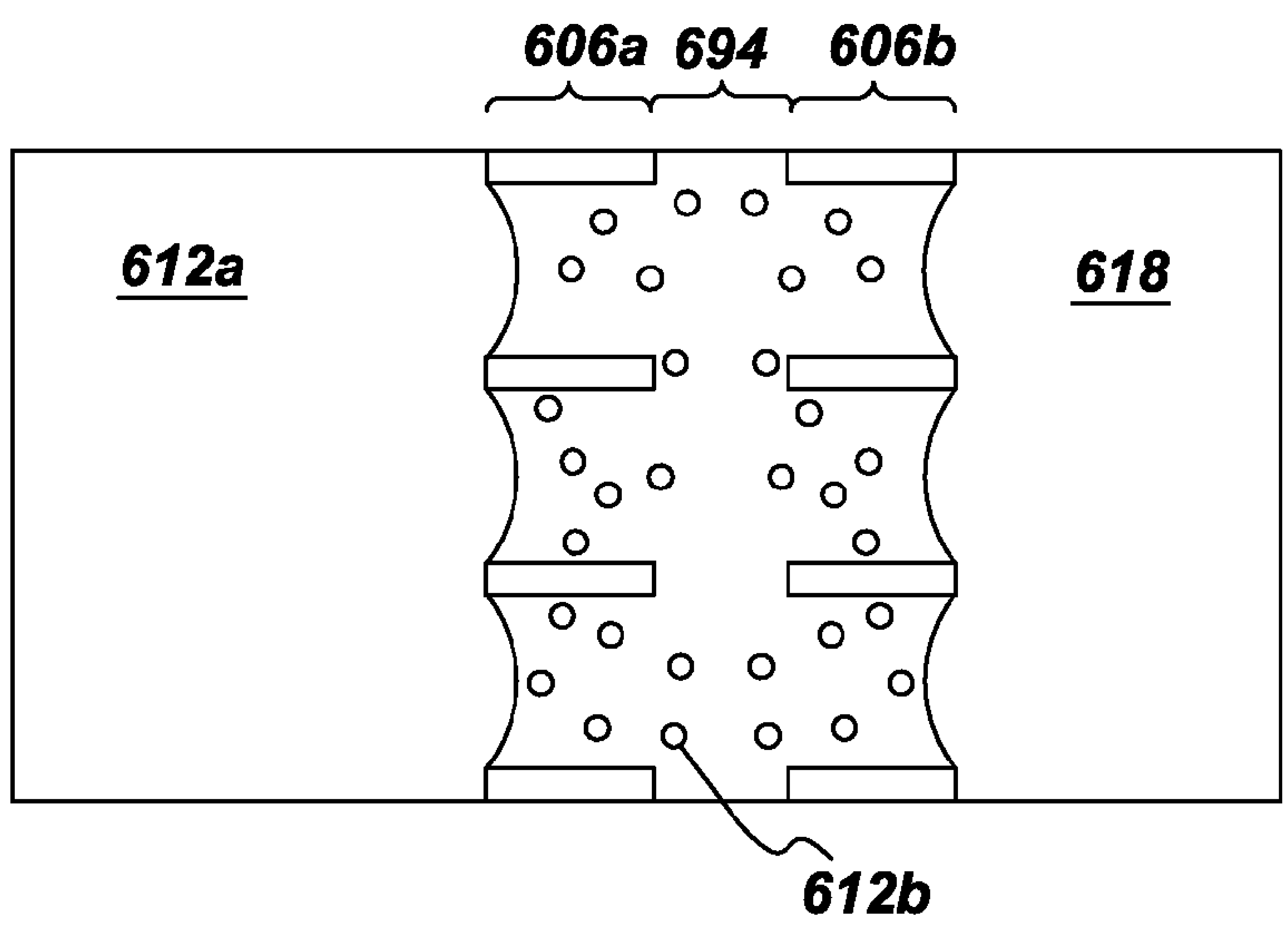

606a
694
606b
612a
618
612b

Fig. 17

ABSORPTION CHILLER AND SYSTEM INCORPORATING THE SAME

BACKGROUND

[0001] Currently, there are approximately one million ground source geothermal (GSG) systems installed in the U.S., which GSG systems are utilized in a range of government, commercial, and residential contexts. Further, approximately 50,000 residential GSG systems are added each year. The installation cost of GSG systems currently varies with geographic region, but can be as much as $10,000 per ton capacity or more. And, while energy savings are expected with the use of GSG systems as compared to more conventional heating and cooling systems, the payback period for typical GSG systems is estimated to range from 5 to 10 years. It may therefore be desirable to develop a less complex and/or more efficient GSG system, such that the cost of installation and/or the payback period can be reduced.

BRIEF DESCRIPTION

[0002] In a first aspect, a device, such as an absorption chiller sub-system, is provided. The absorption chiller sub-system can include an evaporator and an absorber. The evaporator can be configured to receive a liquid first working fluid and to produce first working fluid vapor. The absorber can be configured to receive and combine first working fluid vapor and a second working fluid, for example, so as to release thermal energy.

[0003] A divider having opposing first and second sides in respective fluid communication with the evaporator and the absorber can also be included. For example, the evaporator and the absorber can be respectively coupled to the first side and second sides of the divider. The divider can be configured to allow first working fluid vapor to pass therethrough between the first and second sides and to inhibit movement of liquid first working fluid therethrough between the first and second sides. For example, the divider may define holes therethrough having diameters, say, less than or equal to about 100 nm. In some embodiments, the divider can include a membrane.

[0004] The absorber can be configured to combine at least some first working fluid vapor passing through the divider and a second working fluid so as to cause at least some first working fluid vapor passing through the divider to become liquid. In some cases, the absorber can be configured to receive the second working fluid such that an equilibrium second partial pressure of first working fluid vapor at the second side of the divider is less than a first partial pressure of first working fluid vapor at the first side. For example, the evaporator can be configured to receive liquid NH_3 as the liquid first working fluid, and the absorber is configured to receive water or a mixture of water and NH_3 as the second working fluid.

[0005] In some embodiments, the evaporator can be configured such that a total pressure therein is at least twice a partial pressure of first working fluid vapor at the first side of the divider. The absorber can be configured such that a total pressure therein is at least twice a partial pressure of first working fluid vapor at the second side of the divider. Each of the evaporator and the absorber may be configured such that a respective total pressure therein is greater than or equal to about atmospheric pressure.

[0006] The evaporator can be configured to receive liquid water and to produce water vapor, and the absorber can be configured to combine water vapor passing through the divider and a relatively concentrated solution containing lithium bromide so to produce a relatively diluted solution containing lithium bromide. The divider can be formed at least partially of substantially hydrophobic material (e.g., polytetrafluoroethylene, polypropylene, or polyvinylidene fluoride) such that holes defined by the divider are defined by the substantially hydrophobic material.

[0007] A generator may be included and configured to receive the relatively diluted solution containing lithium bromide from the absorber and to produce separate outputs of water vapor and the relatively concentrated solution containing lithium bromide. A condenser can also be included and configured to receive water vapor from the generator and to provide liquid water to the evaporator. The generator and condenser can be in fluid communication with opposing sides of a second divider that is configured to allow water vapor to pass therethrough and to inhibit movement of liquid water therethrough, such that water vapor from the generator can pass through to the condenser while liquid water in the generator is substantially prevented from reaching the condenser.

[0008] A geothermal well, a heat exchanger, and a water heater can also be included. Each of the condenser, absorber, and evaporator can be configured to selectively thermally communicate with the geothermal well and the heat exchanger. In some embodiments, thermal energy may be transferred from the absorber and the condenser into a heated fluid stream, and thermal energy may be transferred from a cooled fluid stream into the liquid first working fluid, with the heated fluid stream being in selective fluid communication with each of the water heater, the heat exchanger, and the geothermal well, and the cooled fluid stream being in selective fluid communication with each of the heat exchanger and the geothermal well. The geothermal well and the heat exchanger may also be configured to selectively exchange thermal energy directly therebetween and to avoid exchanging thermal energy with each of the generator, condenser, evaporator, and absorber.

[0009] In another aspect, a method is provided, which includes providing a device including an evaporator, an absorber, and a divider having opposing first and second sides in fluid communication with the evaporator and the absorber, respectively. The divider can be configured to allow first working fluid vapor to pass therethrough between the first and second sides and to inhibit movement of liquid first working fluid therethrough between the first and second sides. Liquid first working fluid (e.g., liquid water) can be provided to the evaporator so as to produce first working fluid vapor (e.g., water vapor) that contacts the first side of the divider. First working fluid vapor passing through the divider from the first side to the second side and a second working fluid (e.g., a relatively concentrated solution containing lithium bromide) can be received at the absorber, and at least some first working fluid vapor passing through the divider can be combined in the absorber with the second working fluid, for example, so as to cause at least some of the first working fluid vapor passing through the divider to become liquid and/or release thermal energy (say, producing a relatively diluted solution containing lithium bromide).

[0010] In some embodiments, thermal energy can be supplied to the relatively diluted solution containing lithium bromide so as to cause water to evaporate out and thereby produce the relatively concentrated solution containing lithium bromide. Further, thermal energy can be removed from the water vapor produced from the relatively diluted solution containing lithium bromide so as to produce liquid water to be provided to the evaporator.

[0011] In some embodiments, the thermal energy removed from the water vapor produced from the relatively diluted solution containing lithium bromide can be selectively transferred to a heated fluid stream along with thermal energy from the absorber. Thermal energy can also be selectively transferred from a cooled fluid stream to the liquid water circulated to the evaporator. Further, thermal energy can be selectively transferred between the heated fluid stream and at least one of a heat exchanger or a geothermal well, and also between the cooled fluid stream and at least one of the heat exchanger and the geothermal well. In some cases, a target temperature can be selected, and, when the target temperature is higher than a ground temperature of the geothermal well, a geothermal fluid stream can be circulated between the geothermal well and the heat exchanger without receiving the thermal energy removed from the water vapor produced from the relatively diluted solution containing lithium bromide and without exchanging thermal energy with the absorber.

DRAWINGS

[0012] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0013] FIG. **1** is a schematic view of an absorption chiller sub-system configured in accordance with an example embodiment;

[0014] FIG. **2** is a cross sectional view of the absorption chiller sub-system of FIG. **1**;

[0015] FIG. **3** is a perspective exploded view of the absorption chiller sub-system of FIG. **1**;

[0016] FIG. **4** is a magnified view of the area labeled **4** in FIG. **2**;

[0017] FIG. **5** is a magnified view of the area labeled **5** in FIG. **4**;

[0018] FIG. **6** is a schematic side view of another example embodiment of the absorption chiller sub-system of FIG. **1**;

[0019] FIG. **7** is a magnified view of the area labeled **7** in FIG. **6**;

[0020] FIG. **8** is a schematic view of the absorption chiller sub-system of FIG. **1** in thermal communication with a source and a sink of thermal energy;

[0021] FIG. **9** is a schematic view of an absorption refrigeration system configured in accordance with an example embodiment;

[0022] FIG. **10** is a schematic view of a heating and cooling system configured in accordance with an example embodiment;

[0023] FIG. **11** is a schematic view of an absorption refrigeration system configured in accordance with another example embodiment;

[0024] FIG. **12** is a schematic cross-sectional view of an absorption chiller system configured in accordance with another example embodiment;

[0025] FIG. **13** is a magnified view of the area labeled **13** in FIG. **12**;

[0026] FIG. **14** is a schematic cross-sectional view of an absorption chiller system configured in accordance with yet another example embodiment;

[0027] FIG. **15** is a magnified view of the area labeled **15** in FIG. **14**;

[0028] FIG. **16** is a schematic cross-sectional view of an absorption chiller system configured in accordance with still another example embodiment; and

[0029] FIG. **17** is a magnified view of the area labeled **17** in FIG. **16**.

DETAILED DESCRIPTION

[0030] Example embodiments of the present invention are described below in detail with reference to the accompanying drawings, where the same reference numerals denote the same parts throughout the drawings. Some of these embodiments may address the above and other needs.

[0031] Referring to FIGS. **1-4**, therein is shown a device, such as an absorption chiller sub-system **100**, configured in accordance with an example embodiment. The absorption chiller sub-system **100** can include an evaporator **102** and an absorber **104**. A divider, such as a membrane **106**, can be disposed between the evaporator **102** and the absorber **104**. The membrane **106** can have opposing first and second sides **108**, **110**, with the evaporator **102** being in fluid communication with the first side and the absorber **104** being in fluid communication with the second side. For example, in one embodiment, the evaporator **102** can be coupled to the first side **108** and the absorber **104** can be coupled to the second side **110**. In other embodiments, the evaporator **102** and absorber **104** may not be directly coupled to the first and second sides **108**, **110**, respectively, but may still be configured to allow fluid to pass thereto, for example, through an intermediate conduit.

[0032] The evaporator **102** can be configured to receive a liquid first working fluid **112***a* and to produce first working fluid vapor **112***b*. For example, in one embodiment, the first working fluid **112** may be water, and the evaporator **102** may receive liquid water (for example, through a liquid inlet port **114**) and may produce water vapor. Other candidate first working fluids are discussed below. Liquid first working fluid **112***a* may circulate through the evaporator **102**, such that unevaporated portions are outputted from the evaporator, say, at a liquid outlet port **116**.

[0033] The absorber **104** can be configured to receive first working fluid vapor **112***b* and to combine at least some of that first working fluid vapor with a second working fluid **118**. The second working fluid **118** may circulate through the absorber **104**, such that the second working fluid is received, say, at an inlet port **120**, travels through the absorber, and exits at an outlet port **122**. Given that the second working fluid **118** enters the absorber **104** and then is combined therein with first working fluid vapor **112***b*, the second working fluid **118***a* entering the absorber has a relatively lesser concentration therein of first working fluid than does the second working fluid **118***b* inside and exiting the absorber. The second working fluid **118***a* entering the absorber **104** at the inlet port **120** is therefore referred to herein as "relatively concentrated second working fluid," and the second working fluid **118***b* inside the absorber and exiting at the outlet port **122** is referred to herein as "relatively diluted second working fluid."

[0034] The first and second working fluids **112**, **118** may be chosen such that the act of combining first working fluid vapor **112***b* and the second working fluid causes a release of thermal energy. For example, the absorber **104** can be configured to combine first working fluid vapor **112***b* and the second working fluid **118** so as to cause at least some first working fluid vapor **112***b* to become liquid, thereby causing a release of the latent heat of evaporation associated with the vapor. In some embodiments, the second working fluid **118** may include at least one component (an "absorbent") that tends to form a liquid solution with the first working fluid vapor **112***b*, such that when the first working fluid vapor comes into contact with the second working fluid, the first working fluid vapor tends to transform into a liquid component of the liquid solution with the absorbent, thereby causing a release of the heat of absorption. In other embodiments, a chemical reaction may occur between the first working fluid vapor **112***b* and a component of the second working fluid **118**, which reaction may be exothermic and/or may induce a transformation of the first working fluid vapor **112***b* to a liquid, thereby releasing heat of reaction and/or latent heat.

[0035] Referring to FIGS. **1**-**7**, as mentioned, the membrane **106** can be disposed between, and in fluid communication with, the evaporator **102** and the absorber **104**. The first side **108** of the membrane **106** may therefore be contacted by liquid first working fluid **112***a* and first working fluid vapor **112***b*, and the second side **110** may be contacted by the second working fluid **118** and first working fluid vapor that may be disposed in the absorber **104**. In some embodiments, virtually all of the volume within the evaporator **102** may be occupied by liquid first working fluid **112***a* and/or all of the volume within the absorber **104** may be occupied by the second working fluid **118** (as depicted in FIGS. **4** and **5**). In such cases, first working fluid vapor **112***b* in the evaporator **102** would be found mainly at the first side **108** of the membrane **106**, and first working fluid vapor **112***b* in the absorber **104** would be found mainly at the second side **110**. In other embodiments (depicted by FIGS. **6** and **7**), the volumes of the evaporator **102** and absorber **104** may be only partially occupied by liquid first working fluid **112***a* and (liquid) second working fluid **118**, such that first working fluid vapor **112***b* may be found not only at the first and second sides **108**, **110**, but throughout the volumes of the evaporator and absorber that are not otherwise occupied by liquids.

[0036] The membrane **106** may be configured to allow first working fluid vapor **112***b* to pass therethrough between the first and second sides **108**, **110** and to inhibit movement of liquid first working fluid **112***a*, and the second working fluid **118**, therethrough between said first and second sides. For example, the membrane **106** may define holes **124** therethrough. The holes **124** may be sized in accordance with the properties of the first and second working fluids **112**, **118** and those of the material making up the membrane **106** in order to assure that the interfacial energies of liquid first and second working fluids and the membrane are such that the liquid first and second working fluids are energetically prevented from assuming a configuration necessary to pass through the holes in the membrane. Further details regarding the sizing of the holes **124**, as well as the selection of the working fluids **112**, **118** and material for the membrane **106**, are provided below. A general discussion of the use of porous membranes in fluid separation applications is provided in Marcel Mulder, *Basic Principles of Membrane Technology* (Kluwer Academic Publishers, 1996), which is incorporated herein by reference in its entirety, and also in K. W. Lawson and D. R. Lloyd, "Review Membrane Distillation," Journal of Membrane Science, 124 (1997), pp. 1-25, which is also incorporated herein by reference in its entirety.

[0037] The second working fluid **118** can be chosen such that, when received at the absorber **104** (under appropriate conditions), an equilibrium partial pressure P**2** of first working fluid vapor **112***b* at the second side **110** (and possibly throughout the absorber) is less than a partial pressure P**1** of first working fluid vapor at the first side **108** (and possibly throughout the evaporator **102**). For example, the first and second working fluids **112**, **118** can be chosen such that the second working fluid includes as a component thereof a liquid that has a strong affinity for the first working fluid. In such a case, the equilibrium partial pressure P**2** of the first working fluid vapor **112***b* in the vicinity of the second working fluid **118** will tend to be low relative, say, to the partial pressure P**1** expected in the vicinity of liquid first working fluid **112***a*. Examples of pairs of first and second working fluids **112**, **118** that may be utilized in conjunction with embodiments of the above described absorption chiller sub-system **100** include, but are not limited to, water and lithium bromide; NH_3 and water (or a mixture of water and NH_3); water and $LiClO_3$; water and $CaCl_2$, water and $ZnCl_2$; water and HnBr; water and H_2SO_4; and SO_2 and organic solvents.

[0038] The difference in partial pressures P**1** and P**2** of first working fluid vapor **112***b* across the membrane **106** results in a driving force for diffusion of first working fluid vapor from the first side **108** to the second side **110**. Once first working fluid vapor **112***b* reaches the second side **110**, it can be combined in the absorber **104** with the second working fluid **118**, with this combination being made more likely by the proper choice of a second working fluid having an affinity for first working fluid. Mass (i.e., first working fluid **112**) will therefore be transferred from the evaporator **102** to the absorber **104**. In addition, as mass is transferred from the evaporator **102** to the absorber **104**, the balance in the evaporator between liquid first working fluid **112***a* and first working fluid vapor **112***b* will be disrupted, driving further evaporation of liquid first working fluid. It is noted that continued evaporation of liquid first working fluid **112***a* in the evaporator **102** does not necessarily require the input of energy, but instead may proceed simply due to the affinity of the second working fluid **118** for first working fluid.

[0039] As liquid first working fluid **112***a* evaporates in the evaporator **102** to form first working fluid vapor **112***b*, thermal energy is absorbed from the liquid first working fluid and used to overcome the latent heat of evaporation of the first working fluid **112**. As the first working fluid vapor **112***b* moves through the membrane **106** and is combined in the absorber **104** with the second working fluid **118** to form a liquid, thermal energy in the form of latent heat of evaporation and/or absorption can be released (as well as heat produced by any exothermic chemical reactions that may take place between the first and second working fluids). The overall result is a thermal energy transfer, associated with the mass transfer, from the liquid first working fluid **112***a* in the evaporator **102** to the second working fluid **118** in the absorber **104**. The membrane **106** can be configured such that the surface area presented to the first working fluid **112** at the first side **108** and to the second working fluid **118** at the second side **110** is sufficient to facilitate a desired level of thermal energy transfer.

[0040] With the evaporator **102** and the absorber **104** separated by the membrane **106** as discussed above, it may not be required that the total pressure within either of the evaporator or the absorber is approximately the same as the respective partial pressure therein of first working fluid vapor **112***b*, as may have been the case for previous absorption chiller sub-systems. Rather, the evaporator **102** may be configured such that the total pressure therein is at least twice the partial pressure P**1** of first working fluid vapor **112***b*. Further, the absorber **104** may be configured such that the total pressure therein is at least twice the partial pressure P**2** of first working fluid vapor **112***b*. As such, embodiments of the absorption chiller sub-system **100** may have a total size and weight that is significantly reduced with respect to previous absorption chiller sub-systems.

[0041] For the first working fluid vapor **112***b* to be driven from one side of the membrane **106** to the other, particular temperatures and pressures are needed. As mentioned above, the evaporation of liquid first working fluid **112***a* in the evaporator **102**, the diffusion of first working fluid vapor **112***b* from the first side **108** of the membrane **106** to the second side **110**, and the absorption of first working fluid vapor (or other energy-releasing event) in the absorber **104** can proceed spontaneously, acting to transfer thermal energy from the evaporator to the absorber. However, as thermal energy is transferred, the temperature of the liquid first working fluid **112***a* (in the absence of any other energy transfers) will drop, thereby reducing (and eventually eliminating) the tendency for further evaporation. At the same time, the temperature of the second working fluid **118** (again, in the absence of any other energy transfers) will rise, thereby decreasing (and eventually eliminating) the tendency of first working fluid vapor **112***b* therein to be absorbed. It is noted that, in some embodiments, the membrane **106** may include a thermally insulating material, thereby preventing the transfer of heat therethrough from the absorber **104** to the evaporator **102**.

[0042] Referring to FIG. **8**, in order to allow the transfer of thermal energy from the evaporator **102** to the absorber **104** to continue, the evaporator can be brought into thermal contact with a thermal energy source **126**, while the absorber can be brought into thermal contact with a thermal energy sink **128**. For example, a cooled fluid stream **130** (e.g., air or water) can be circulated between the thermal energy source **126** and the evaporator **102** by a pump **132**, and a heated fluid stream **134** (e.g., air or water) can be circulated between the absorber **104** and the thermal energy sink **128** by a pump **136**. The absorption chiller sub-system **100** can therefore be used to extract thermal energy from the thermal energy source **126** and to deposit thermal energy at a thermal energy sink **128**. In some embodiments, the temperature T_{source} at the thermal energy source **126** may be lower than the temperature T_{sink} at the thermal energy sink **128**, in which case the absorption chiller sub-system **100** operates as a heat pump. Any barriers separating the first working fluid **112***a* in the evaporator **102** and the cooled fluid stream **130** (e.g., an outer wall defining the evaporator), and/or any barriers separating the second working fluid **118***a* in the absorber **104** and the heated fluid stream **134** (e.g., an outer wall defining the absorber), can be configured to have a relatively low thermal resistance, thereby facilitating thermal energy transfer thereacross.

[0043] Referring to FIG. **9**, therein is shown an absorption refrigeration system **140** (also referred to as an absorption chiller system) that incorporates the absorption chiller sub-system **100**. A generator **142** may receive the relatively diluted second working fluid **118***b* that is outputted at the outlet port **122** of the absorber **104**. As mentioned above, the second working fluid **118***b* that is outputted from the absorber **104** has been combined therein with first working fluid vapor **112***b* passing through the membrane **106**. A pump **144** can be used to urge the relatively diluted second working fluid **118***b* towards the generator **142**. The generator **142** can be configured to receive the relatively diluted second working fluid **118***b* and to produce separate outputs of first working fluid vapor **112***b* and a relatively concentrated second working fluid **118***a*. For example, thermal energy **146** can be added at the generator **142** in order to raise the temperature of the relatively diluted second working fluid **118***b*, thereby driving some of the first working fluid dissolved therein out of the solution as first working fluid vapor **112***b*. The remaining second working fluid, now being relatively concentrated second working fluid **118***a*, can be directed back to the inlet port **120** of the absorber **104**.

[0044] The first working fluid vapor **112***b* outputted from the generator **142** can be directed to a condenser **148**. The condenser **148** can receive the first working fluid vapor **112***b* and to provide liquid first working fluid **112***a* to the evaporator **102**. For example, thermal energy **150** can be removed at the condenser **148**, say, through the use of a heat exchanger, in order to cause the first working fluid vapor **112***b* to condense.

[0045] Overall, the evaporator **102**, absorber **104**, generator **142**, and condenser **148** may operate so as to form a continuous cycle in which the second working fluid **118** is combined with first working fluid **112** at the absorber and separated from first working fluid at the generator, and first working fluid is converted from gas to liquid at the condenser and from liquid to gas at the evaporator. The system **140** acts to affect the transfer of thermal energy from a source **126** to a sink **128**. The only input of energy that may be required to sustain the operation of the system **140** is the thermal energy **146** that is directed to the generator **142** (and a small amount of energy required to circulate the second working fluid **118**, for example, through the operation of the pump **144**), which thermal energy may be supplied by, for example, the exhaust of an internal combustion engine, engine fluid such as water/glycol or oil, a burner, a solar collector, and/or the exhaust of a gas turbine.

[0046] Referring to FIG. **10**, therein is shown a heating and cooling system **260** configured in accordance with an example embodiment. The heating and cooling system **260** can include an absorption refrigeration system **240** that incorporates an absorption chiller sub-system **200** as described above with an evaporator **202** and an absorber **204** separated by a membrane **206**. The absorption chiller sub-system **200** can employ water as the first working fluid **212**, such that the evaporator **202** is configured to receive liquid water **212***a* and to produce water vapor **212***b*.

[0047] The membrane **206** can define holes **224** that extend between the evaporator **202** and the absorber **204**. The membrane **206**, or at least the portions through which the holes **224** are defined, may be formed of substantially hydrophobic material (e.g., polytetrafluoroethylene, polypropylene, and/or polyvinylidene fluoride). By forming the holes **224** with a maximum diameter of about 100 nm from a substantially hydrophobic material, the movement of liquid water **212***a* through the membrane **206** is substantially prevented, due to the surface energy effects discussed above, while water vapor **212***b* is permitted to pass through the holes between the evaporator **202** and absorber **204**. As mentioned earlier, in some embodiments, the membrane **206** may be formed of thermally insulating material, with examples being the hydrophobic materials listed above.

[0048] The absorption chiller sub-system **200** can also employ a solution of lithium bromide and water **218** as the second working fluid. The absorber **204** can be configured to combine water vapor **212***b* passing through the membrane **206** with the lithium bromide-water solution **218***a* entering at an inlet port **220**, thereby forming in the absorber a lithium bromide-water solution **218***b* that is relatively diluted with respect to lithium bromide content (the solution previously being relatively concentrated with respect to lithium bromide content prior to being combined with water vapor passing through the membrane **206**). Lithium bromide tends to have a strong affinity for water, such that the partial pressure of water vapor in the vicinity of lithium bromide tends to be relatively low and the diffusion of water vapor through the membrane **206** is facilitated.

[0049] As mentioned above, the use of a membrane **206** between the evaporator **202** and absorber **204** may alleviate the need to maintain the total pressure in either of the evaporator or the absorber at a level that is about equal to the partial pressure of water vapor in either one. Specifically, each of the evaporator **202** and the absorber **204** may be configured such that a respective total pressure therein is greater than or equal to about atmospheric pressure. This may reduce the size, cost, and/or complexity of the evaporator **202** and absorber **204**. In other embodiments either the evaporator **202** or the absorber **204** may be configured to operate either above or below atmospheric pressure.

[0050] The absorption refrigeration system **240** can also include a generator **242**, which can receive the relatively diluted lithium bromide-water solution **218***b* from the absorber **204** (e.g., the relatively diluted lithium bromide-water solution exiting the absorber at the outlet port **222**) and thermal energy **246** from an external source (not shown) to heat the diluted lithium bromide-water solution so as to produce separate outputs of water vapor **212***b* and the relatively concentrated containing lithium bromide-water solution **218***a* that is ultimately received at the inlet port **220**. The lithium bromide-water solution **218** can be circulated between the absorber **204** and the generator **242**, say, through the use of a pump **244**.

[0051] As the absorption refrigeration system **240** operates, thermal energy can be transferred from the evaporator **202** to the absorber **204**. The thermal energy deposited at the absorber **204** can then be rejected, say, to the ambient environment or some other energy sink. A cooled water stream **230** can be disposed in thermal contact with the evaporator **202**, and thermal energy can be transferred from the cooled water stream to the evaporator (e.g., to the water **212***a* therein), thereby affecting (in the absence of other thermal transfers) a temperature decrease in the cooled water stream.

[0052] The water vapor **212***b* outputted by the generator **242** can be directed to a condenser **248**, at which thermal energy can be removed from the water vapor in order to produce liquid water **212***a*. The liquid water **212***b* can then be directed to the evaporator **202** to repeat the cycle. A heated water stream **262** can be disposed in thermal contact with the condenser **248** such that the thermal energy extracted from the water vapor **212***b* is transferred (at least in part) to the heated water stream, thereby affecting (in the absence of other thermal transfers) a temperature increase in the heated water stream.

[0053] The heated water stream **262** can be circulated to each of a geothermal well **264**, a water heater **266**, and a heat exchanger **268** (the last of which may be used, for example, as a space heater/cooler) via manifolds **270**. Thermal energy in the heated water stream **262** (received, for example, at the condenser **248**) can then used to produce heat and hot water for residential or commercial use via the heat exchanger **268** and water heater **266**, respectively, and/or can be rejected at the geothermal well **264**. The heated water stream **262** can be connected to the geothermal well **264** and the heat exchanger **268** with valves **272** that allow the heated water stream to be selectively directed to or away from each of the geothermal well and the heat exchanger. In this way, heat can be provided via the heat exchanger only when desired (e.g., in the winter). In some embodiments, the heated water stream **262** may also be disposed in thermal communication with the absorber **204**, such that thermal energy rejected at the absorber may be used to heat the heated water stream.

[0054] The cooled water stream **230** can be circulated to each of the geothermal well **264** and a heat exchanger **268** (the last of which may be used, for example, as a space heater/cooler) via manifolds **274**. Thermal energy can then be transferred to the cooled water stream **230** at the heat exchanger **268** in order to provide ambient cooling or at the geothermal well **264** (with the thermal energy ultimately being rejected, for example, at the evaporator **202**). The cooled water stream **230** can be connected to the geothermal well **264** and the heat exchanger **268** with valves **272** that allow the cooled water stream to be selectively directed to or away from each of the geothermal well and the heat exchanger. In this way, cooling can be provided via the heat exchanger only when desired (e.g., in the summer).

[0055] Valves **276** may be included that function so as to selectively create a geothermal fluid circulation loop **278** that allows fluid (a "geothermal fluid stream") to circulate directly between the geothermal well **264** and the heat exchanger **268**, this loop being otherwise isolated from the absorption refrigeration system **240**. When the valves **276** are so positioned to isolate the fluid circulation loop **278** from the absorption refrigeration system **240**, the geothermal well **264** and heat exchanger **268** may exchange thermal energy directly therebetween (via the geothermal fluid stream in the geothermal fluid circulation loop) without exchanging thermal energy with any of the generator **242**, condenser **248**, evaporator **202**, and/or absorber **204**.

[0056] The valves **276** may allow the heating and cooling system **260** to be operated more efficiently, under certain conditions, by foregoing the use of the absorption refrigeration system **240**, the use of which requires some energy input at the generator **242**. For example, considering the use of the heat exchanger **268** as a residential air conditioning unit for cooling a home, during summer months, the temperature of the ground surrounding the geothermal well **264** may be lower than a desired air temperature (a "target" temperature) for the home. In that case, the valves **276** can be adjusted to cause the geothermal fluid stream to circulate (say, with the help of a pump **279**) directly between the geothermal well **264** and the heat exchanger **268**, without interacting with the absorption refrigeration system **240**. At these times, operation of the absorption refrigeration system **240** can be ceased entirely, avoiding the expenditure of energy otherwise required to operate that system. The heating and cooling system **260** can be configured to automatically switch between this "direct geothermal mode" of operation and the absorption refrigeration mode of operation in response to the ground temperature of the geothermal well **264** and a user-selected target temperature.

[0057] Referring to FIG. **11**, therein is shown an absorption refrigeration system **340** configured in accordance with another example embodiment. As with the embodiment depicted in FIG. **9** and described above, the absorption refrigeration system **340** includes an absorption chiller sub-system **300**. The absorption chiller sub-system **300** has an evaporator **302** and an absorber **304** separated by a first divider, such as a first membrane **306***a*, that is configured, for selected working fluids (including a first working fluid), to allow vapor to pass therethrough and to substantially prevent the passage of liquid. Liquid first working fluid **312***a* can be received by the evaporator **302** so as to produce first working fluid vapor **312***b* that passes through the first membrane **306***a* and to the absorber **304**, where it is combined with relatively concentrated second working fluid **318***a* in order to produce relatively diluted second working fluid **318***b*. As mentioned earlier, this process can result in the transfer of thermal energy **380** into the evaporator **302** and across the first membrane **306***a* and into the absorber **304**, with thermal energy **382** ultimately being rejected at the absorber.

[0058] The absorption refrigeration system **340** can also include a generator **342** and a condenser **348** each in fluid communication with opposing sides of a second membrane **306***b*. The second membrane **306***b*, like the first membrane **306***a*, can be configured to allow first working fluid vapor to pass therethrough and to inhibit movement of liquid first working fluid therethrough. The generator **342** can receive the relatively diluted second working fluid **318***b* being outputted from the absorber **304**. Thermal energy **346** can be provided to the relatively diluted second working fluid **318***b* so as to cause first working fluid vapor **312***b* to be released from the second working fluid, thereby producing relatively concentrated second working fluid **318***a* that can be directed to the absorber **304**. The first working fluid vapor **312***b* released from the second working fluid **318** can then pass through the second membrane **306***b* to the condenser **348**, where thermal energy **350** can be removed to transform the vapor to liquid first working fluid **312***a*.

[0059] Referring to FIGS. **12** and **13**, therein is shown an absorption chiller sub-system **400** configured in accordance with another example embodiment. The absorption chiller sub-system **400** can include an evaporator **402** and an absorber **404**. A membrane **406** can be disposed between the evaporator **402** and the absorber **404**. The membrane **406** can have opposing first and second sides **408**, **410**, and second working fluid **418** in the absorber **404** can be in direct contact with the second side. A barrier **490** can be included between the evaporator **402** and the membrane **406**, being separated from the membrane by spacers **492**. The barrier **490** can be configured such that liquid first working fluid **412***a* in the evaporator **402** is substantially prevented from contacting the first side **408** of the membrane, while first working fluid vapor **412***b* is allowed to pass through the barrier to the membrane and, ultimately, the absorber **404**. The barrier **490** therefore results in the establishment of a vapor gap **494** between liquid first working fluid **412***a* in the evaporator **402** and the membrane **406**.

[0060] The barrier **490** can be a relatively simple structure, such as a mesh, that is relatively permeable to liquids. Penetration of liquid first working fluid **412***a* from the evaporator **402** through the barrier **490** can be substantially prevented by configuring the absorption chiller sub-system **400** such that the liquid first working fluid entering the evaporator at the inlet port **414** has a relatively low hydrostatic pressure and a velocity V directed substantially parallel to the barrier. In this way, the liquid first working fluid **412***a* in the evaporator **402** would be expected to have a small (nearly zero) velocity component directed toward the barrier **490**.

[0061] The vapor gap **494** may affect a decrease in the rate at which thermal energy is transmitted from the (potentially hotter) absorber **404** to the (potentially colder) evaporator **402**. Conduction across the vapor gap **494** will be substantially limited to the energy transferred between colliding gaseous molecules, which process is expected to be substantially less efficient than conduction through a solid body. The vapor gap **494** may also result in a reduction in the mass transfer rate between the evaporator **402** and the absorber **404**, causing a corresponding loss in thermal transfer efficiency from the evaporator to the absorber.

[0062] Referring to FIGS. **14** and **15**, in another embodiment, a vapor gap can be established on the absorber side of the membrane rather than on the evaporator side, as in the previous embodiment. That is, an absorption chiller sub-system **500** can include a membrane **506** can have opposing first and second sides **508**, **510**, with liquid first working fluid **512***a* in the evaporator **502** being in direct contact with the first side. A barrier **590** can be included between the absorber **504** and the membrane **506**, being separated from the membrane by spacers **592**. The barrier **590** can be configured such that second working fluid **518** in the absorber is substantially prevented from passing through the barrier, while first working fluid vapor **412***b* is allowed to pass through the barrier to the absorber **404**. The barrier **590** therefore results in the establishment of a vapor gap **594** between the membrane **506** and second working fluid **518** in the absorber **504**.

[0063] As mentioned above, in order to assure that the liquid does not penetrate the barrier **490**, **590**, the hydrostatic pressure of the fluid contacting the barrier should be relatively small. Referring to FIGS. **16** and **17**, in another embodiment, an absorption chiller sub-system **600** can include an evaporator **602** and an absorber **604** separated by a pair of membranes **606***a*, **606***b*. The membranes **606***a*, **606***b* can be configured as discussed earlier so as to allow passage therethrough of first working fluid vapor **612***b* but not liquid first or second working fluids **612***a*, **618**. The pair of membranes **606***a*, **606***b* (which may be integrated into a unitary structure) can be separated by a vapor gap **694**, thereby limiting thermal conduction across the membranes from the absorber **604** to the evaporator **602**. In some embodiments, the hydrostatic pressure of either of liquid first working fluid **612***a* in the evaporator **602** or second working fluid **618** in the absorber **604** can be relatively high, which aspect may simplify the overall design of the absorption chiller sub-system **600**.

[0064] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. For example, while absorption refrigeration systems have been described that incorporate an evaporator and absorber coupled across a porous membrane and utilized in conjunction with either a conventional generator and condenser or a generator-condenser combination in which the generator and condenser are coupled across a porous membrane, it is also possible to utilize a generator-membrane-condenser combination with a conventional evaporator and absorber. Finally, while single stage or "single effect" absorption refrigeration systems have been described above, the concepts disclosed herein are also amenable to use in "multiple effect" or cascaded systems, in which the thermal energy that is outputted from one thermal cycling system (say, at the absorber and/or condenser) acts as the driving force for another thermal cycle (say, being the input to the generator). 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.

What is claimed:

1. A device comprising:

an evaporator configured to receive a liquid first working fluid and to produce first working fluid vapor;

an absorber configured to receive and combine first working fluid vapor and a second working fluid

a divider having opposing first and second sides in respective fluid communication with said evaporator and said absorber, said divider being configured to allow first working fluid vapor to pass therethrough between said first and second sides and to inhibit movement of liquid first working fluid therethrough between said first and second sides.

2. The device of claim **1**, wherein said evaporator is coupled to said first side of said divider and said absorber is coupled to said second side of said divider.

3. The device of claim **1**, wherein said absorber is configured to combine at least some first working fluid vapor passing through said divider and a second working fluid so as to cause at least some first working fluid vapor passing through said divider to become liquid.

4. The device of claim **1**, wherein said divider includes a membrane.

5. The device of claim **1**, wherein said divider defines holes therethrough.

6. The device of claim **1**, wherein said absorber is configured to combine at least some first working fluid vapor passing through said divider and a second working fluid so as to release thermal energy.

7. The device of claim **1**, wherein said absorber is configured to receive a second working fluid such that an equilibrium second partial pressure of first working fluid vapor at said second side is less than a first partial pressure of first working fluid vapor at said first side.

8. The device of claim **1**, wherein said evaporator is configured to receive liquid NH_3 as the liquid first working fluid.

9. The device of claim **8**, wherein said absorber is configured to receive at least one of water or a mixture of water and NH_3 as the second working fluid.

10. The device of claim **1**, wherein said evaporator is configured such that a total pressure therein is at least twice a partial pressure of first working fluid vapor at said first side.

11. The device of claim **10**, wherein said absorber is configured such that a total pressure therein is at least twice a partial pressure of first working fluid vapor at said second side.

12. The device of claim **1**, wherein said evaporator is configured to receive liquid water and to produce water vapor, and said absorber is configured to combine water vapor passing through said divider and a relatively concentrated solution containing lithium bromide so to produce a relatively diluted solution containing lithium bromide.

13. The device of claim **12**, wherein each of said evaporator and said absorber is configured such that a respective total pressure therein is greater than or equal to about atmospheric pressure.

14. The device of claim **12**, wherein said divider defines holes therethrough having diameters less than or equal to about 100 nm.

15. The device of claim **12**, wherein said divider is formed at least partially of substantially hydrophobic material such that holes defined by said divider are defined by said substantially hydrophobic material.

16. The device of claim **15**, wherein said substantially hydrophobic material includes at least one of polytetrafluoroethylene, polypropylene, or polyvinylidene fluoride.

17. The device of claim **12**, further comprising:

a generator configured to receive the relatively diluted solution containing lithium bromide from said absorber and to produce separate outputs of water vapor and the relatively concentrated solution containing lithium bromide; and

a condenser configured to receive water vapor from said generator and to provide liquid water to said evaporator.

18. The device of claim **17**, further comprising a second divider configured to allow water vapor to pass therethrough and to inhibit movement of liquid water therethrough, wherein said generator and said condenser are in fluid communication with opposing sides of said second divider such that water vapor from said generator can pass through said second divider to said condenser while liquid water in said generator is substantially prevented from reaching said condenser.

19. The device of claim **17**, further comprising:

a geothermal well; and

a heat exchanger,

wherein each of said condenser, absorber, and evaporator are configured to selectively thermally communicate with said geothermal well and said heat exchanger.

20. The device of claim **19**, further comprising a water heater, wherein said device is configured such that thermal energy is transferred from said absorber and said condenser into a heated fluid stream, and thermal energy is transferred from a cooled fluid stream into the liquid first working fluid, the heated fluid stream being in selective fluid communication with each of said water heater, said heat exchanger, and said geothermal well, and the cooled fluid stream being in selective fluid communication with each of said heat exchanger and said geothermal well.

21. The device of claim **19**, wherein said geothermal well and said heat exchanger are configured to selectively exchange thermal energy directly therebetween and to avoid exchanging thermal energy with each of said generator, condenser, evaporator, and absorber.

22. A method comprising:

providing a device including

an evaporator,

an absorber, and

a divider having opposing first and second sides in fluid communication with the evaporator and the absorber, respectively, and configured to allow first working fluid vapor to pass therethrough between the first and second sides and to inhibit movement of liquid first working fluid therethrough between the first and second sides;

providing liquid first working fluid to the evaporator so as to produce first working fluid vapor that contacts the first side of the divider;

receiving at the absorber first working fluid vapor passing through the divider from the first side to the second side and a second working fluid; and

combining in the absorber at least some first working fluid vapor passing through the divider and the second working fluid.

23. The method of claim **22**, wherein said combining at least some first working fluid vapor passing through the divider and the second working fluid includes combining at least some first working fluid vapor passing through the divider and the second working fluid so as to cause at least some of the first working fluid vapor passing through the divider to become liquid.

24. The method of claim **22**, wherein said combining at least some first working fluid vapor passing through the divider and the second working fluid includes combining at least some first working fluid vapor passing through the divider and the second working fluid so as to release thermal energy.

25. The method of claim **22**, wherein said providing a liquid first working fluid to the evaporator includes providing liquid water to the evaporator so as to produce water vapor, and said combining in the absorber at least some first working fluid vapor and the second working fluid includes combining at least some water vapor and a relatively concentrated solution containing lithium bromide.

26. The method of claim **25**, wherein said providing liquid water to the evaporator so as to produce water vapor includes providing liquid water to the evaporator so as to produce water vapor with a first partial pressure at the first side, and said receiving at the absorber a relatively concentrated solution containing lithium bromide includes receiving at the absorber a relatively concentrated solution containing lithium bromide such that an equilibrium second partial pressure of water vapor at the second side is less than the first partial pressure at the first side.

27. The method of claim **25**, wherein said providing a device includes providing a device that includes a divider formed at least partially of substantially hydrophobic material and defining holes therethrough, the holes having diameters less than or equal to about 100 nm.

28. The method of claim **25**, further comprising

supplying thermal energy to a relatively diluted solution containing lithium bromide so as to cause water to evaporate out and thereby produce the relatively concentrated solution containing lithium bromide; and

removing thermal energy from the water vapor produced from the relatively diluted solution containing lithium bromide so as to produce liquid water to be provided to the evaporator.

29. The method of claim **28**, further comprising:

selectively transferring the thermal energy removed from the water vapor produced from the relatively diluted solution containing lithium bromide and transferring thermal energy from the absorber to a heated fluid stream;

selectively transferring thermal energy from a cooled fluid stream to the liquid water circulated to the evaporator;

selectively transferring thermal energy between the heated fluid stream and at least one of a heat exchanger or a geothermal well; and

selectively transferring thermal energy between the cooled fluid stream and at least one of the heat exchanger and the geothermal well.

30. The method of claim **29**, further comprising:

selecting a target temperature; and

causing, when the target temperature is higher than a ground temperature of the geothermal well, a geothermal fluid stream to circulate between the geothermal well and the heat exchanger without receiving the thermal energy removed from the water vapor produced from the relatively diluted solution containing lithium bromide and without exchanging thermal energy with the absorber.

31. A device comprising:

a first working fluid;

a second working fluid;

a divider having opposing first and second sides in respective fluid communication with said evaporator and said absorber, said divider being configured such that first working fluid vapor passes therethrough while movement of liquid first working fluid therethrough is inhibited;

an evaporator in fluid communication with said first side, said evaporator receiving said first working fluid as liquid first working fluid and producing first working fluid vapor with a first partial pressure at said first side; and

an absorber that receives said second working fluid under conditions such that an equilibrium second partial pressure of first working fluid vapor at said second side is less than the first partial pressure, such that said first working fluid vapor moves from said first side to said second side and is combined with said second working fluid in said absorber.

32. The device of claim **31**, wherein said second working fluid is received in said absorber as liquid second working fluid and combined with first working fluid vapor passing through said divider so as to cause at least some of said first working fluid vapor passing through said divider to become liquid.

33. The device of claim **31**, wherein a total pressure in said evaporator is at least twice the first partial pressure.

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