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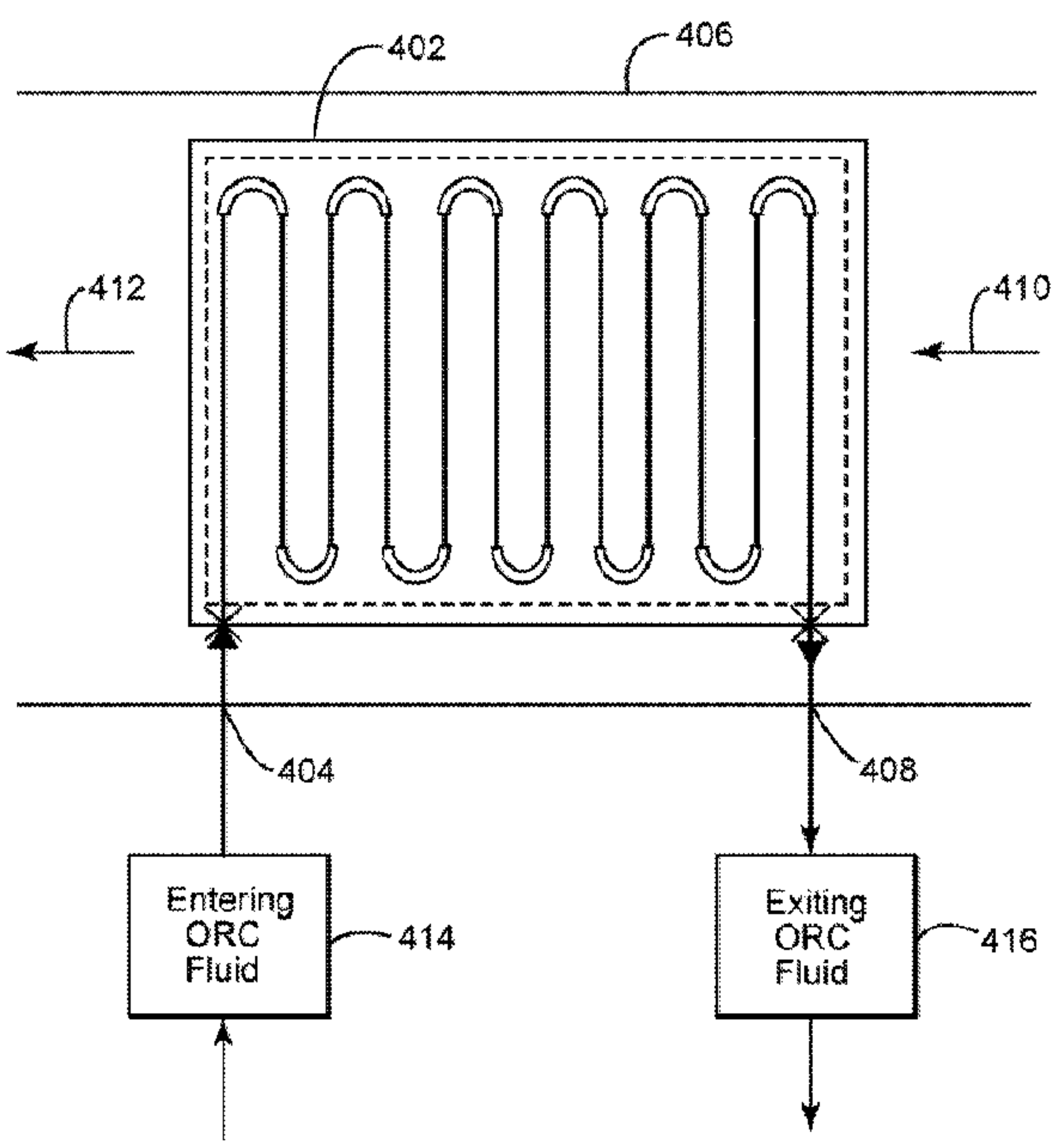
(54) **Titre :** SYSTEME D'EVAPORATEUR DIRECT ET PROCEDE POUR DES SYSTEMES A CYCLE DE RANKINE ORGANIQUE
(54) **Title:** DIRECT EVAPORATOR SYSTEM AND METHOD FOR ORGANIC RANKINE CYCLE SYSTEMS



(57) **Abrégé/Abstract:**
Systems and methods include heat exchangers using Organic Rankine Cycle (ORC) fluids in power generation systems. A system for power generation using an Organic Rankine Cycle (ORC) includes: a heat exchanger configured to be mounted entirely inside a duct, the heat exchanger being configured to include a single inlet which traverses from an outer side of the duct to an inner side of the duct, a single outlet which traverses from the inner side of the duct to the outer side of the duct, and a conduit connecting the single inlet to the single outlet, the conduit being provided entirely inside the duct.

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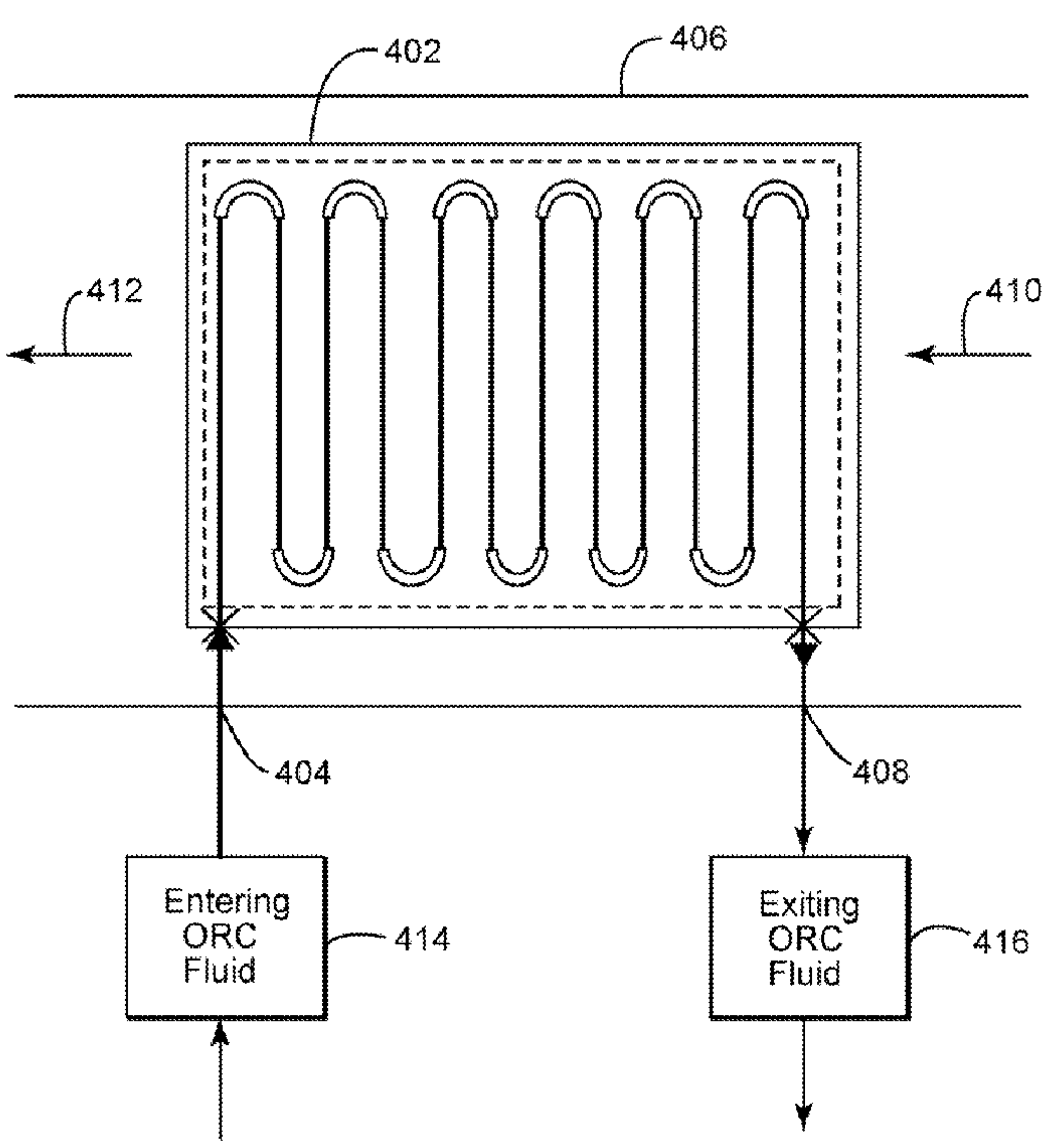
FIG. 4



(57) Abstract: Systems and methods include heat exchangers using Organic Rankine Cycle (ORC) fluids in power generation systems. A system for power generation using an Organic Rankine Cycle (ORC) includes: a heat exchanger configured to be mounted entirely inside a duct, the heat exchanger being configured to include a single inlet which traverses from an outer side of the duct to an inner side of the duct, a single outlet which traverses from the inner side of the duct to the outer side of the duct, and a conduit connecting the single inlet to the single outlet, the conduit being provided entirely inside the duct.

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DIRECT EVAPORATOR SYSTEM AND METHOD FOR ORGANIC RANKINE CYCLE SYSTEMS

DESCRIPTION

TECHNICAL FIELD

The embodiments of the subject matter disclosed herein generally relate to power generation systems and more particularly to Organic Rankine Cycle (ORC) systems.

BACKGROUND

Rankine cycles use a working fluid in a closed cycle to gather heat from a heating source or a hot reservoir by generating a hot gaseous stream that expands through a turbine to generate power. The expanded stream is condensed in a condenser by transferring heat to a cold reservoir and pumped up to a heating pressure again to complete the cycle. Power generation systems such as gas turbines or reciprocating engines (primary system) produce hot exhaust gases that are either used in a subsequent power production process (by a secondary system) or lost as waste heat to the ambient. For example, the exhaust of a large engine may be recovered in a waste heat recovery system used for production of additional power, thus improving the overall system efficiency. A common waste heat power generation system is a Rankine cycle as shown in Figure 1.

The power generation system 100 includes a heat exchanger 2, also known as a boiler, a turbine 4, a condenser 6 and a pump 8. Walking through this closed loop system, beginning with the heat exchanger 2, an external heat source 10, e.g., hot flue gases, heats the heat exchanger 2. This causes the received pressurized liquid medium 12 to turn into a pressurized vapor 14, which flows to the turbine 4. The turbine 4 receives the pressurized vapor stream 14 and can generate power 16 as the pressurized vapor expands. The expanded lower pressure vapor stream 18 released by the turbine 4 enters the condenser 6, which condenses the expanded lower pressure vapor stream 18 into a lower pressure liquid stream 20. The lower pressure liquid stream 20 then enters the pump 8, which both generates the higher pressure liquid stream 22 and keeps the closed loop system flowing. The higher pressure liquid stream 12 then is pumped to the heat exchanger 2 to continue this process.

One working fluid that can be used in a Rankine cycle is an organic working fluid. Such an organic working fluid is referred to as an organic Rankine cycle (ORC) fluid. ORC systems have been deployed as retrofits for engines as well as for small-scale and medium-scale gas turbines, to capture waste heat from the hot flue gas stream. This waste heat may be used in a secondary power generation system to generate up to an additional 20% power on top of the power delivered by the engine producing the hot flue gases alone.

A conventional boiler 2, which is often used to heat fluids under subcritical conditions, is now described with respect to Figure 2. Initially, a pressurized ORC liquid 204 enters a heat exchanger 202 in a preheating section 206, which is typically located towards the cooler end of a gas flow 218, inside exhaust duct 216. From a preheating section 206 the ORC fluid moves into an evaporator section 208 for evaporation. Because during transient operation not all the ORC fluid may have evaporated, the ORC fluid exits from the evaporator section 208 and enters into a separating drum 210, which separates out any liquid that did not evaporate. The multiple piercings of the duct 216, four in this example, are shown by the “X”s 220. The vapor then reenters duct 216 to enter a superheating section 212 of the heat exchanger 202 for superheating. The vapor then exits as superheated ORC vapor 214 en route to the expansion stage of the ORC cycle. Figure 2 shows a simplified ORC heating system. However, an ORC system includes other elements between evaporator section 208 and superheating section 212, traditionally placed outside duct 216, which are not shown.

ORC systems often operate below the critical pressure of the working fluid. When a fluid is below its critical point, but above its triple point (a point at which the fluid can coexist as a liquid, vapor, and solid) along a curve connecting the triple point and the critical point on a pressure versus temperature diagram, the fluid can be a gas, a liquid or performing the phase change between the two, e.g., evaporating. At temperature and pressure combinations above the critical point, i.e., where the pressure and temperature are both above the critical point, the fluid is considered to be a supercritical fluid. A graphical representation of these regions is shown in Figure 3 and is now described. Some media, including ORC fluids, can be described using a pressure (P) versus temperature (T) diagram 300 to illustrate certain characteristics of the medium under various pressures and temperatures. Point A represents the triple point. Point B represents the critical point for which the pressure and temperature are both at their respective Pc and Tc values and beyond this point there is no clear distinction between the liquid phase and the gas phase, i.e., there is no phase transition. The curve 302 linking A and B represents those points having various temperatures and pressure combinations where the medium can boil, with the gas phase being the region 304 below the curve 302 and the liquid phase being the region 306 above the curve 302.

A subcritical region is defined by those points on curve 302, along a lower 50% of curve 302. ORC systems generally operate in the subcritical region using various types of heat exchanger designs. One such heat exchanger is a plate-fin system, which is generally considered to be a compact heat exchanger. However, compact heat exchangers are not generally used to heat a working fluid in a near-critical or supercritical region in an ORC system because the relatively low pressure vapor generated during boiling creates impractically large pressure drops through the narrow channels within the heat exchanger. For this reason, the plate-fin system is used in the subcritical region. Operating ORC systems in the supercritical region can generate an efficiency improvement in the power generation system. However the exchangers for such a region are expensive to build.

Accordingly, systems and methods for reducing cost and improving the efficiency for using ORC systems in power generation systems are desirable.

SUMMARY

According to an exemplary embodiment a system for power generation using an Organic Rankine Cycle (ORC) includes: a heat exchanger configured to be mounted entirely inside a duct, the heat exchanger being configured to include, a single inlet which traverses from an outer side of the exhaust duct to an inner side of the duct, a single outlet which traverses from the inner side of the duct to the outer side of the duct, and a conduit between the single inlet and the single outlet, the conduit being provided entirely inside the duct. The heat exchanger is configured to receive an ORC fluid at the single inlet as a pressurized liquid at a pressure greater than or equal to the critical pressure of the ORC fluid, to heat the ORC fluid to a temperature greater than or equal to the critical temperature of the ORC fluid, and to exit the ORC fluid through the single outlet as a supercritical fluid. The supercritical fluid is defined as having a temperature greater than the critical temperature and a pressure greater than the critical pressure.

According to another exemplary embodiment a system for power generation using an Organic Rankine Cycle (ORC) includes: a heat exchanger configured to be mounted inside a duct. The heat exchanger is configured to include an inlet which traverses from an outer side of the duct to an inner side of the duct and is configured to receive an ORC fluid, an outlet which traverses from the inner side of the duct to the outer side of the duct and is configured to discharge the ORC fluid, and a conduit connecting the inlet and the outlet and configured to heat the ORC fluid. The heat exchanger is configured to operate in a near-critical region of the ORC fluid. The near-critical region of the ORC fluid is described by an upper half of a curve linking a triple point and a critical point for the ORC fluid, and the curve is defined by pressure values and temperature values which define boiling points for the ORC fluid.

According to another exemplary embodiment a method for performing a heat exchange in a power generation system using an Organic Rankine Cycle (ORC) fluid includes: receiving at a heat exchanger heat from a source, wherein the heat exchanger is configured to be mounted entirely inside a duct, the heat exchanger having a single inlet, a conduit and a single outlet; receiving said ORC fluid as a pressurized liquid at a pressure greater than or equal to a critical pressure of the ORC fluid at the single inlet which traverses from an outer side of the duct to an inner side of the duct; exiting the ORC fluid in a supercritical phase at the single outlet which traverses from the inner side of the duct to the outer side of the duct; and passing the ORC fluid through the conduit between the single inlet and the single outlet. The conduit is provided entirely inside the duct. The ORC fluid is heated to change from the pressurized liquid to a supercritical fluid. The heat exchanger is configured to heat the ORC fluid to a temperature greater than or equal to a critical temperature of the ORC fluid, and to exit the ORC fluid through the single outlet as a supercritical fluid. The supercritical fluid is defined by the temperature being greater than the critical temperature and the pressure being greater than the critical pressure.

According to another exemplary embodiment, a method for heating an Organic Rankine Cycle (ORC) fluid in a heat exchanger includes: receiving at a heat exchanger heat from a source, wherein the heat exchanger is configured to be mounted inside a duct and has an inlet, a conduit and an outlet; receiving the ORC fluid as a pressurized liquid at the inlet which traverses from an outer side of the duct to an inner side of the duct; exiting the ORC fluid in a near-critical region at the outlet which traverses from the inner side of the duct to the outer side of the duct, and passing the ORC fluid through the conduit between the inlet and the outlet, the conduit being provided inside the duct. The ORC fluid is heated to change from the pressurized liquid to the near-critical region. The near-critical region of the ORC fluid is described by an upper half of a curve linking a triple point and a critical point for the ORC fluid, and the curve is defined by pressure values and temperature values which define boiling points for the ORC fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate exemplary embodiments, wherein:

Figure 1 depicts a conventional Rankine Cycle;

Figure 2 illustrates a heat exchanger which uses an organic fluid disposed within an exhaust duct;

Figure 3 shows a generic phase change diagram;

Figure 4 illustrates a once-through heat exchanger according to exemplary embodiments;

Figure 5 shows a once-through heat exchanger for subcritical and near-critical operations according to exemplary embodiments;

Figure 6 shows a once-through heat exchanger for subcritical and near-critical operations according to other exemplary embodiments;

Figure 7 illustrates an ORC cycle for a near-critical operation according to exemplary embodiments;

Figure 8 shows a vertical tube heat exchanger according to exemplary embodiments;

Figure 9 shows a plate-and-fin heat exchanger to be used in a near-critical or supercritical operation according to exemplary embodiments;

Figure 10 is a flowchart illustrating steps for operating a heat exchanger in a supercritical region according to exemplary embodiments; and

Figure 11 is a flowchart illustrating steps for operating a heat exchanger in a near-critical region according to exemplary embodiments.

DETAILED DESCRIPTION

The following detailed description of the exemplary embodiments refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. Additionally, the drawings are not necessarily drawn to scale. Also, the following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims. For simplicity, the following description refers to a heat exchanger being placed in a duct in which flue gases are passing. However, the heat source may be different, for example, geothermal water and the heat exchanger may not be placed in a duct.

Reference throughout the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with an embodiment is included in at least one embodiment of the subject matter disclosed. Thus, the appearance of the phrases "in one embodiment" or "in an embodiment" in various places throughout the specification is not necessarily referring to the same embodiment. Further, the particular features, structures or characteristics may be combined in any suitable manner in one or more embodiments.

As described in the Background, and shown in Figure 1, a Rankine cycle can be used in secondary power generation systems to reuse some of the wasted energy from the hot exhaust gases of the primary power generation system. A primary system produces the bulk of the energy while also wasting energy. A secondary system can be used to capture a portion of the wasted energy from the primary system. An ORC system can be used in these power generation systems depending upon system temperatures and other specifics of the power generation systems. According to exemplary embodiments, ORC systems can be used for small to mid-sized gas turbine power generation systems to capture additional heat/energy from the hot flue gas. Examples of ORC fluids include, but are not limited to, pentane, propane, cyclohexane, cyclopentane, butane, a fluorohydrocarbon such as R-245fa, a ketone such as acetone or an aromatic such as toluene or thiophene.

According to exemplary embodiments, a once-through direct heat exchanger may be used to reduce size, cost and improve efficiency as illustrated in Figure 4. According to an exemplary embodiment, a heat exchanger 402 can have a single inlet 404 traversing an exhaust duct 406 and a single outlet 408 traversing the exhaust duct 406 and no other parts of the heat exchanger 402 traversing a wall of the exhaust duct 406. This is in contrast to the traditional heat exchanger shown in Figure 1 in which different portions of the heat exchanger communicate through the wall of the exhaust duct with other elements placed outside the exhaust duct. The hot exhaust 410 may first contact the heat exchanger 402 near the working fluid outlet 408 and the cold (or relatively cooler) exhaust gas 412 may leave the heat exchanger 402 near the working fluid inlet 404. This exemplary heat exchanger can be used with various working fluids in various pressure and temperature ranges. Additionally, while showing the hot exhaust 410 as the heat source in Figure 1, other heat sources may be used in exemplary embodiments described herein, such as, other hot gases and hot liquids, e.g., geothermal brine.

Additionally, according to exemplary embodiments, the heat source fluid, e.g., an exhaust gas or a liquid such as a geothermal brine flow, may operate in a counter flow path relative to a flow of the ORC working fluid within the piping of the heat exchanger 402. Also, according to exemplary embodiments, using this once-through heat exchanger the ORC fluid is brought to a gaseous state (or supercritical fluid state) without the ORC fluid being taken out of the duct 406, which is in contrast to the conventional system shown in Figure 1. For this reason, the novel heat exchanger of this exemplary embodiment is called a once-through heat exchanger. For such a once-through heat exchanger to produce the ORC fluid in the supercritical fluid state, dimensions of the heat exchanger are calculated based on the mass flow and properties of the specific ORC fluid passing through it as well as the mass flow and temperature of the heat source medium used in the heat exchanger.

According to an exemplary embodiment, the heat exchanger 402 can be operated in a supercritical region. In this exemplary case, the ORC fluid 414 enters the heat exchanger as a liquid or as a quasi liquid at or above the critical pressure (Pc) for the type of ORC fluid used. It may be desirable that the pressure of the working ORC fluid when entering the heat exchanger 402 be higher than the critical pressure of the ORC fluid to compensate for the relatively small decreases in pressure that can occur due to, for example, flow obstructions. The ORC fluid is heated as it travels through the piping in the heat exchanger 402. Prior to exiting the heat exchanger 402, the ORC fluid reaches a temperature at or greater than the ORC fluid critical temperature (Tc). Therefore, the exiting ORC fluid 416 is, in this exemplary case, a supercritical ORC fluid. Depending upon the ORC fluid used, the critical temperature can be approximately 240 ^{0}C and the critical pressure can be approximately 45 bar.

According to exemplary embodiments, various other heat exchanger types can be used as a once-through heat exchanger shown in Figure 4. For example, exemplary heat exchanger designs can include, for supercritical ORC applications, but are not limited to, plate, plate-fin, shell-and-tube, compact fin-tube, and continuous-plate-fin tube heat exchangers. As these types of heat exchangers are known in the art, their description is omitted herein. Also, this exemplary process can be expanded to be performed in series or parallel to match the desired scale, capacity and temperature change. Thus, more than one conduit may be used between the inlet 404 and the outlet 408.

According to another exemplary embodiment, the once-through heat exchangers can be used in subcritical and near-critical ORC applications as shown in Figure 5. A near-critical ORC application can be defined by those points on curve 302 in Figure 3 that are in the upper 50% of the curve.

Additionally, according to exemplary embodiments, near-critical points can also include those points having pressures and temperatures which are around the critical point. With regard to Figure 5, a pressurized ORC liquid 514 enters the heat exchanger 502 through an inlet 510 (while not shown each inlet/outlet corresponds to a piercing of the exhaust duct by piping) into a preheating section 504 of the heat exchanger 502. The preheating section 504 is located towards the end of the heat exchanger 502 where the cooler exhaust gas 520 leaves the heat exchanger 502. The preheated liquid then moves on to a boiler or evaporator section 506 for evaporation. After evaporation, the ORC vapor continues on to a superheating stage 508 in the heat exchanger. In this exemplary embodiment, the evaporator section 506 is located between the preheating section 504 and the superheating section 508 of the heat exchanger 502, with the superheating section 508 being located closest to the entry point of the hot exhaust gas 518. After superheating, the superheated vapor ORC 516 exits at outlet 512 the heat exchanger 502 and advances to the next step of the power generation cycle, e.g., expansion.

According to an alternative exemplary embodiment, the location of the various heat exchanging stages can occur in different locations within the heat exchanger 502 as shown in Figure 6. In this alternative exemplary embodiment, the locations of the superheating section 508 and the evaporator section 506 are reversed. This change results in the evaporator section being located closer to the hot exhaust gas 518 entrance to the heat exchanger 502. Additionally, this change can alter the relative exit point 512 from the heat exchanger 502 (and exhaust duct (not shown)) of the superheated vapor ORC 516 as well as, in some exemplary cases, mitigate otherwise excessive fluid temperatures under certain exhaust and ORC fluid conditions. This change in order within the heat exchanger 502 can be used in both subcritical and near-critical ORC systems.

According to other exemplary embodiments, various types of heat exchangers can implement the once-through design, for subcritical and near-critical ORC systems, shown in Figures 4-6. For example, exemplary heat exchanger types can include, but are not limited to, plate, vertical tube (as shown in Figure 8), plate-fin (as shown in Figure 9), shell-and-tube, and compact tube-fin heat exchangers. Additionally, the once-through design of the heat exchanger allows for reducing cost (and space requirements) associated with the heat exchanger by removing various conventional intermediate stages, e.g., a separator between evaporation and superheating, other storage stages, etc. Also, reductions in cost can be realized by a potential reduction in system maintenance and downtime due to reduction of components when using this exemplary once-through heat exchanger. According to exemplary embodiments, this exemplary process can be expanded to be performed in series or parallel to match the desired scale and capacity.

As described above, according to exemplary embodiments, a once-through heat exchanger can be used in subcritical and near-critical ORC systems. Near-critical ORC systems allow for some of the efficiency improvements gained from supercritical ORC systems while still using, as desired, the physical components of the less expensive subcritical systems. The near-critical ORC systems are configured to operate at temperatures and pressures combinations along the upper 10 percent or upper 20 percent or upper 50 percent of the curve 302 (see Figure 3) linking the triple point to the critical point for an ORC fluid and also at points described in the pressure versus temperature plane as having a pressure less than the critical pressure. Curve 302 defines the boiling/condensation point for the ORC fluid at the various pressure/temperature combinations. Thus, near-critical ORC systems are configured to operate such that a pressure P of the medium is less than Pc and a temperature T of the medium is less than Tc, in the preheating and evaporation stages. However, according to exemplary embodiments, in some cases the pressure may be above the critical point value. After evaporation, e.g., during superheating, T can become greater than Tc to create a superheated vapor as long as P remains less than Pc. According to alternative exemplary embodiments, near-critical ORC systems can also operate using conventional heat exchangers with piping that enters and exits the exhaust duct two or more times, e.g., the piping exits to communicate the fluid to a separator and then provides the pure vapor back into the duct.

According to exemplary embodiments, an ORC fluid, e.g., cyclopentane or isopentane, can be used in near-critical ORC power generation systems as is described with respect to a power generation system 700 shown in Figure 7. In this exemplary embodiment, the critical point of the ORC fluid is defined by approximately 45 bar and 240 ^{0}C. Beginning with a pump 702 in the closed-loop power generation system 700, the ORC fluid is received as a relatively low pressure and temperature liquid, e.g., 1 bar at 50 ^{0}C, and is pressurized to at least 40 bar (by comparison a standard subcritical ORC system will operate on its high pressure side at approximately 20 bar). This pressurized ORC fluid passes through a recuperator 704 and is heated to approximately 110 ^{0}C prior to being received by a preheater section 708 of the heat exchanger 706. The heat exchanger receives, for example, an exhaust gas at 500° C, which heats the various stages of the heat exchanger 706. These stages can include the preheater 708 and a boiler/superheater section 710. Alternatively, other styles of heat exchangers can be used, e.g., the once-through heat exchangers shown in Figures 5 and 6. After heating the ORC fluid, the exhaust gas exits the heat exchanger 706 at, for example, 120° C.

As described above, the pressurized ORC fluid enters the preheater 708 and then is moved on to the boiler/superheater 710. As the ORC fluid arrives at the heat exchanger at a pressure near, but below, its critical pressure, it is evaporated (and possibly superheated) at a temperature near its critical temperature and the ORC fluid exits the heat exchanger as a high pressure vapor or a high pressure superheated vapor, e.g., 40 bar and 250°C, and travels on to the turbine 712 for power generation and expansion. The ORC vapor exits the turbine 712 at a lower pressure then the ORC vapor which entered the turbine 712 and then passes through the recuperator 704, which cools the vapor. The ORC vapor then enters a condenser 714, is condensed into a liquid phase, and is moved on back to the pump 702 as a low pressure liquid.

While various temperatures and pressures are shown in Figure 7, there can be some variances to these purely illustrative values which will not significantly alter the ability of the system to perform as desired. Additionally, the type of exhaust generator can vary the inlet exhaust temperature, which can be compensated by, for example, increasing the length of the piping used in the heat exchanger 708. Also, various temperature and pressure combinations can be used for different ORC fluids and/or when at different points in the near-critical point region.

According to exemplary embodiments, as described above, various heat exchanger designs can be used in near-critical ORC systems. For example, a vertical tube bank heat exchanger 802 as shown in Figure 8 can be used. The vertical tube bank heat exchanger 802 can be mounted inside the exhaust duct 804. The vertical tube bank heat exchanger 802 includes a vertically oriented bank of tubes in which the working ORC fluid is vaporized, surmounted by a vessel that redistributes the unboiled liquid evenly among the tubes.

According to exemplary embodiments, a system for power generation using an Organic Rankine Cycle (ORC) in a heat exchanger, includes: an inlet which traverses from an outer side of an exhaust duct to an inner side of the exhaust duct; an outlet which traverses from the inner side of the exhaust duct to the outer side of the exhaust duct; and a conduit fluidly and directly connecting the inlet to the outlet and configured to either (i) receive an ORC fluid at a pressure higher than a critical pressure of the ORC fluid and increase a temperature of the ORC fluid above a critical temperature of the ORC fluid while the ORC fluid is inside the heat exchanger or (ii) receive the ORC fluid and increase the temperature of the ORC fluid to a subcritical value before outputting the ORC fluid out of the heat exchanger. Additionally, the length of the conduit, or piping, used to connect the inlet to the outlet can be a calculated length. Inputs to calculating this length can include, but are not limited to, various parameters, such as, exhaust heat temperature, ORC fluid selected, piping diameter, type of heat exchanger used, physical space limitation, inlet fluid pressure, fluid flow rates, operating range, e.g., subcritical, near-critical or supercritical, and the like.

According to another exemplary embodiment, heat exchange in a power generation system using an ORC fluid can include receiving at a heat exchanger heat from a source, wherein the heat exchanger is configured as a relatively inexpensive counter flow or cross flow compact heat exchanger such as a plate or plate-and-fin heat exchanger 902 as shown in Figure 9. As shown in Figure 9, an exemplary plate-and-fin heat exchanger 902 includes plate sections 904, a fin section 906 with the fluid flow direction shown by arrow 908. Additionally, side bars can be used, as well as a series of plate and fin sections. However, various types of plate-and-fin heat exchangers 902 can be used in the exemplary embodiments described herein.

According to another exemplary embodiment, the heat exchanger 902 receives the ORC fluid as a pressurized liquid at a pressure greater than or equal to a critical pressure of the ORC fluid at one inlet, discharging the ORC fluid in a supercritical phase at an outlet on the other end of the heat exchanger conduit. Alternatively, the heat exchanger 902 can receive and discharge the ORC fluid at a near critical pressure. In a respective other conduit, e.g., an exhaust duct, the heating medium flows from an inlet to a respective opposite outlet as a liquid or gaseous heating medium from which heat is transferred across a wall of the other conduit to the ORC fluid, thereby cooling the heating medium. In these exemplary embodiments, when the heating occurs in the near-critical or supercritical region, the volume occupied by the now relatively high-pressure vapor results in a far lower pressure drop through the constricted passages of compact heat exchangers like the plate or plate-fin varieties, which makes the plate or plate-fin heat exchangers viable for these specific regions.

Utilizing the above-described exemplary systems according to exemplary embodiments, a method for heat exchange is shown in the flowchart of Figure 10. Initially a method for performing a heat exchange in a power generation system using an Organic Rankine Cycle (ORC) fluid includes: receiving at a heat exchanger heat from a source in step 1002, wherein the heat exchanger is configured to be mounted entirely inside an exhaust duct, the heat exchanger having a single inlet, a conduit and a single outlet; receiving the ORC fluid as a pressurized liquid in step 1004 at a pressure greater than or equal to a critical pressure of the ORC fluid at the single inlet which traverses from an outer side of the exhaust duct to an inner side of the exhaust duct; exiting the ORC fluid in a supercritical phase in step 1006 at the single outlet which traverses from the inner side of the exhaust duct to the outer side of the exhaust duct; and passing the ORC fluid through the conduit between the single inlet and the single outlet in step 1008, while heating the ORC fluid to change a phase from the pressurized liquid to the supercritical phase. The heat exchanger is configured to heat the ORC fluid to a temperature greater than or equal to a critical temperature of the ORC fluid, and to exit the ORC fluid through the single outlet as a supercritical fluid, and the supercritical fluid is defined by the temperature being greater than the critical temperature and the pressure being greater than the critical pressure.

Utilizing the above-described exemplary systems according to exemplary embodiments, a method for heating an ORC fluid is shown in the flowchart of Figure 11. A method for heating an Organic Rankine Cycle (ORC) fluid in a heat exchanger includes: receiving at a heat exchanger heat from a source in step 1102, where the heat exchanger is configured to be mounted inside a duct and has an inlet, a conduit and an outlet; receiving the ORC fluid as a pressurized liquid in step 1104 at the inlet which traverses from an outer side of the duct to an inner side of the duct; exiting the ORC fluid in a near-critical region in step 1106 at the outlet which traverses from the inner side of the duct to the outer side of the duct, and passing the ORC fluid through the conduit between the inlet and the outlet in step 1108. The ORC fluid is heated to change from the pressurized liquid to the near-critical region, wherein the near-critical region of the ORC fluid is described by an upper half of a curve linking a triple point and a critical point for the ORC fluid. The subcritical region of the ORC fluid is described by a lower half of the curve, and the curve is defined by pressure values and temperature values which define boiling points for the ORC fluid.

The above-described exemplary embodiments are intended to be illustrative in all respects, rather than restrictive, of the present invention. Thus the present invention is capable of many variations in detailed implementation that can be derived from the description contained herein by a person skilled in the art. All such variations and modifications are considered to be within the scope and spirit of the present invention as defined by the following claims. No element, act, or instruction used in the description of the present application should be construed as critical or essential to the invention unless explicitly described as such. Also, as used herein, the article “a” is intended to include one or more items.

This written description uses examples of the subject matter disclosed to enable any person skilled in the art to practice the same, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the subject matter is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims.

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WHAT IS CLAIMED IS:

1. A system for power generation using an Organic Rankine Cycle (ORC), the system comprising:

a heat exchanger (402) configured to be mounted entirely inside a duct (406), said heat exchanger being configured to include,

a single inlet (404) which traverses from an outer side of said duct to an inner side of said duct,

a single outlet (408) which traverses from said inner side of said duct to said outer side of said duct, and

a conduit between said single inlet and said single outlet, said conduit being provided entirely inside said duct,

wherein said heat exchanger (402) is configured to receive an ORC fluid at said single inlet as a pressurized liquid at a pressure greater than or equal to a critical pressure of said ORC fluid, to heat said ORC fluid to a temperature greater than or equal to a critical temperature of said ORC fluid without the ORC fluid being taken out of the duct (406), and to exit said ORC fluid through said single outlet (408) as a supercritical fluid, and

said supercritical fluid is defined by said temperature being greater than said critical temperature and said pressure being greater than said critical pressure.

2. The system of claim 1, wherein said critical pressure and critical temperature for said ORC fluid define a point at which said ORC fluid becomes supercritical.

3. The system of claim 1, wherein said ORC fluid is selected from a group comprising pentane, propane, cyclohexane, butane, a fluorohydrocarbon, a ketone, an aromatic, or a combination thereof.

4. The system of claim 1, wherein said ORC fluid is heated to a temperature greater than or equal to said critical temperature of said ORC fluid inside of said conduit without leaving said exhaust duct (406).

5. The system of claim 1, wherein said heat exchanger (402) is one of a plate or plate-and-fin heat exchanger.

6. A system for power generation using an Organic Rankine Cycle (ORC), the system comprising:

a heat exchanger (402) configured to be mounted inside a duct (406), said heat exchanger being configured to include,

an inlet (404) which traverses from an outer side of said duct (406) to an inner side of said duct and is configured to receive an ORC fluid,

an outlet (408) which traverses from said inner side of said duct to said outer side of said duct and is configured to exit said ORC fluid, and

a conduit connecting said inlet (404) to said outlet (408) and configured to heat said ORC fluid without the ORC fluid being taken out of the duct (406),

wherein said heat exchanger is configured to operate in a near-critical region of said ORC fluid, and

said near-critical region of said ORC fluid being described by an upper half of a curve linking a triple point and a critical point for the ORC fluid, and the curve is defined by pressure values and temperature values which define boiling points for the ORC fluid.

7. The system of claim 6, wherein said heat exchanger further comprises:

a preheater section connected to said inlet and located towards a cooler end of said duct;

an evaporator section connected to said preheater section and located towards a warmer end of said duct, said evaporator section being configured to evaporate a pressurized liquid; and

a superheater section connected to said evaporator section and connected to said outlet, said superheater section being located between said preheater section and said evaporator section and said superheater section being configured to superheat a vapor from said evaporator section.

8. The system of claim 6, wherein said near-critical region of said ORC fluid is described by an upper twenty percent of said curve linking said triple point and said critical point for said ORC fluid.

9. A method for performing a heat exchange in a power generation system using an Organic Rankine Cycle (ORC) fluid, the method comprising:

receiving at a heat exchanger heat from a source (1002), wherein said heat exchanger is configured to be mounted entirely inside a duct, said heat exchanger having a single inlet, a conduit and a single outlet;

receiving said ORC fluid as a pressurized liquid (1004) at a pressure greater than or equal to a critical pressure of said ORC fluid at said single inlet which traverses from an outer side of said duct to an inner side of said duct;

exiting said ORC fluid in a supercritical phase (1006) at said single outlet which traverses from said inner side of said duct to said outer side of said duct; and

passing said ORC fluid through said conduit between said single inlet and said single outlet (1008), said conduit being provided entirely inside said duct, while heating said ORC fluid to change from said pressurized liquid to said supercritical fluid without the ORC fluid being taken out of the duct (406),

wherein said heat exchanger is configured to heat said ORC fluid to a temperature greater than or equal to a critical temperature of said ORC fluid, and to exit said ORC fluid through said single outlet as a supercritical fluid, and

said supercritical fluid is defined by said temperature being greater than said critical temperature and said pressure being greater than said critical pressure.

10. A method for heating an Organic Rankine Cycle (ORC) fluid in a heat exchanger, the method comprising:

receiving at a heat exchanger heat from a source (1102), wherein said heat exchanger is configured to be mounted inside a duct and has an inlet, a conduit and an outlet;

receiving said ORC fluid as a pressurized liquid (1104) at said inlet which traverses from an outer side of said duct to an inner side of said duct;

exiting said ORC fluid in a near-critical region (1106) at said outlet which traverses from said inner side of said duct to said outer side of said duct, and passing said ORC fluid through said conduit between said inlet and said outlet (1108), said conduit being provided inside said duct, while heating said ORC fluid to change from said pressurized liquid to said near-critical region without the ORC fluid being taken out of the duct (406),

wherein said near-critical region of said ORC fluid is described by an upper half of a curve linking a triple point and a critical point for said ORC fluid, and

said curve is defined by pressure values and temperature values which define boiling points for said ORC fluid.

FIG. 1
Background Art

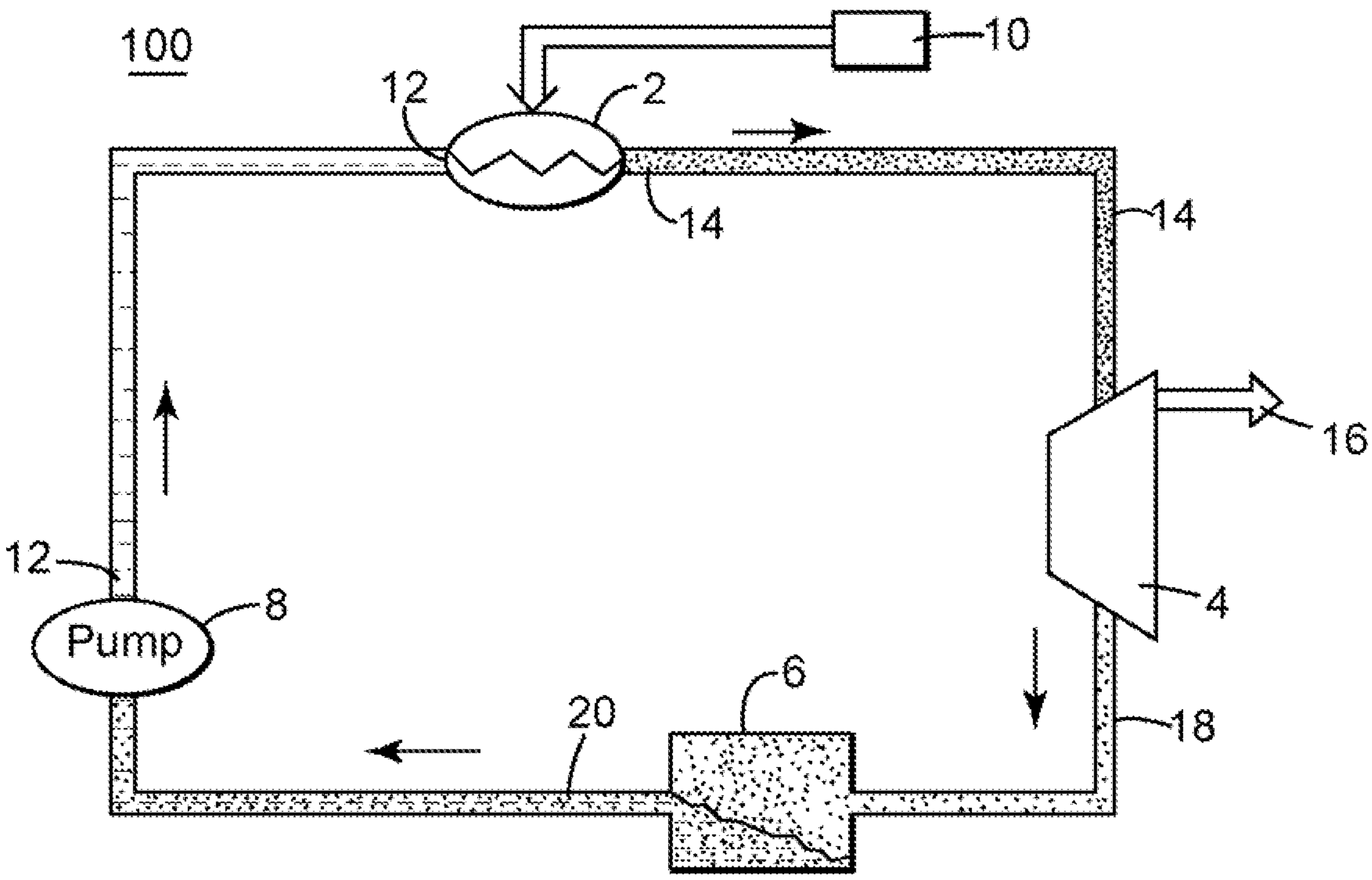


FIG. 2
Background Art

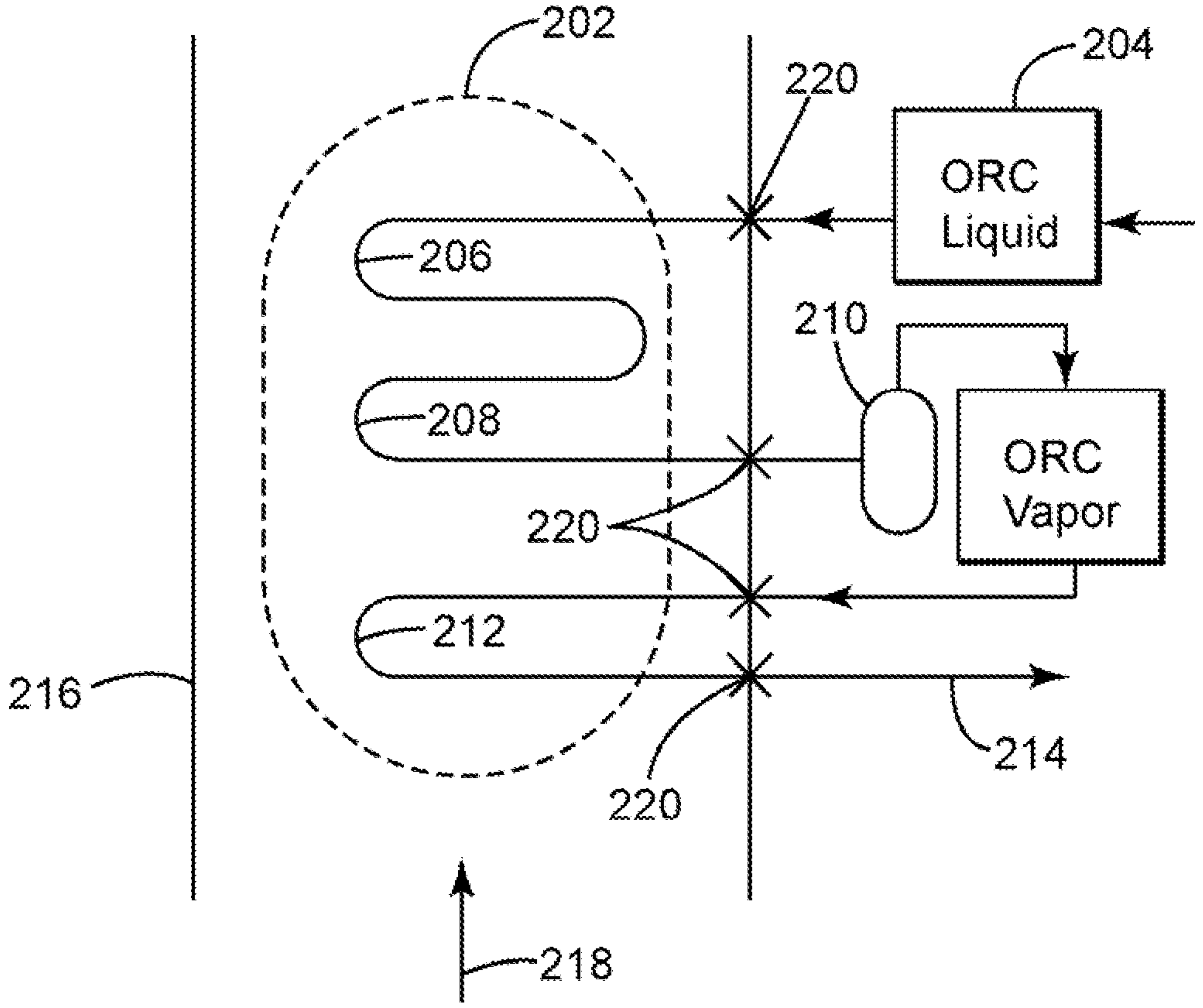


FIG. 3
Background Art

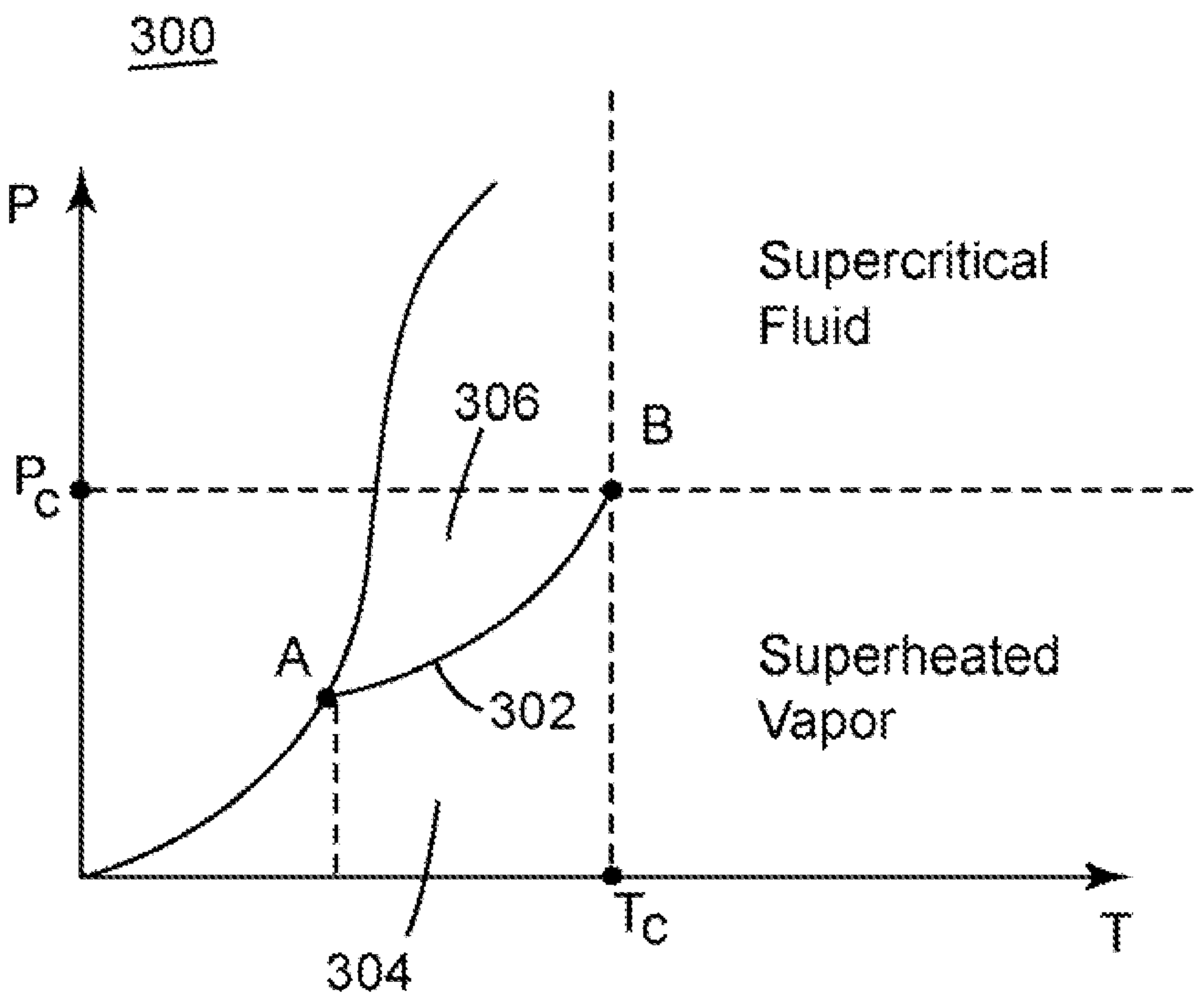


FIG. 4

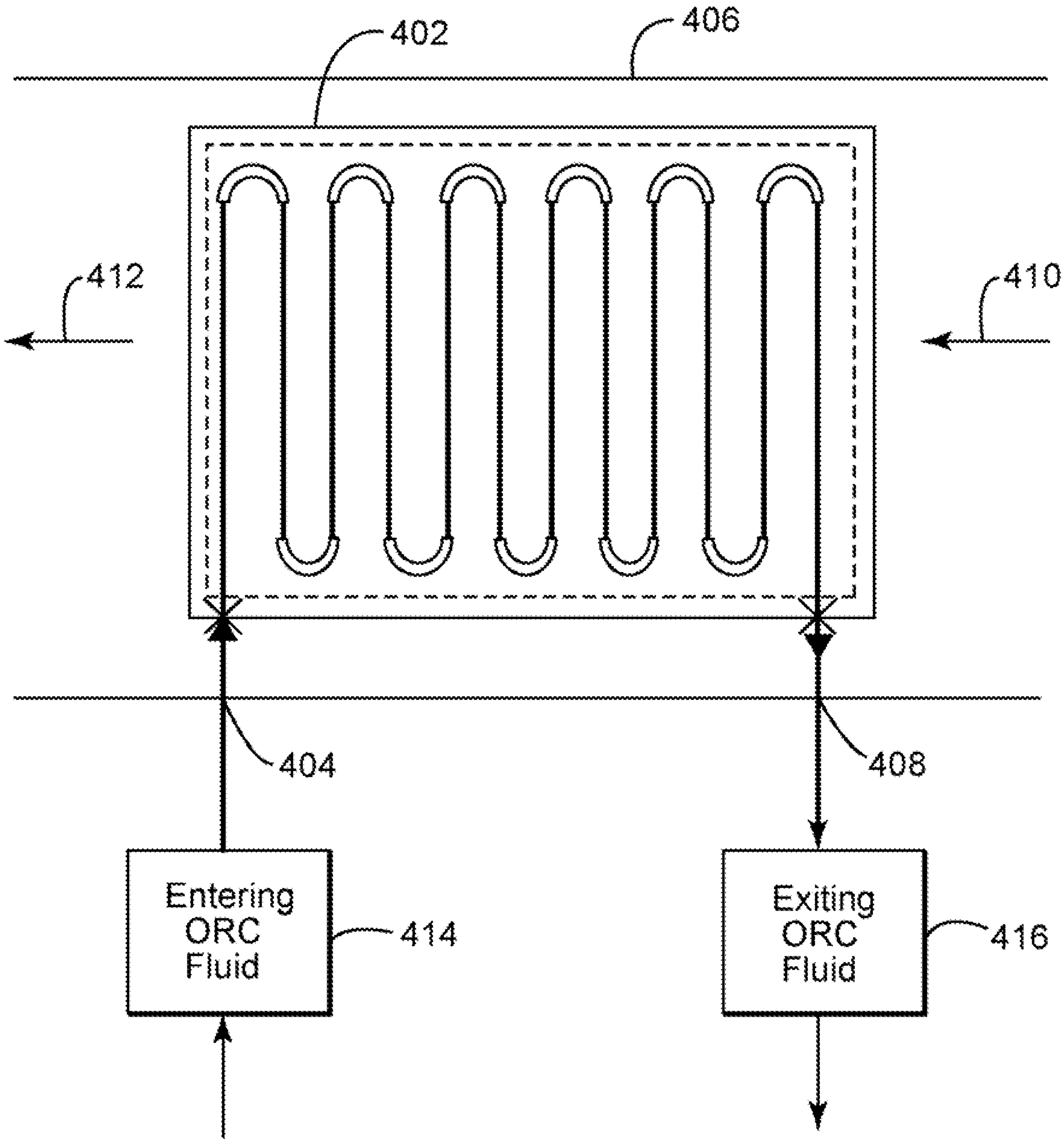

402
406
412
410
404
408
Entering ORC Fluid
414
Exiting ORC Fluid
416

FIG. 5

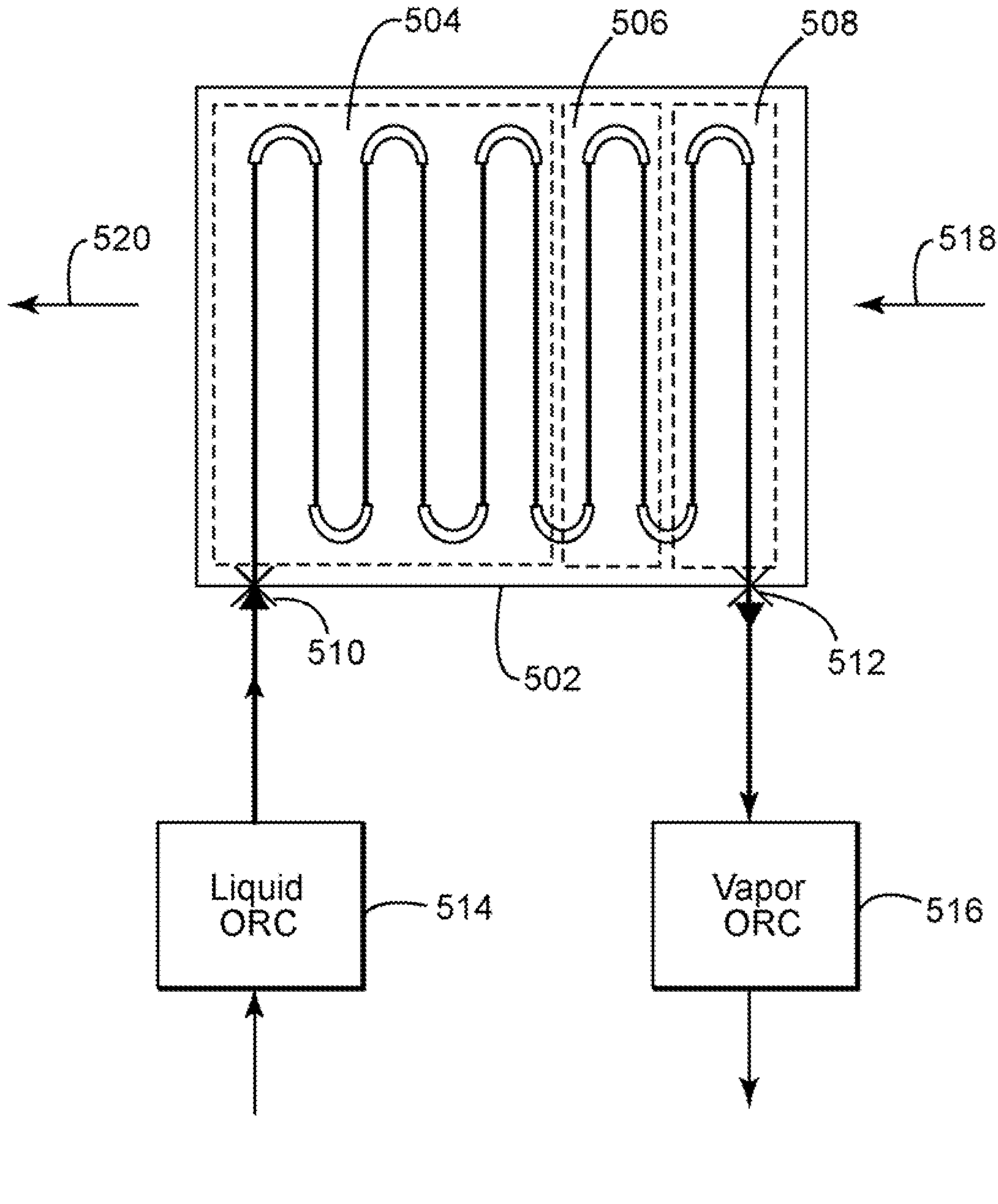


FIG. 6

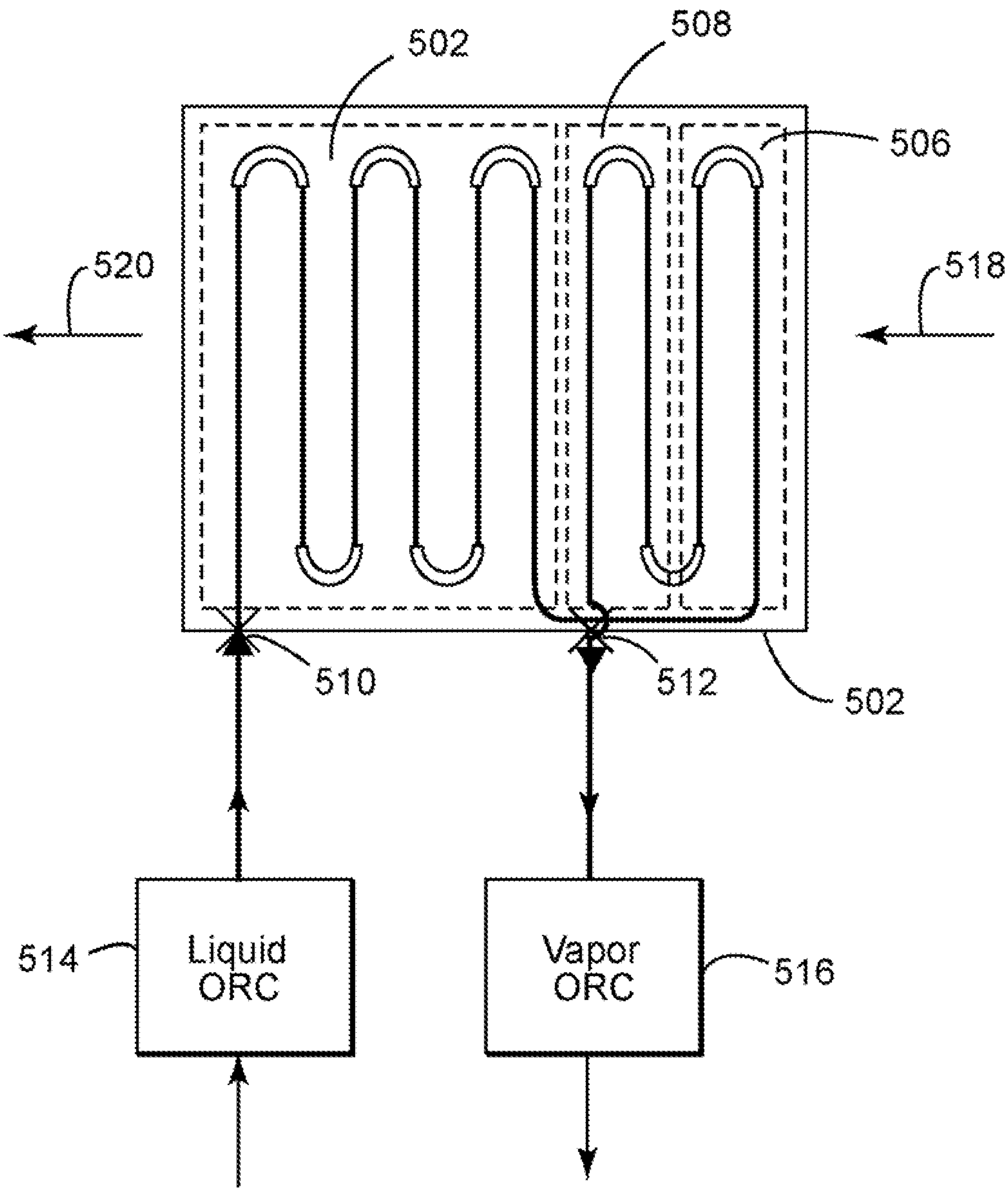


FIG. 7

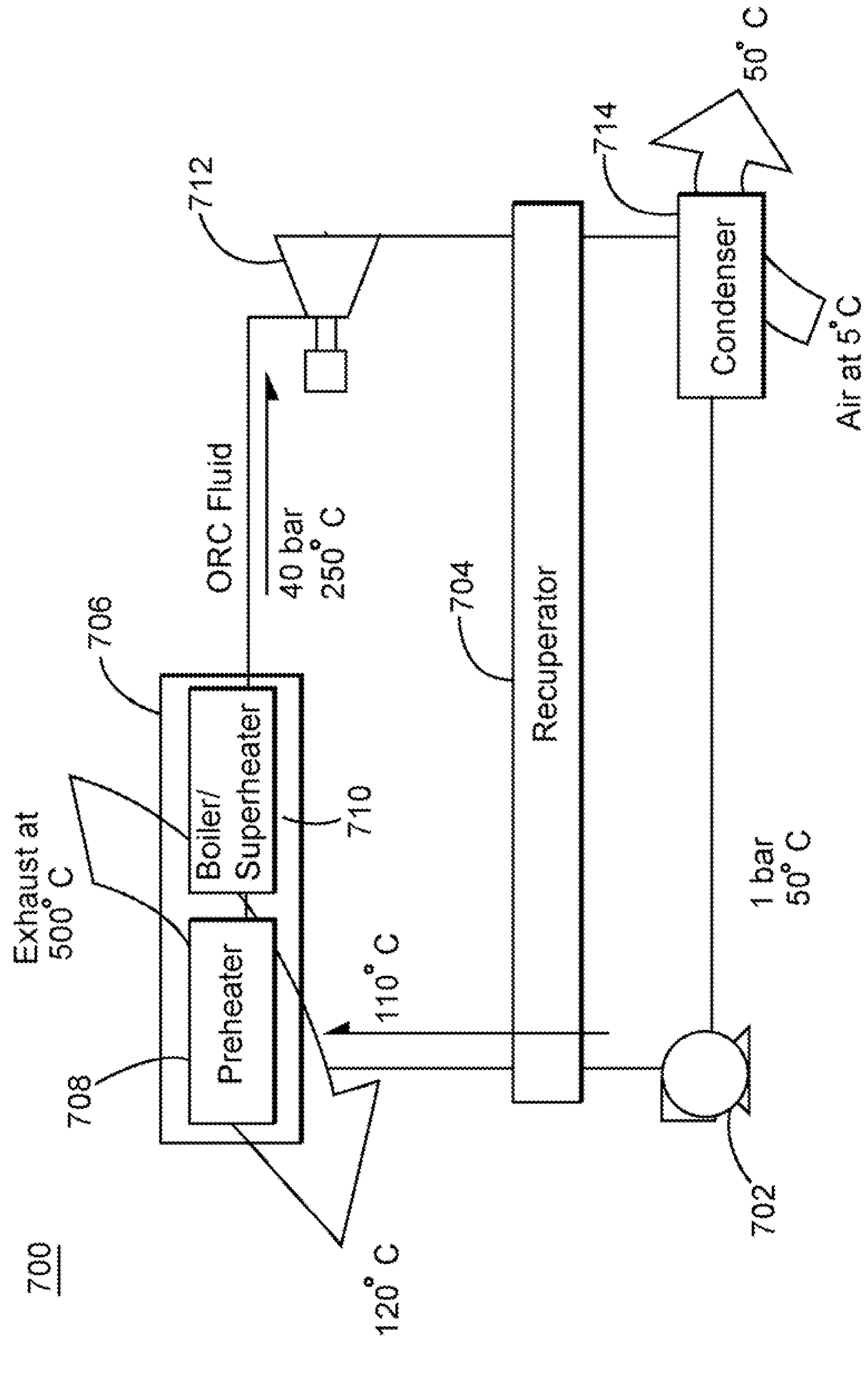

700
Exhaust at
500° C
120° C
708
Preheater
Boiler/
Superheater
706
710
110° C
ORC Fluid
40 bar
250° C
712
704
Recuperator
702
1 bar
50° C
714
Condenser
50° C
Air at 5°C

FIG. 8

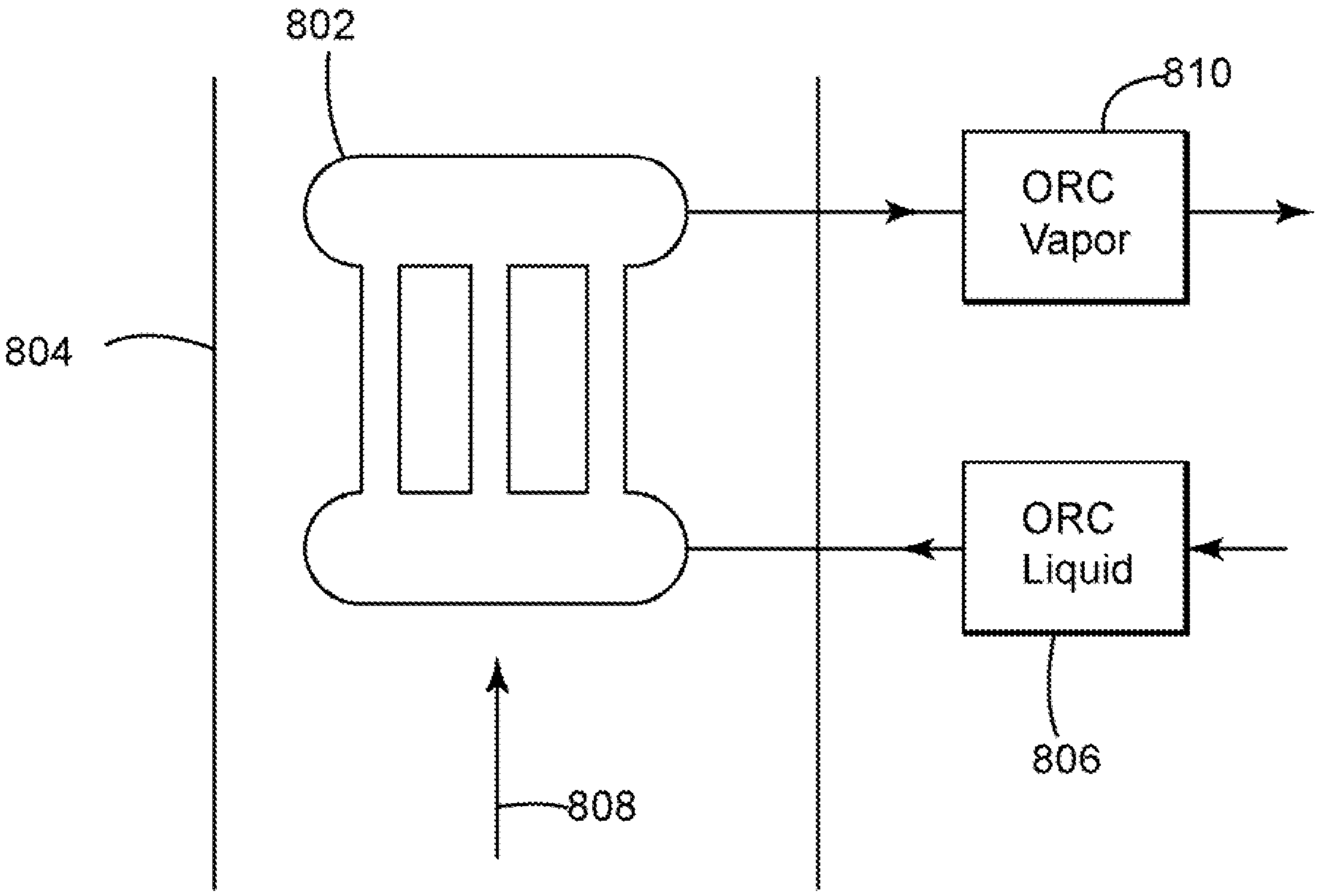


FIG. 9

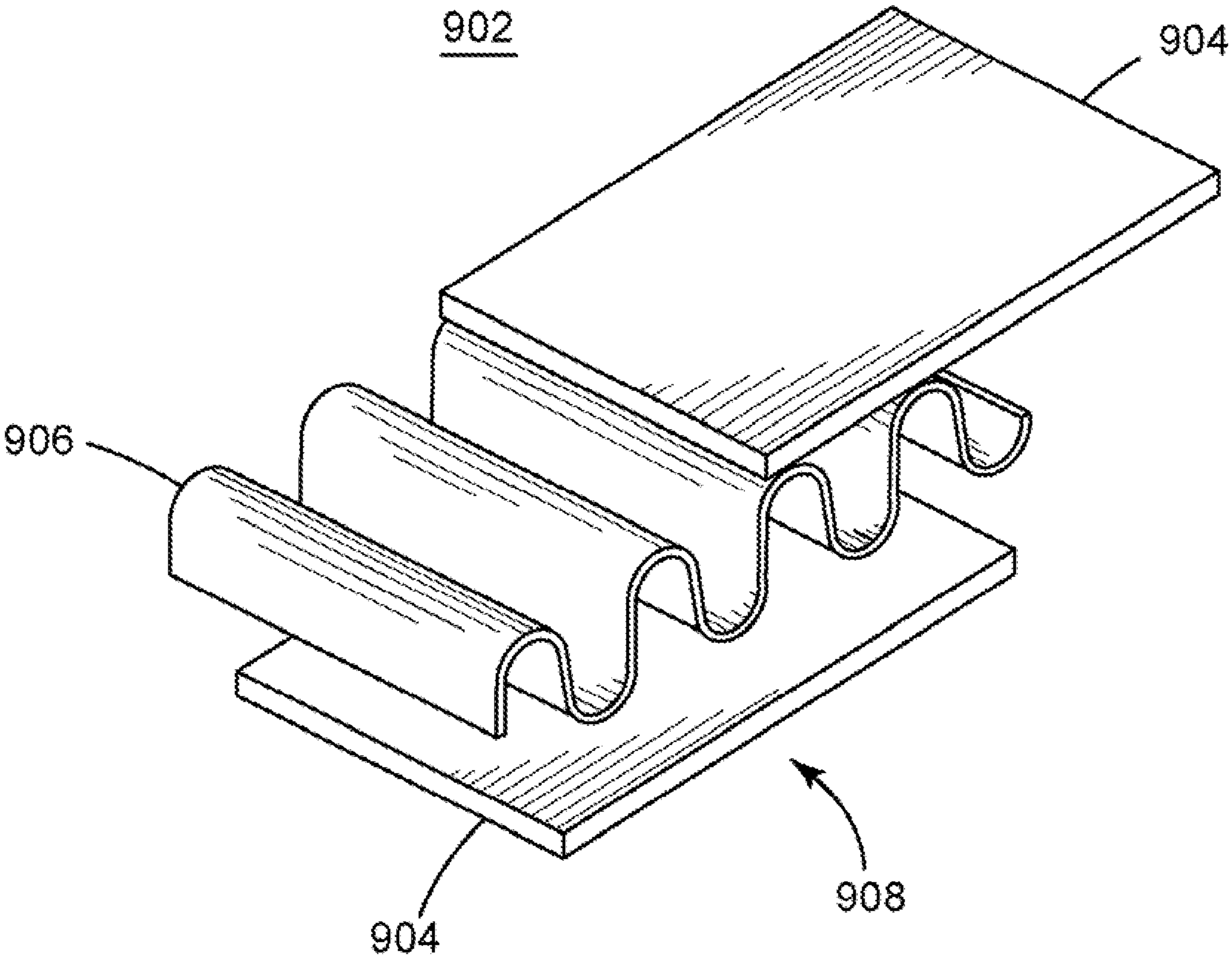


FIG. 10

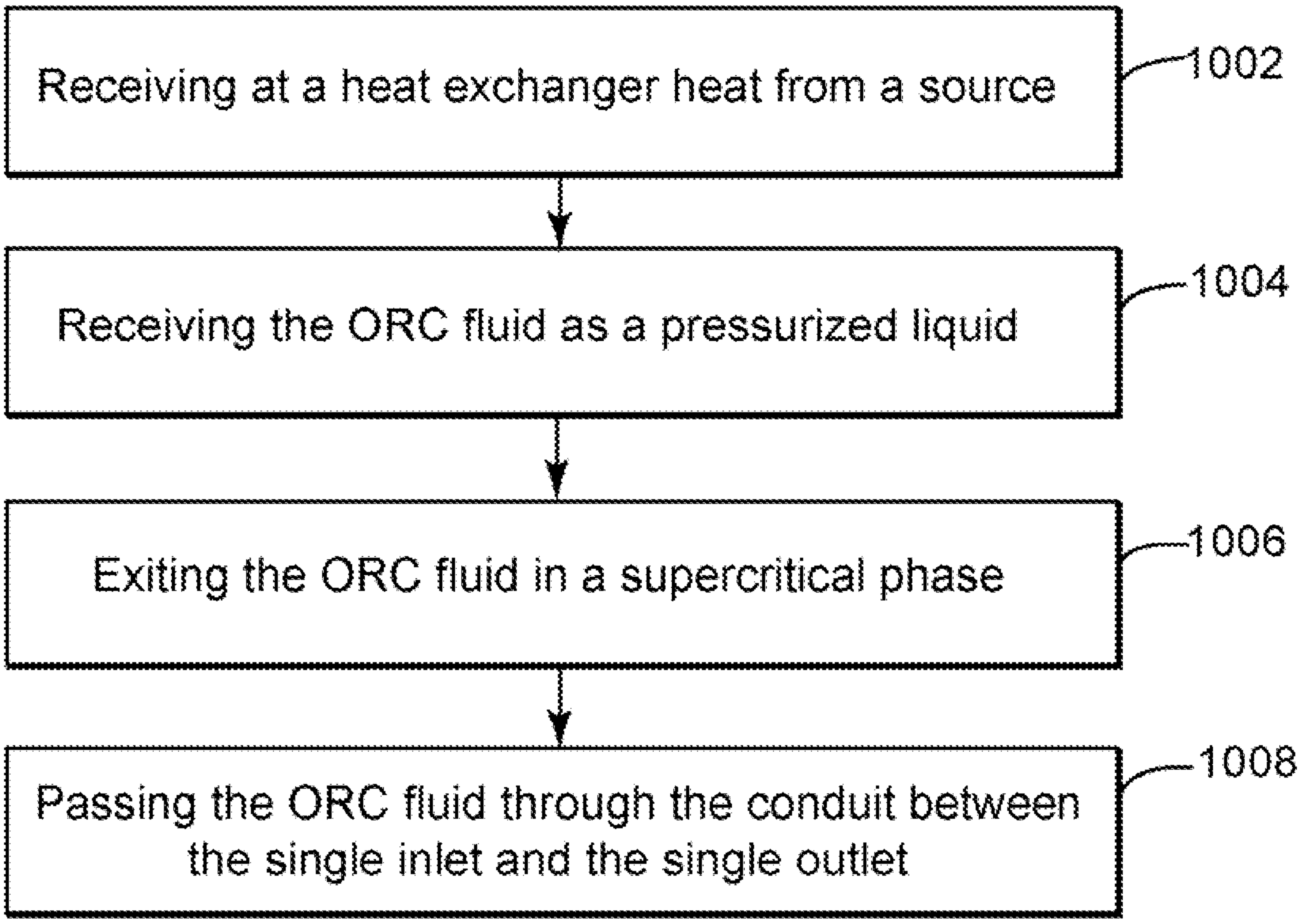
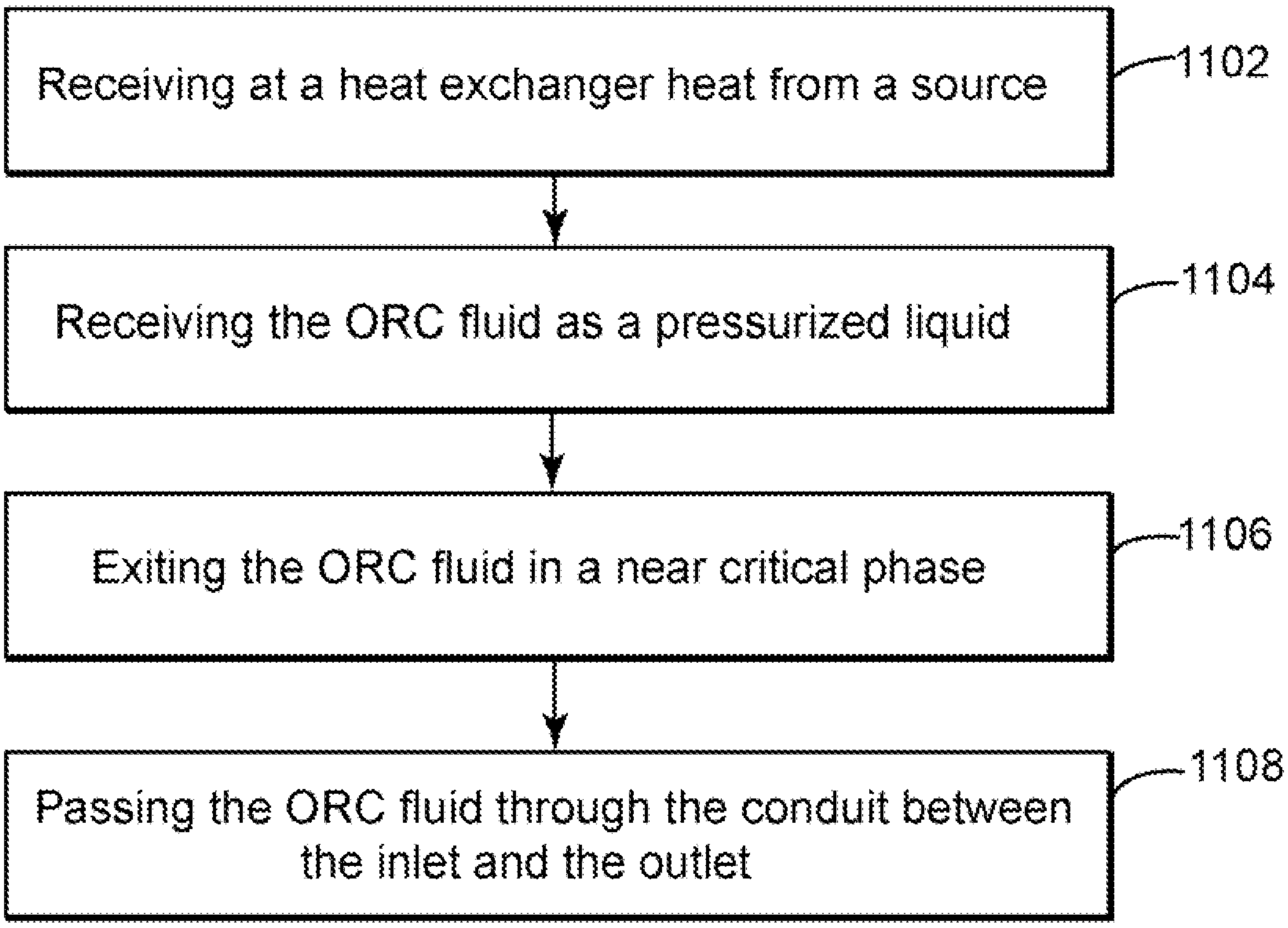
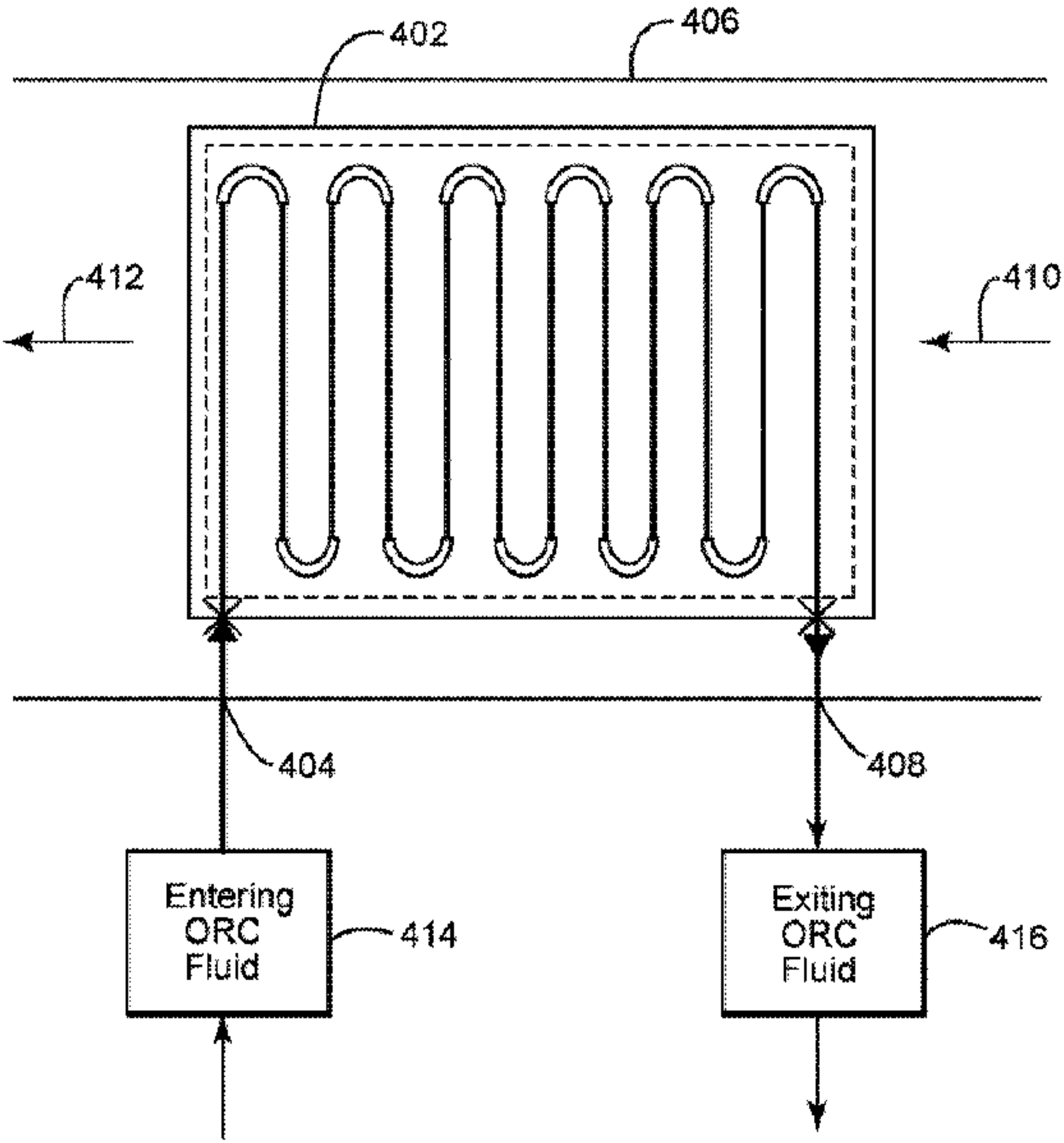

Receiving at a heat exchanger heat from a source
1002
Receiving the ORC fluid as a pressurized liquid
1004
Exiting the ORC fluid in a supercritical phase
1006
Passing the ORC fluid through the conduit between the single inlet and the single outlet
1008

FIG. 11


Receiving at a heat exchanger heat from a source
1102
Receiving the ORC fluid as a pressurized liquid
1104
Exiting the ORC fluid in a near critical phase
1106
Passing the ORC fluid through the conduit between the inlet and the outlet
1108


402
406
412
410
404
408
Entering ORC Fluid
414
Exiting ORC Fluid
416