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(54) **ABSORPTION HEAT PUMP SYSTEM AND METHOD OF USING THE SAME**

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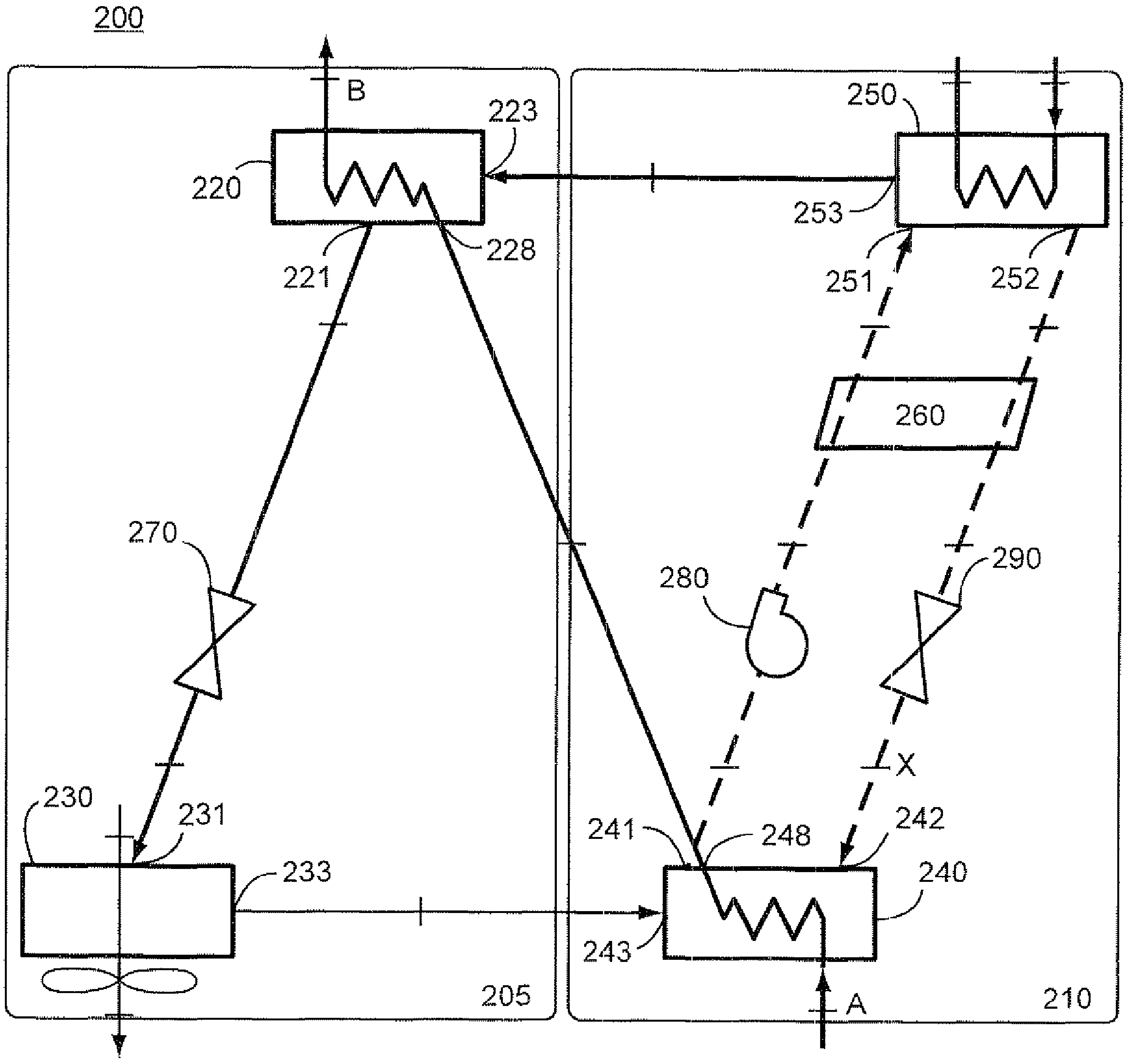
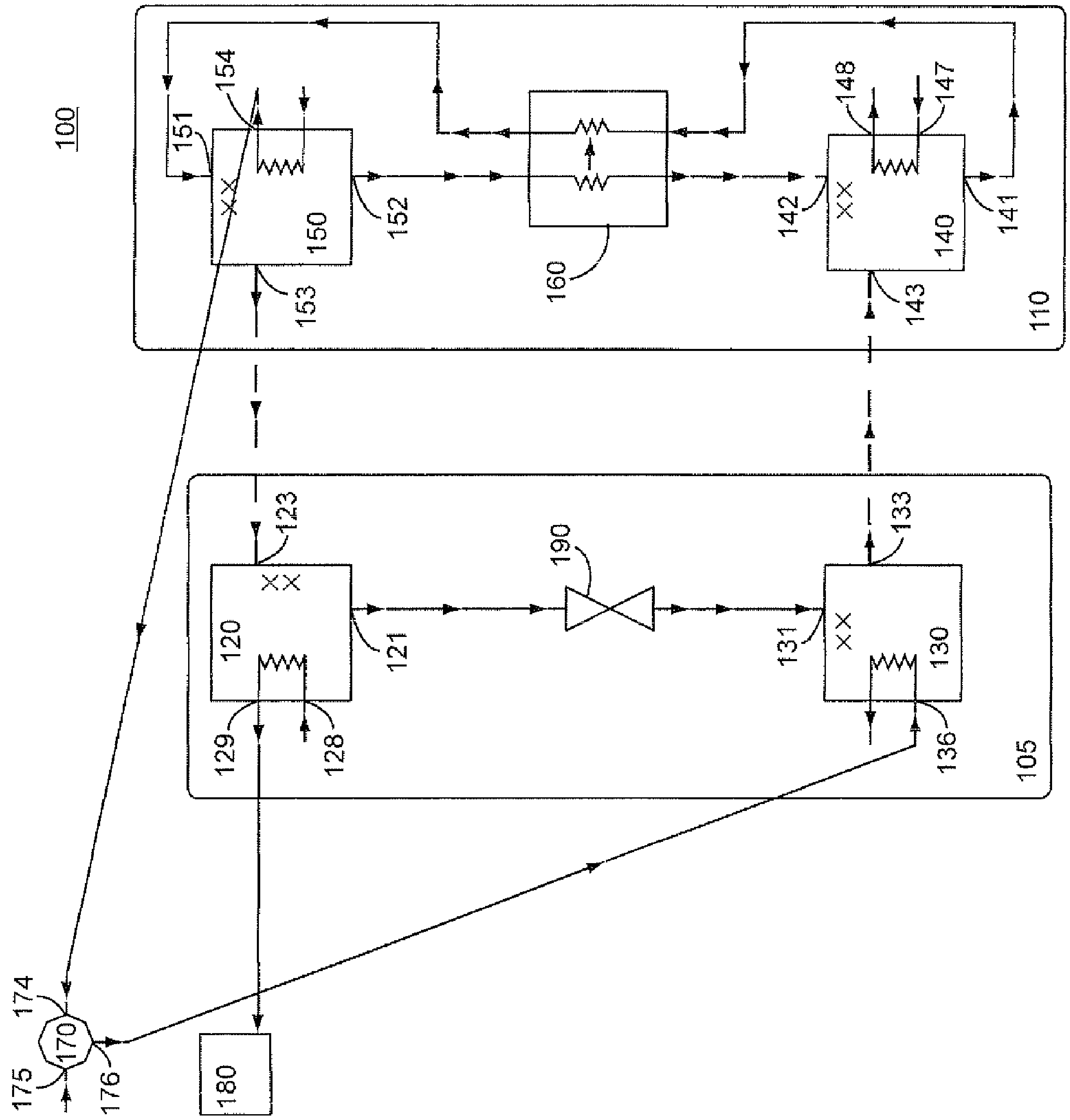
(57) **ABSTRACT**

An absorption heat pump system that can include a first assembly, a second assembly, and a thermal coupler is disclosed herein. The first assembly can include a condenser and an evaporator. The second assembly can include an absorber, a desorber, and a heat exchanger. The thermal coupler can include a first gas inlet, a second fluid inlet, and a mixed fluid outlet. The system can be configured with a first gas outlet of the desorber in fluid communication with the first gas inlet of the thermal coupler, and the mixed fluid outlet of the thermal coupler in fluid communication with a mixed fluid inlet of the evaporator. The system can also include a coolant absorber inlet and outlet on the absorber and a coolant condenser inlet and outlet on the condenser, with the coolant absorber outlet in fluid communication with the coolant condenser inlet.

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110
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151
152
153
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141
142
143
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131
133
136
170
174
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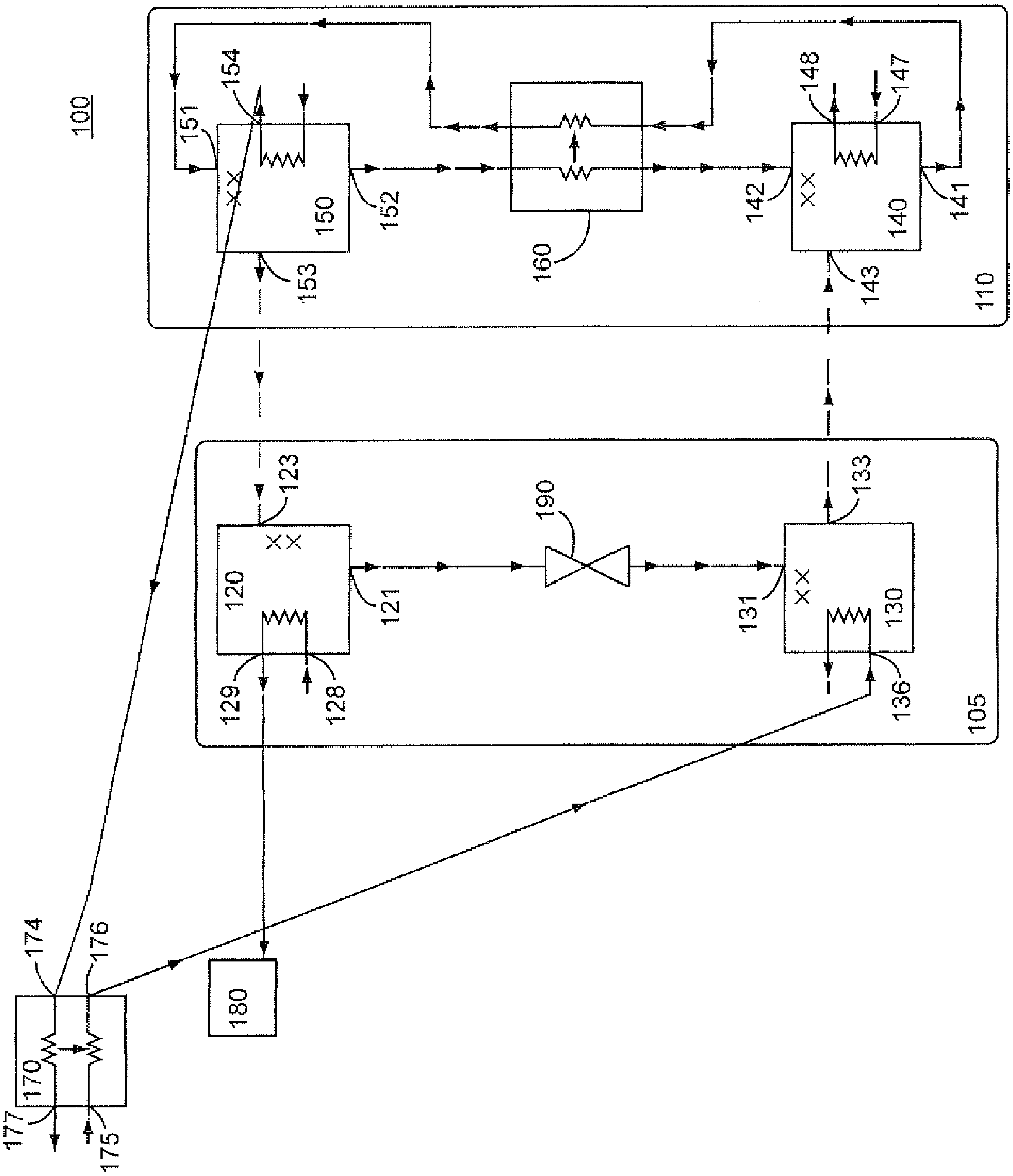
176
180

FIGURE 1A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133
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154
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175
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177
180
190

FIGURE 1B

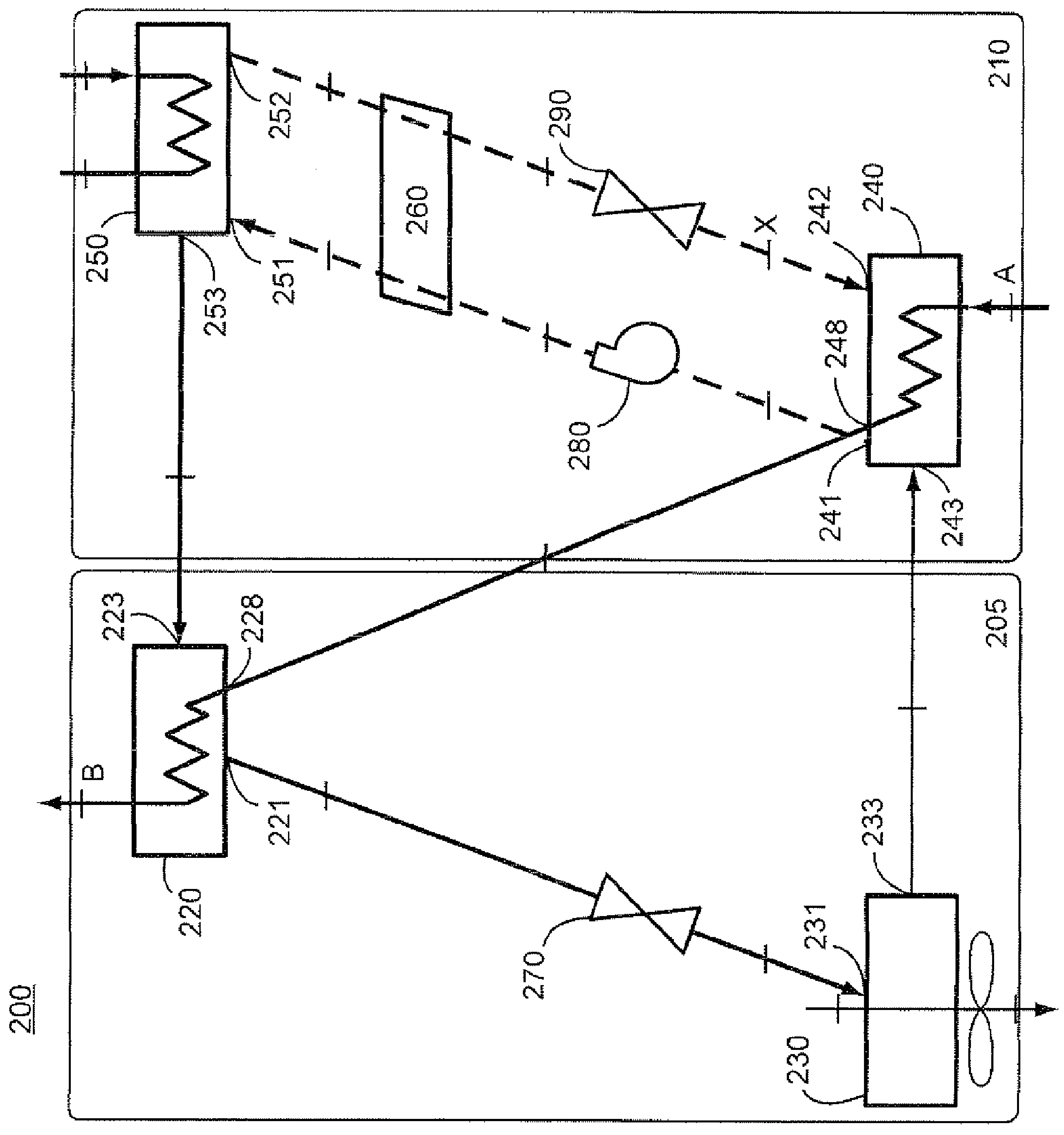
200
205
210
220
221
223
228
B
230
231
233
270
240
241
242
243
248
A
X
250
251
252
253
260
280
290

FIGURE 2

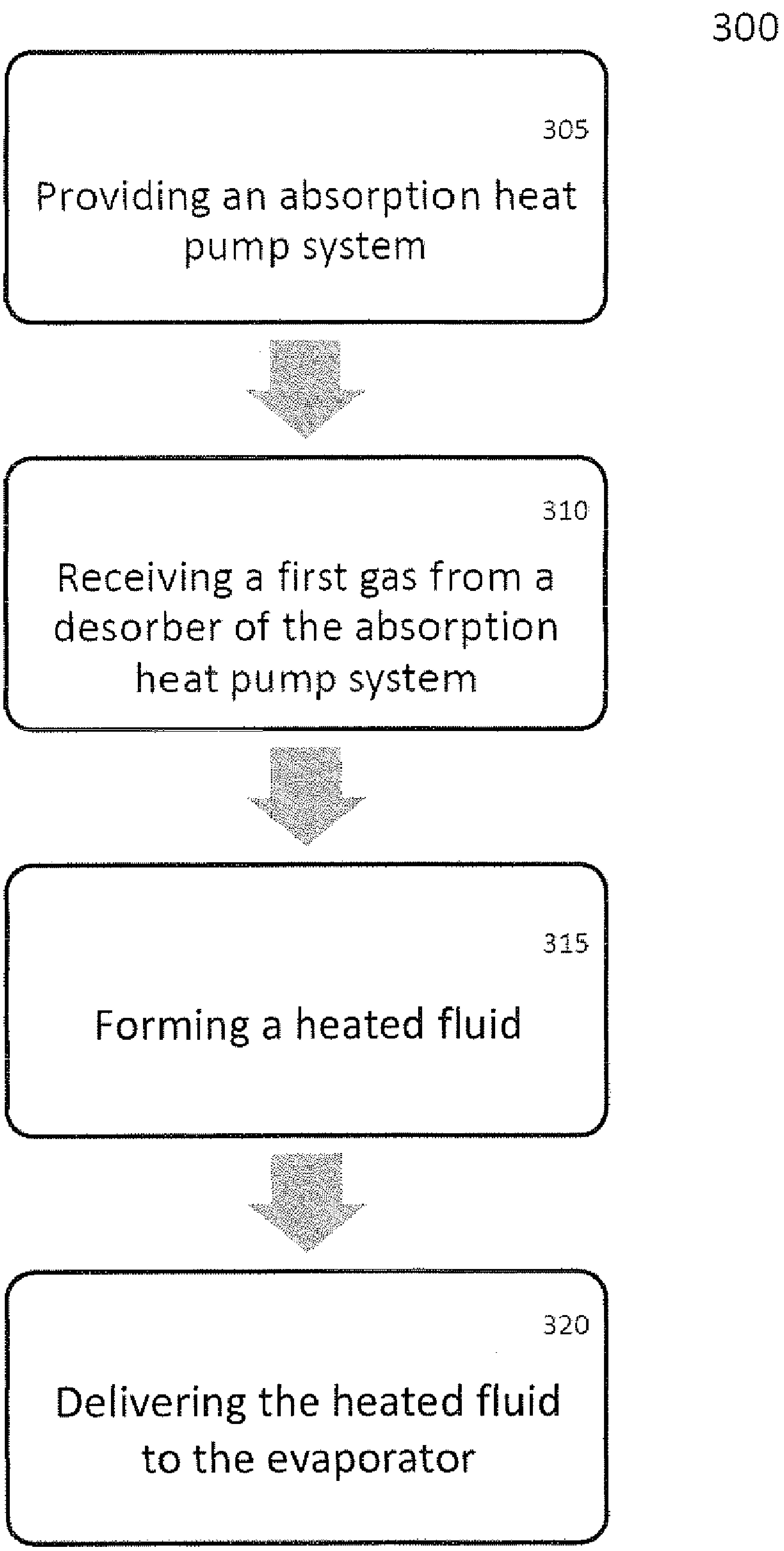
300
305
Providing an absorption heat pump system
310
Receiving a first gas from a desorber of the absorption heat pump system
315
Forming a heated fluid
320
Delivering the heated fluid to the evaporator

FIGURE 3

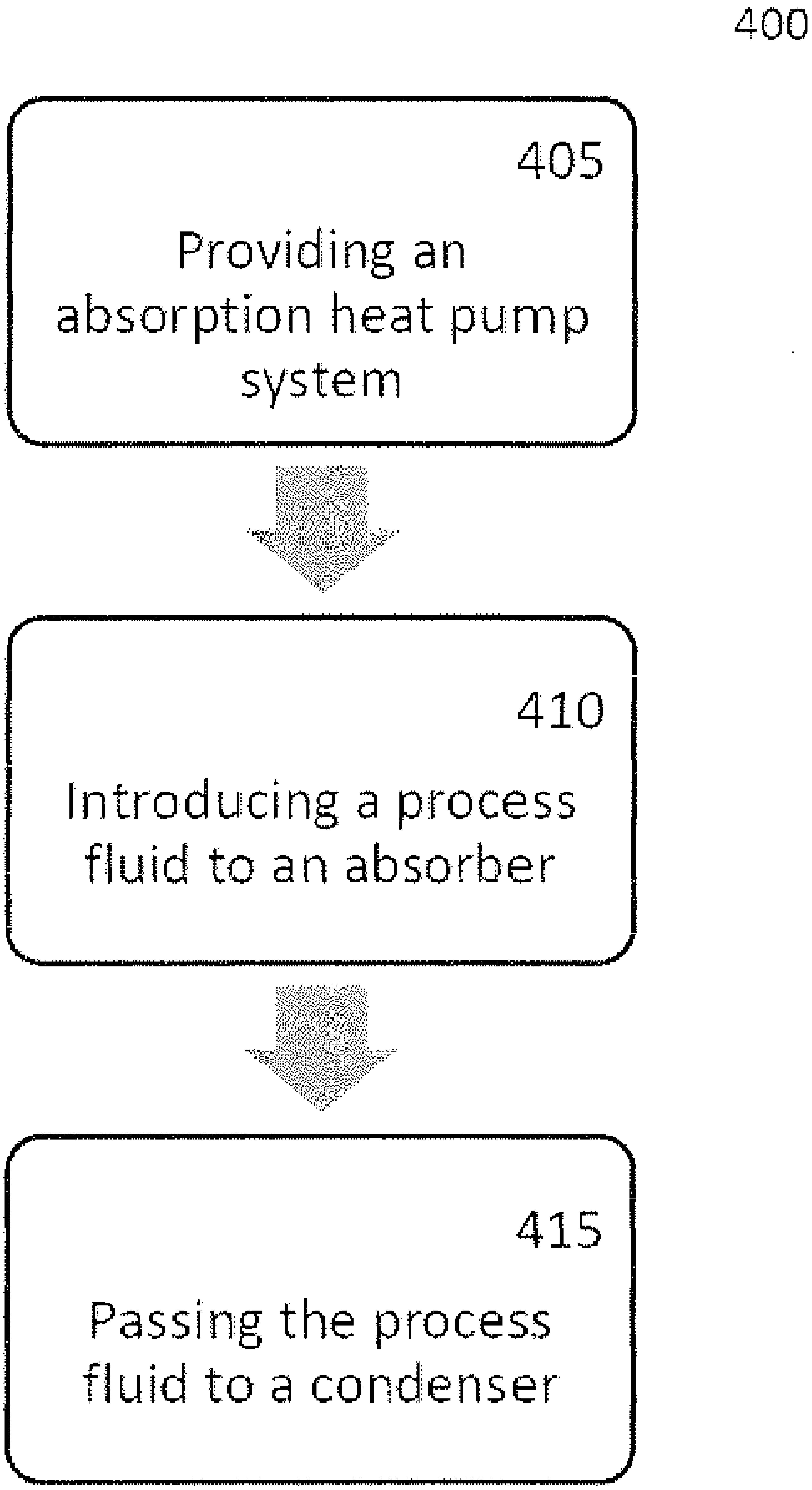
400
405
Providing an absorption heat pump system
410
Introducing a process fluid to an absorber
415
Passing the process fluid to a condenser

FIGURE 4

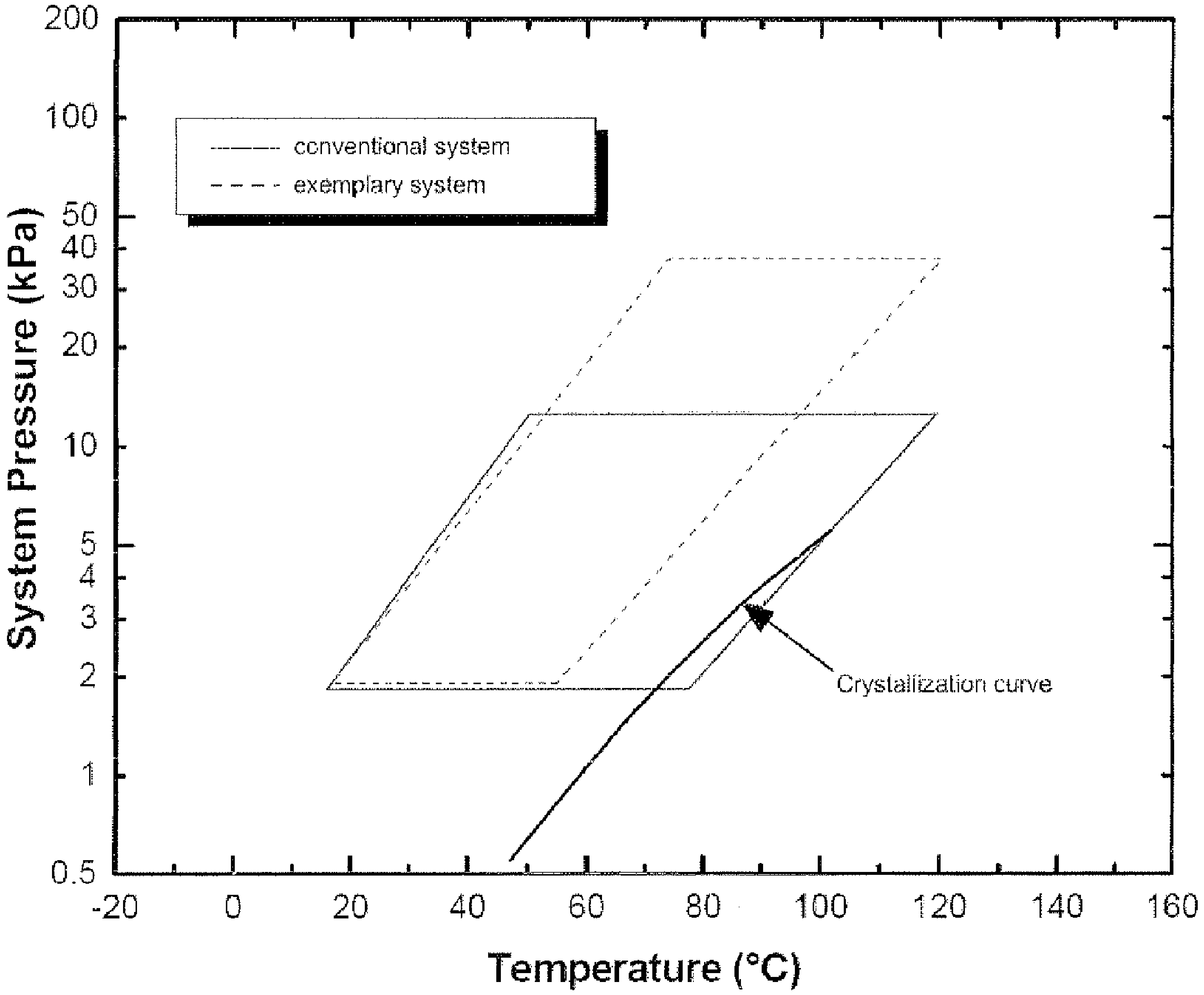
200
100
50
40
30
20
10
5
4
3
2
1
0.5
System Pressure (kPa)
-20
0
20
40
60
80
100
120
140
160
Temperature (°C)
conventional system
exemplary system
Crystallization curve

FIGURE 5

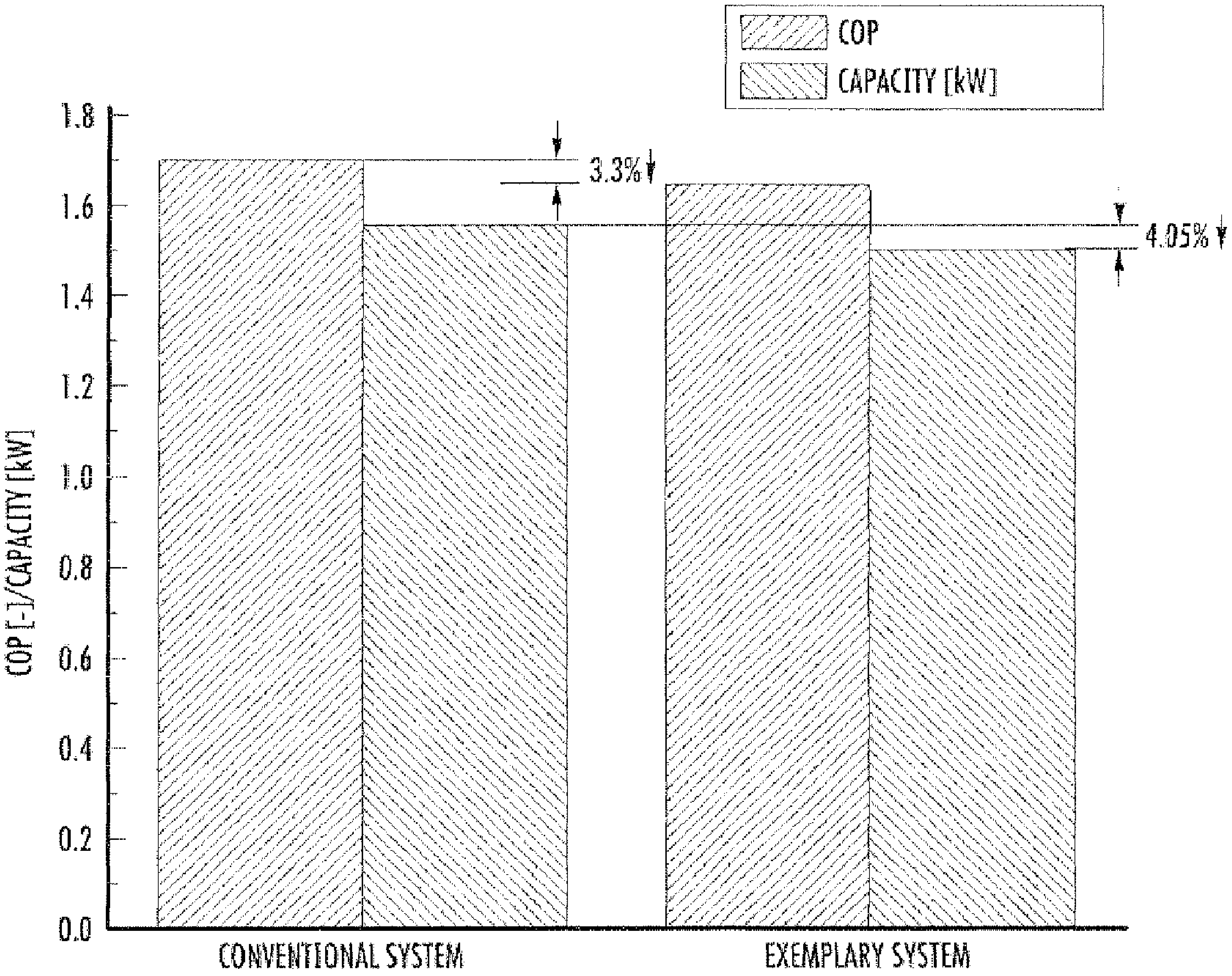
COP
CAPACITY [kW]
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
COP [-]/CAPACITY [kW]
3.3%
4.05%
CONVENTIONAL SYSTEM
EXEMPLARY SYSTEM

FIGURE 6

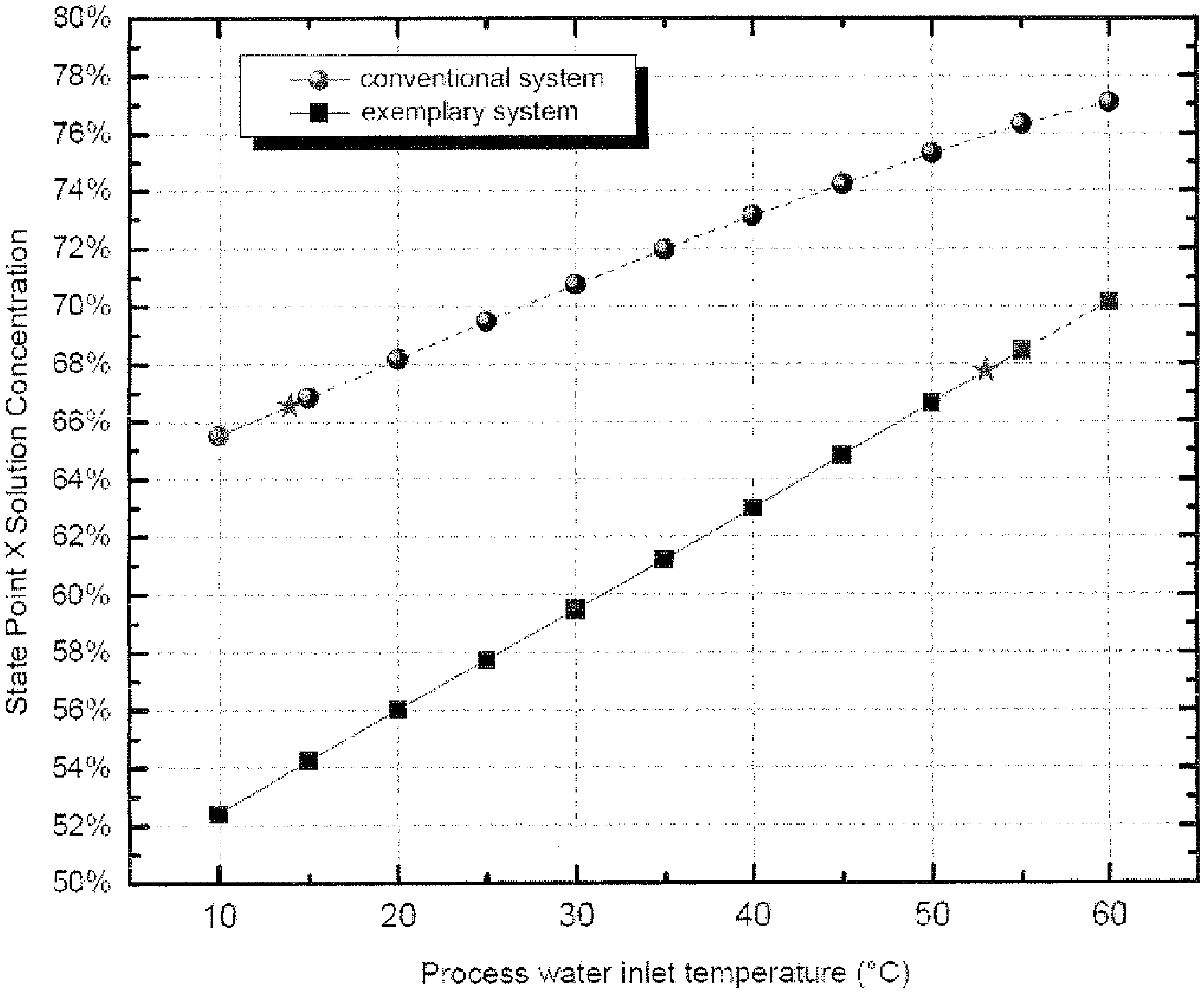
conventional system
exemplary system
State Point X Solution Concentration
80%
78%
76%
74%
72%
70%
68%
66%
64%
62%
60%
58%
56%
54%
52%
50%
10
20
30
40
50
60
Process water inlet temperature (°C)

FIGURE 7

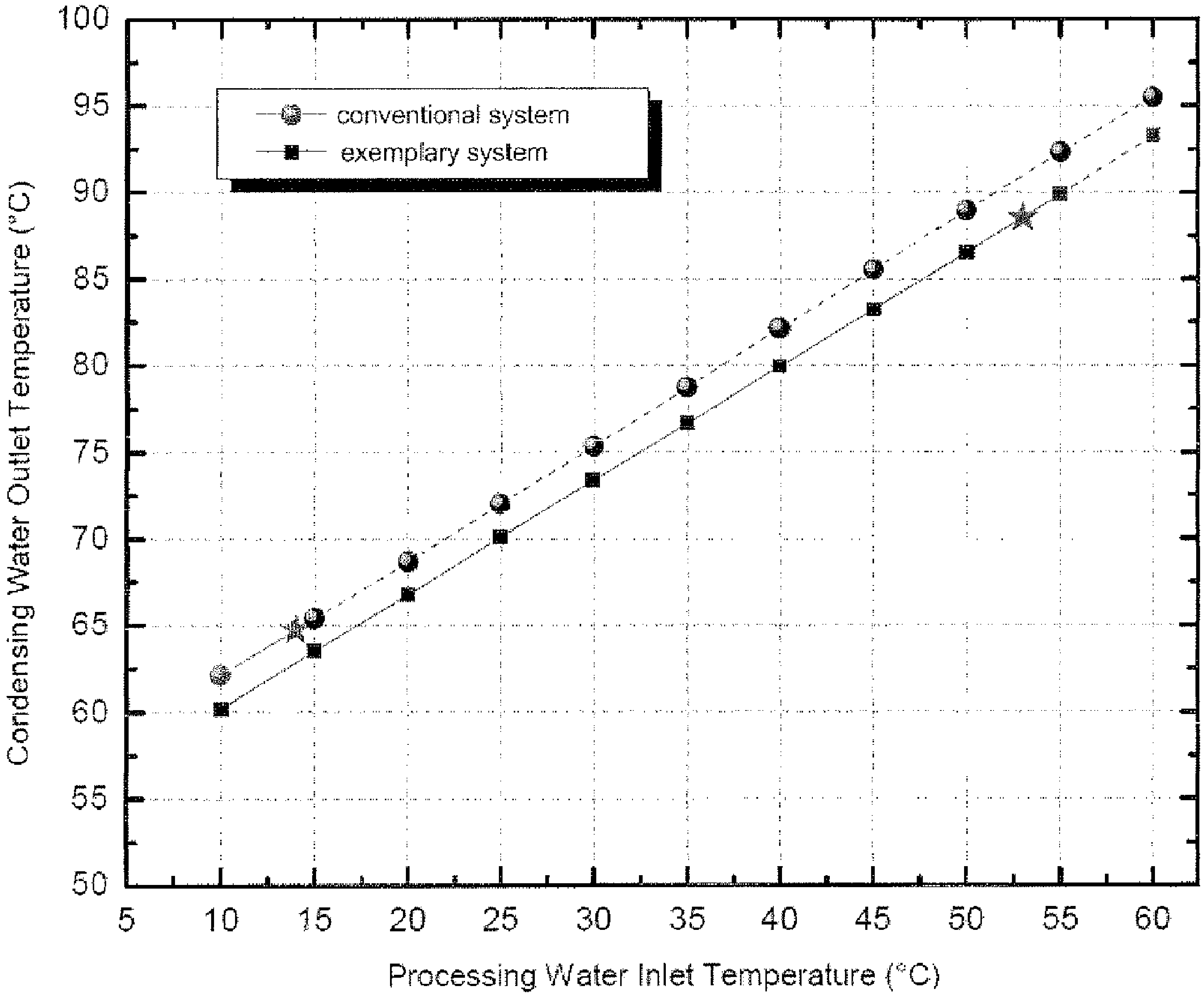
100
95
90
85
80
75
70
65
60
55
50
5
10
15
20
25
30
35
40
45
50
55
60
Condensing Water Outlet Temperature (°C)
Processing Water Inlet Temperature (°C)
conventional system
exemplary system

FIGURE 8

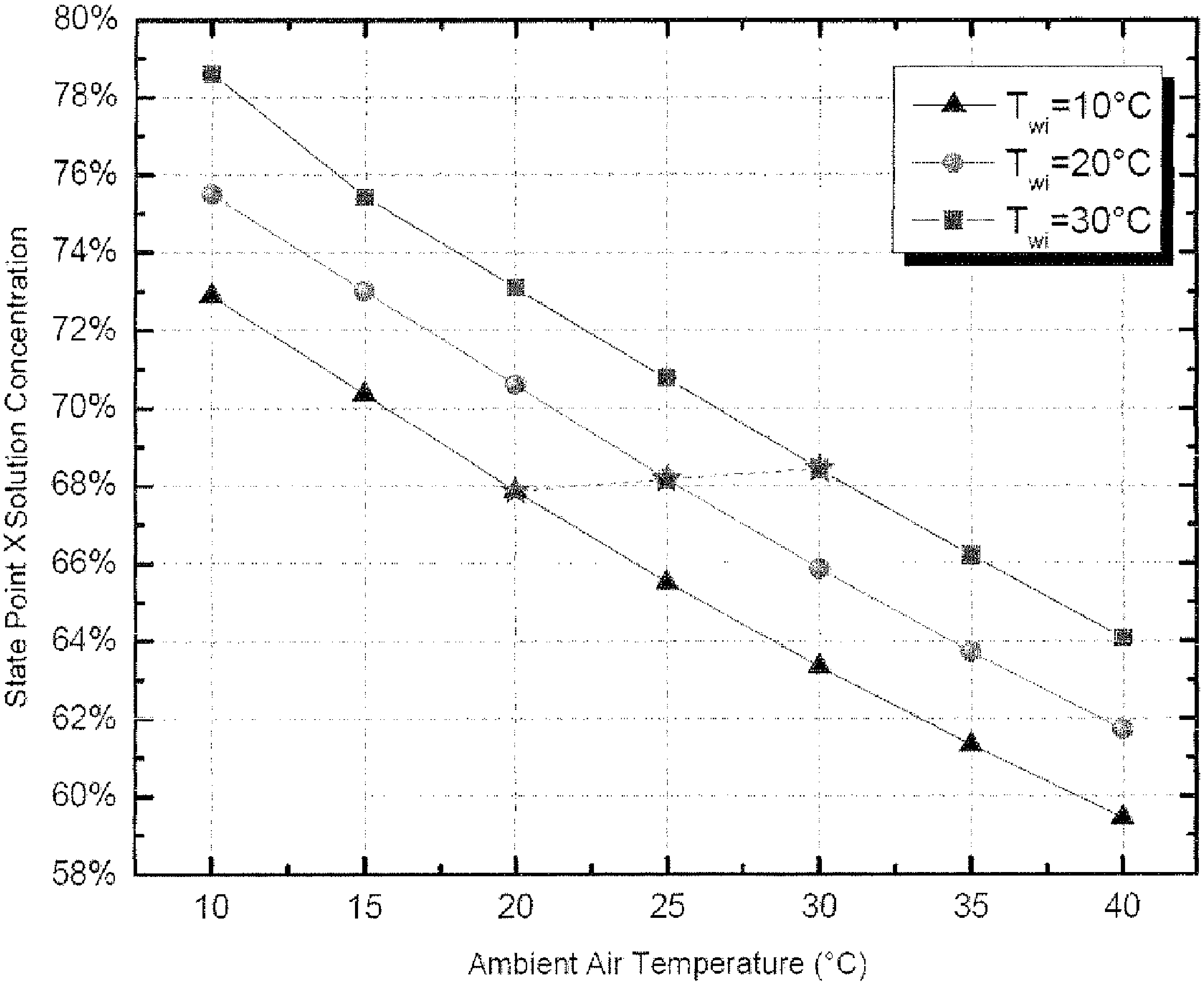
80%
78%
76%
74%
72%
70%
68%
66%
64%
62%
60%
58%
State Point X Solution Concentration
10
15
20
25
30
35
40
Ambient Air Temperature (°C)
T_{wi}=10°C
T_{wi}=20°C
T_{wi}=30°C

FIGURE 9A

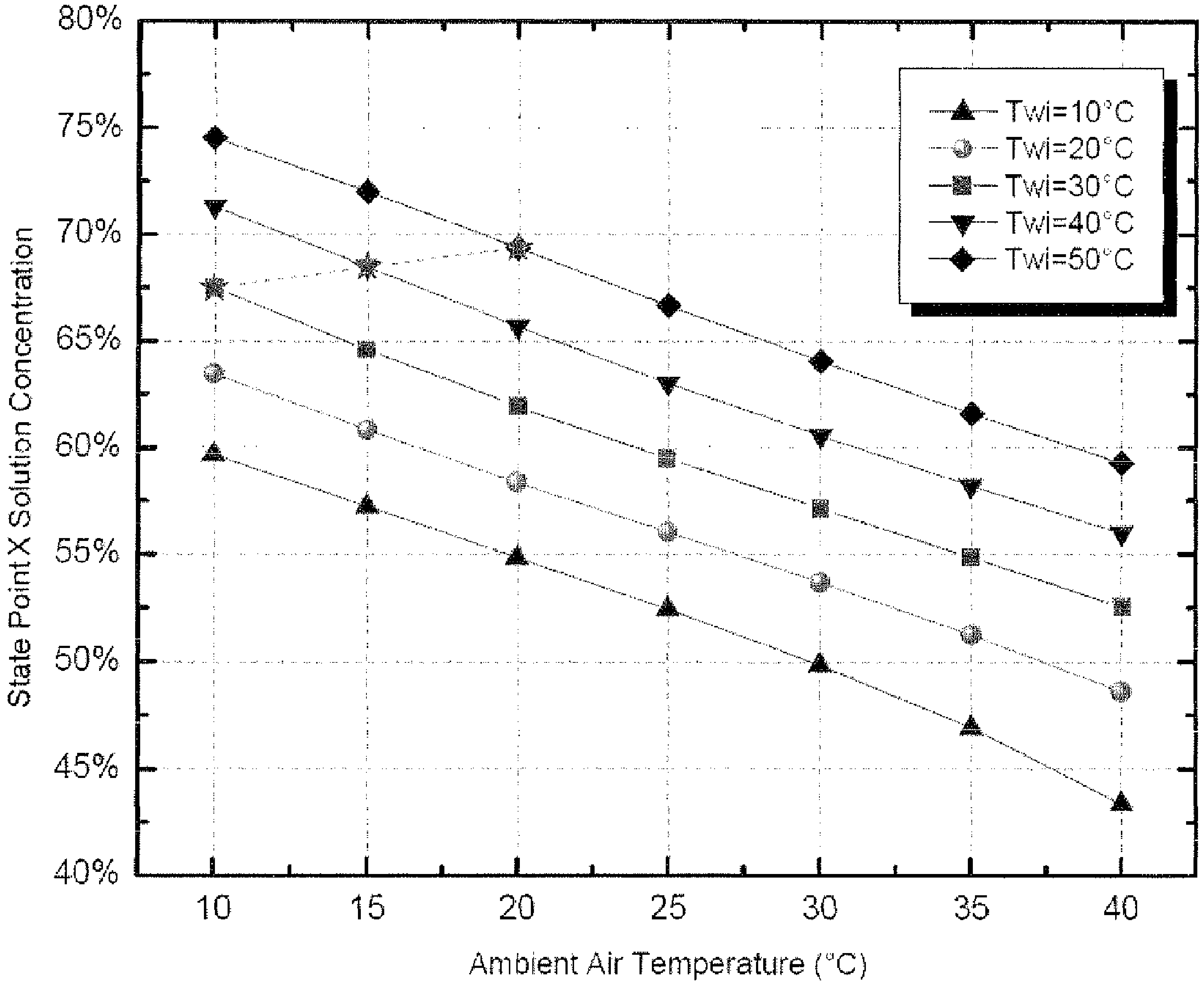
80%
75%
70%
65%
60%
55%
50%
45%
40%
State Point X Solution Concentration
10
15
20
25
30
35
40
Ambient Air Temperature (°C)
Twi=10°C
Twi=20°C
Twi=30°C
Twi=40°C
Twi=50°C

FIGURE 9B

ABSORPTION HEAT PUMP SYSTEM AND METHOD OF USING THE SAME

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0001] The United States Government has rights in this invention pursuant to Contract No. DE-AC05-00OR22725 between the United States Department of Energy and UT-Battelle, LLC. The Government has certain rights in the invention.

FIELD OF THE INVENTION

[0002] This disclosure relates to the field of heat pumps, and more particularly to apparatus and methods of using absorption heat pump systems.

BACKGROUND OF THE INVENTION

[0003] According to the 2009 Buildings Energy Data Book, space cooling and heating, as well as water heating, use 49.8% and 25.2% of primary energy consumed in U.S. residential and commercial buildings, respectively. (U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, 2009a). Moreover, most of the primary energy is produced by fossil fuels which result in the emissions of gasses which harm the environment. Thus, it has become more important than ever to develop energy-efficient and environmental friendly heat pumping technologies.

[0004] Absorption heat pump water heater technology offers a substantial energy saving compared to conventional gas fired water heaters by utilizing additional heat input from the ambient environment. Lithium bromide (Liar)/water (H_2O) absorption systems are an excellent potential candidate since they have been commercialized for cooling applications. One drawback to LiBr/water absorption water heater systems is that they are unable to operate at typical water heating temperatures due to solution crystallization hazards. When LiBr is dissolved in water for use in a LiBr/water absorption heat pump system, there is a specific minimum solution temperature for any given salt concentration. Below this minimum temperature, the LiBr salt begins to precipitate from the solution and crystallize. If the solution concentration is too high or the solution temperature drops below a threshold level, crystallization will occur. Crystallization results in interruption of machine operation.

[0005] Crystallization is more prone to occur in the strong solution entering the absorber, when the concentrated solution is at the lowest temperature. Specifically, the crystallization of LiBr salt generally occurs between the solution heat exchanger outlet and the absorber of the absorption heat pump system.

[0006] In absorption heat pumps, the crystallization line for lithium bromide and water is usually close to the working concentrations needed for practical LiBr/water absorption systems. However, crystallization must be avoided to prevent the formation of slush in the piping network, which results in flow blockages and service interruptions. If this occurs, the concentrated solution temperature needs to be raised significantly above its saturation point in order to dissolve salt crystals within a reasonable time. Restarting absorber operation after crystallization is a labor intensive and time consuming process, which prevents LiBr/water from being a viable working fluid for absorption heat pumping systems.

SUMMARY OF THE INVENTION

[0007] The absorption heat pump system described herein is drawn to a first assembly, a second assembly, and a thermal coupler. The first assembly can include a condenser and an evaporator. The first assembly can be configured with a refrigerant outlet of the condenser in fluid communication with a refrigerant inlet of the evaporator. The evaporator can operate at temperatures greater than 5° C. The second assembly can include an absorber, a desorber, a solution pump, and a heat exchanger. The second assembly can be configured with a solution outlet of the absorber in fluid communication with a solution inlet of the desorber, an absorbent outlet of the desorber in fluid communication with an absorbent inlet of the absorber, and the heat exchanger can be disposed in fluid communication between the absorber and the desorber. The thermal coupler can include a first gas inlet, a second fluid inlet, and a heated fluid outlet. The thermal coupler can include a mixer or a heat exchanger.

[0008] The system can be configured such that a refrigerant outlet of the evaporator is in fluid communication with a refrigerant inlet of the absorber, a refrigerant outlet of the desorber is in fluid communication with a refrigerant inlet of the condenser, a first gas outlet of the desorber is in fluid communication with the first gas inlet of the thermal coupler, and the heated fluid outlet of the thermal coupler is in fluid communication with a heated fluid inlet of the evaporator.

[0009] The absorber of the system can also include a coolant absorber inlet and a coolant absorber outlet. The condenser of the system can also include a coolant condenser inlet and a coolant condenser outlet. The system can be configured such that the coolant absorber outlet is in fluid communication with the coolant condenser inlet and with a pump driving a process fluid from the absorber coolant outlet to the condenser coolant inlet. The process fluid is used as the coolant in this instance.

[0010] The system can also include a refrigerant fluid and an absorbent fluid. The refrigerant fluid can include water (**1120**), and the absorbent fluid can include a liquid which can include lithium bromide (LiBr).

[0011] A method of using an absorption heat pump is also disclosed herein. The method can include providing an absorption heat pump system, coupling an exhaust gas from a desorber of the absorption heat pump system with a second fluid to form a second heated fluid, and delivering the second heated fluid to an evaporator of the absorption heat pump system. Coupling can include mixing the exhaust gas and the second fluid to form the second heated fluid and heat transfer from the exhaust gas to the second fluid through at least one solid surface to form the second heated fluid.

[0012] The method can also include introducing a process fluid to an absorber of the absorption heat pump system before passing the process fluid to a condenser of the absorption heat pump system, and a temperature of the process fluid exiting the condenser can be greater than a temperature of the process fluid exiting the absorber.

[0013] The method can also include circulating a refrigerant fluid from the evaporator through an absorber of the absorption heat pump system then through the desorber then through a condenser of the absorption heat pump system; and circulating an absorbent fluid between the absorber and the desorber. The refrigerant fluid can include water, and the absorbent fluid can include LiBr.

[0014] The method can also include receiving refrigerant fluid in the absorber and receiving absorbent fluid in the absorber. The refrigerant fluid can include a vapor phase. A solution can be formed including the refrigerant fluid and the absorbent fluid, such that the solution has a concentration of less than 65% LiBr immediately after exiting the absorber.

[0015] The method can also include operating the evaporator at a temperature greater than 5° C. The method can also include operating the absorption heat pump system without forming LiBr crystals proximate the absorber.

[0016] These and other embodiments are described in more detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] A fuller understanding of the present invention and the features and benefits thereof will be obtained upon review of the following detailed description together with the accompanying drawings, in which:

[0018] FIG. **1***a* is a schematic of an exemplary absorption heat pump system with a mixer as the thermal coupler;

[0019] FIG. **1***b* is a schematic of an exemplary absorption heat pump system with a heat exchanger as the thermal coupler;

[0020] FIG. **2** is a schematic of an exemplary absorption heat pump system;

[0021] FIG. **3** is a flow diagram of an exemplary method of using an absorption heat pump system;

[0022] FIG. **4** is a flow diagram of an exemplary method of using an absorption heat pump system;

[0023] FIG. **5** is a pressure-temperature diagram for the exemplary absorption heat pump system of FIG. **2** and a conventional absorption heat pump system;

[0024] FIG. **6** is a graph comparing the performance of the exemplary absorption heat pump system of FIG. **2** and a conventional absorption heat pump system;

[0025] FIG. **7** is a chart comparing the exemplary absorption heat pump system of FIG. **2** and a conventional absorption heat pump system at different process fluid inlet temperatures;

[0026] FIG. **8** is a chart comparing process fluid outlet temperature variation with different process water inlet temperature in the exemplary absorption heat pump system of FIG. **2** and a conventional absorption heat pump system;

[0027] FIG. **9***a* is a chart of state point X solution concentration variations versus ambient temperature and process fluid inlet temperature in a conventional absorption heat pump system; and

[0028] FIG. **9***b* is a chart of state point X solution concentration variations versus ambient temperature and process fluid inlet temperature in the exemplary absorption heat pump system of FIG. **2**.

[0029] For a better understanding of the present invention, together with other and further objects, advantages and capabilities thereof, reference is made to the following disclosure and appended claims in connection with the above-described drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0030] As noted earlier, LiBr/H_2O absorption heat pump systems are unable to operate at domestic water heating temperatures due to crystallization of LiBr salt experienced between the solution heat exchanger outlet and the absorber. To overcome these drawbacks, an absorption heat pump system and method are described herein. The absorption heat pump system and method reduce or eliminate the possibility of crystallization in the system and allows for use in domestic and commercial heating and cooling applications.

[0031] In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings, which form a part hereof, and within which are shown by way of illustration the practice of specific embodiments of systems and methods for absorption heat pumps. It is to be understood that other embodiments may be utilized, and that structural changes may be made and processes may vary in other embodiments.

[0032] Prior to describing the invention, it is useful to define a variety of terms relevant to the absorption heat pump system and methods described herein. As used herein, the term “condenser” has its standard meaning in the art, refers to a chamber or component capable of converting at least a portion of vapor to liquid, and can include a heat exchanger. The term “evaporator” has its standard meaning in the art, refers to a chamber or component capable of converting at least a portion of liquid to vapor, and can include a heat exchanger. The term “absorber” has its standard meaning in the art and refers to a chamber or component capable of permeating or absorbing one substance into another substance. The term “heat exchanger” has its standard meaning in the art and refers to a component capable of heat transfer from one medium to another. The term “desorber” has its standard meaning in the art and refers to a chamber or component capable of evaporating a more volatile substance (e.g. refrigerant) from a solution (e.g. working fluid).

[0033] As used herein, the terms “refrigerant,” “absorbent,” “solution,” and “working fluid” have their standard meanings in the art. The refrigerant is a more volatile substance of a working fluid and the absorbent is a less volatile substance with high affinity to absorb the refrigerant. The working fluid or solution can be a mixture of these two substances (refrigerant and absorbent). For example, in LiBr absorption heat pumps, the refrigerant can include water and the absorbent can include an aqueous LiBr solution with high affinity to absorb water (refrigerant).

[0034] As used herein, the phrase “fluid communication” includes direct and indirect communication of liquid, gas, or a mixture of both. Fluids include any liquid, gas, or mixture thereof, and can be a combination of different types of fluids.

[0035] FIGS. **1***a* and **1***b* illustrate an embodiment of an absorption heat pump system **100** that can include first assembly **105**, a second assembly **110**, and a thermal coupler **170**. The first assembly **105** can include a condenser **120** and an evaporator **130**. The condenser **120** can be configured with a refrigerant outlet **121** in fluid communication with a refrigerant inlet **131** of the evaporator **130**. An expansion valve **190** can be included between the refrigerant outlet **121** and the refrigerant inlet **131**. The operating temperature of the evaporator **130** can be greater than 5° C., greater than 10° C., or greater than 15° C. The operating temperature of the evaporator **130** can also be less than the operating temperature of the condenser **120** or absorber **140**.

[0036] The second assembly **110** can include an absorber **140**, a desorber **150**, and a heat exchanger **160**. The absorber **140** can be configured with a solution outlet **141** and an absorbent outlet **152**. The solution outlet **141** can be in fluid communication with a solution inlet **151** of the desorber **150**, and the absorbent outlet **152** of the desorber **150** can be in fluid communication with an absorbent inlet **142** of the absorber **140**. The heat exchanger **160** can be disposed in fluid communication with and between the absorber **140** and the desorber **150**.

[0037] The heat exchanger **160** can include an exchanger solution inlet in fluid communication with the solution outlet **141** of the absorber **140**, and an exchanger solution outlet in fluid communication with the solution inlet **151** of the desorber **150**. The heat exchanger **160** can also include an exchanger absorbent inlet in fluid communication with the absorbent outlet **152** of the desorber **150**, and an exchanger absorbent outlet in fluid communication with the absorbent inlet **142** of the absorber **140**. The second assembly can also include other elements, such as a solution pump disposed in fluid communication between the absorber **140** and the desorber **150**. This is shown in more detail in connection with FIG. **2**.

[0038] The unit operations and interconnection of unit operations shown in FIGS. **1***a*, **1***b* and **2** can be substituted or added in order to further improve these embodiments. For example, the thermal coupler **170** of FIGS. **1***a* and **1***b* can be adapted for use in connection with the embodiment of FIG. **2**.

[0039] The system **100** can be configured such that a refrigerant outlet **133** of the evaporator **130** can be in fluid communication with a refrigerant inlet **143** of the absorber **140**, a refrigerant outlet **153** of the desorber **150** can be in fluid communication with a refrigerant inlet **123** of the condenser **120**. The system **100** can also be configured such that a first gas outlet **154** of the desorber **150** can be in fluid communication with a first gas inlet **174** of the thermal coupler **170**, and a heated fluid outlet **176** of the thermal coupler **170** can be in fluid communication with a heated fluid inlet **136** of the evaporator **130**. A second fluid inlet **175** of the thermal coupler **170** can be open to a lower temperature heat source, e.g., ambient air.

[0040] The thermal coupler **170** can include any chamber, component or other apparatus for coupling a stream of a lower temperature heat source provided through the second fluid inlet **175** to a higher temperature heat source provided through the first gas inlet **174**. The lower temperature heat source can include air, another source of gas, refrigerant circulating in a ground loop, a geothermal source, water, water from the mains, water from a river, water from a cooling tower, or other suitable sources. The higher temperature heat source can include exhaust gases (e.g. flue gases, oil, pressurized water) from the desorber **150**.

[0041] The thermal coupler **170** can be a mixer or a heat exchanger. FIG. **1***a* illustrates an embodiment of the system **100** in which the thermal coupler **170** includes a mixer. The mixer can include a first gas inlet **174**, a second fluid inlet **175**, and a heated fluid outlet **176**. The mixer can form a heated fluid by mixing a first gas and a second fluid.

[0042] FIG. **1***b* illustrates an embodiment of the system **100** in which the thermal coupler **170** includes a heat exchanger. The heat exchanger of the thermal coupler **170** can include a first gas inlet **174**, a second fluid inlet **175**, a heated fluid outlet **176**, and a first gas outlet **177**. The heat exchanger can produce a heated fluid by transferring heat from a first gas to a second fluid.

[0043] The absorber **140** of the system **100** can also include an absorber coolant inlet **147** and an absorber coolant outlet **148**. The condenser **120** can include a condenser coolant inlet **128** and a condenser coolant outlet **129**. The system **100** can be configured such that the absorber coolant outlet **148** is in fluid communication with the condenser coolant inlet **128**. The system **100** can also include a pump for driving a process fluid from the absorber coolant outlet **148** to the condenser coolant inlet **128**. The condenser coolant outlet **129** can be connected to a process hot water outlet **180**, e.g., a hot water faucet.

[0044] As used herein, the terms “coolant” and “process fluid” are used interchangeably and have their standard meanings in the art. Process fluids can include water, glycol mixtures, and antifreeze fluids such as formate-based or acetate-based mixtures.

[0045] The system **100** can also include a refrigerant and an absorbent fluid. The refrigerant fluid can include any suitable fluid known in the art, such as water. The absorbent fluid can include LiBr and can be an aqueous LiBr solution. The absorbent fluid can be in a liquid phase, gas phase, or both depending on the location within the system **100**.

[0046] The system **100** can also operate free from coupling with a waste heat stream from other equipment, e.g. an internal combustion engine. The system **100** can be used for indoor applications or with a low ambient temperature heat source.

[0047] FIG. **2** illustrates another embodiment of an absorption heat pump system **200** that can include a first assembly **205** and a second assembly **210**. The system of FIG. **2** does not include the thermal coupler **170** of FIGS. **1***a* and **1***b*. The first assembly **205** can include a condenser **220** and an evaporator **230**. The condenser **220** can be configured with a refrigerant outlet **221** in fluid communication with a refrigerant inlet **231** of the evaporator **230**. The first assembly **205** can also include other elements, such as an expansion valve **270** disposed in fluid communication between the condenser **220** and the evaporator **230**.

[0048] The second assembly **210** can include an absorber **240**, a desorber **250**, and a heat exchanger **260**. The absorber **240** can be configured with a solution outlet **241** in fluid communication with a solution inlet **251** of the desorber **250**. The desorber can include an absorbent outlet **252** in fluid communication with an absorbent inlet **242** of the absorber **240**. The heat exchanger **260** can be disposed in fluid communication between the absorber **240** and the desorber **250**. The second assembly **210** can also include other elements, such as a solution pump **280** and an expansion valve **290** disposed in fluid communication between the absorber **240** and the desorber **250**. The solution pump **280** can raise the pressure of a weak solution exiting the absorber **240** before it enters the desorber **250**.

[0049] The system **200** can be configured such that a refrigerant outlet **233** of the evaporator **230** can be in fluid communication with a refrigerant inlet **243** of the absorber **240**, and a refrigerant outlet **253** of the desorber **250** can be in fluid communication with a refrigerant inlet **223** of the condenser **220**.

[0050] The system **200** can also be configured such that a coolant outlet **248** of the absorber **240** can be in fluid communication with a coolant inlet **228** of the condenser **220**. The system **200** can also include a pump (not shown) driving a process fluid from the absorber coolant outlet **248** to the condenser coolant inlet **228**.

[0051] FIG. **3** illustrates an embodiment of a method of using an absorption heat pump system. The method **300** can include the steps of providing an absorption heat pump system **305**, receiving a first gas from a desorber of the absorption heat pump system **310**, forming a heated fluid that can include the first gas and a second fluid **315**, and delivering the heated fluid to an evaporator of the absorption heat pump system **320**. The first gas can include exhaust gases from the desorber. The second fluid can include water and air, and the air can be at ambient temperature. The heat pump system can be an absorption heat pump system **100**, **200**, such as those described herein. Depending on the embodiment, the heated fluid can be either (i) a mixture of the first gas and second fluid, e.g., the embodiment of FIG. **1***a*, or (ii) the first gas free from the second fluid, e.g., the embodiment of FIG. **1***b*.

[0052] As used herein, the term "air" means atmospheric gases proximate to the absorption heat pump system. Atmospheric gases generally include a mixture of nitrogen, oxygen, carbon dioxide, small amounts of other gases, including variable amounts of water vapor. As used herein, "ambient temperature" refers to the range of naturally occurring temperatures in the environment surrounding the absorption heat pump system. Ambient temperature can refer to temperatures from about −20° C. to 40° C., or from −10° C. to 40° C. or from 0° C. to 40° C. Ambient temperature can also be greater than 0° C., greater than 5° C., or greater than 10° C.

[0053] The method **300** can also include the steps of introducing a process fluid to an absorber of the absorption heat pump system before passing the process fluid to a condenser of the absorption heat pump system. During this step, a temperature of the process fluid exiting the condenser can be greater than a temperature of the process fluid exiting the absorber.

[0054] The method **300** can also include the steps of circulating a refrigerant fluid from an evaporator through an absorber of the absorption heat pump system then through a desorber then through a condenser of the absorption heat pump system, and circulating an absorbent fluid between the absorber and the desorber. The refrigerant fluid can include water. The absorbent fluid can include LiBr, such as an aqueous LiBr solution.

[0055] The method **300** can also include the steps of feeding a vapor-phase refrigerant fluid to the absorber, feeding absorbent fluid to the absorber, and forming a solution in the absorber. The solution formed in the absorber can include the vapor-phase refrigerant fluid and the absorbent fluid. The solution can have a concentration of less than 65% LiBr immediately after exiting the absorber (e.g., solution outlet **241** of FIG. **2**). The method **300** can also include the steps of operating the evaporator at a temperature greater than 5° C., greater than 10° C., or greater than 15° C. The method can also include operating the absorption heat pump system without forming LiBr crystals proximate the absorber.

[0056] The method **300** can operate an absorption heat pump system without forming LiBr crystals proximate the absorber. As used herein, the term "proximate" has its standard meaning in the art and includes within the absorber and the absorbent inlet **242** of FIG. **2**.

[0057] In another embodiment, the method can include providing an absorption heat pump system, coupling an exhaust gas from a desorber of the absorption heat pump system with a second fluid to form a coupled fluid, and delivering the coupled fluid to an evaporator of the absorption heat pump system. Coupling can include mixing the exhaust gas and the second fluid or heat transfer from the exhaust gas to the second fluid through solid surfaces.

[0058] The method can also include circulating a refrigerant fluid from an evaporator of the absorption heat pump system through the absorber then through a desorber of the absorption heat pump system then through the condenser; and circulating an absorbent fluid between the absorber and the desorber. The refrigerant fluid can include water, and the absorbent fluid can include LiBr.

[0059] FIG. **4** illustrates another embodiment of a method of using an absorption heat pump system. The method **400** can include the steps of providing an absorption heat pump system **405** and introducing a process fluid to an absorber of the absorption heat pump system **410** before passing the process fluid to a condenser of the absorption heat pump system **415**. During these steps, a temperature of the process fluid exiting the condenser can be higher than a temperature of the process fluid exiting the absorber.

[0060] The method **400** can also include the steps of receiving a first gas from a desorber of the absorption heat pump system, coupling the first gas and a second fluid to form a heated fluid stream, and delivering the heated fluid stream (e.g., coupling fluid) to an evaporator of the absorption heat pump system.

[0061] The method **400** can also include the steps of circulating a refrigerant fluid from an evaporator of the absorption heat pump system through the absorber then through a desorber of the absorption heat pump system then through the condenser. The method **400** can include circulating an absorbent fluid between the absorber and the desorber. As previously discussed, the refrigerant fluid can include water, the absorbent fluid can include LiBr, and the absorbent fluid can be an aqueous LiBr solution.

EXAMPLES

[0062] The absorption water heating systems described herein were modeled to show that the proposed systems would enable the use of LiBr-based absorption water heating systems for residential use and eliminate or minimize the risk of crystallization at the absorber. An existing absorption cycle software package, ABSIM, was chosen to investigate single-effect LiBr (absorption water heater) AWH performance. The model treats the heat exchange between the cycle and its surroundings according to several user-specified options differentiated by the required user input. These include 'UA', effectiveness or temperature difference options. The model incorporates a number of working fluid combinations including LiBr/water and ammonia (NH$_3$)/water.

[0063] A model for a conventional 1.6 kW single-effect absorption heat pump system where the process water flows from the condenser to the absorber was developed using ABSIM. A model for an exemplary absorption heat pump system where the process water flows through the absorber then through the condenser, such as in FIG. **2**, was also developed using ABSIM.

[0064] Table 1 shows the operating conditions for both the conventional and exemplary absorption heat pump system models.

TABLE 1

Operating Conditions			
Strong solution flow rate (kg · s^{-1})	0.0045	Flue gas inlet temperature (° C.)	400
Absorber effectiveness	0.85	Flue gas flow rate (kg · s^{-1})	0.0038
Condenser effectiveness	0.83	Ambient air temperature (° C.)	25

TABLE 1-continued

Operating Conditions			
Generator effectiveness	0.70	Ambient air flow rate (kg · s^{-1})	0.14
Evaporator effectiveness	0.50	Process water inlet temperature (° C.)	25
Solution HX effectiveness	0.72	Process water flow rate (kg · s^{-1})	0.0079

[0065] The simulation results under design operating conditions for the modeled comparative system are shown in Table 2 below.

TABLE 2

Results for Comparative Heat Pump System			
COP	1.7	Capacity	1.553 kW
$\dot{Q}_a$	0.86 kW	$\dot{Q}_c$	0.69 kW
$\dot{Q}_g$	0.91 kW	$\dot{Q}_e$	0.64 kW
Q_{SHX}	0.26 kW	$\dot{m}_4$	0.0042 kg/s
$\dot{m}_7$	0.0003 kg/s	P_{low}	1.83 kPa
P_{high}	12.5 kPa	$X_{1,2,3}$	65.2%
$X_{4,5,6}$	69.5%	$T_{1,2}$	68.2° C.
T_3	100.1° C.	$T_{4,7}$	119.5° C.
$T_{5,6}$	82.6° C.	T_8	50.3° C.
$T_{9,10}$	16° C.	T_{11}	400° C.
T_{12}	196.3° C.	T_{14}	46° C.
T_{15}	72° C.	T_{17}	20.5° C.

[0066] The simulation results under design operating conditions for model based on the absorption heating system disclosed herein are shown in Table 3 below.

TABLE 3

Results for Exemplary Absorption Heat Pump System			
COP	1.64	Capacity	1.49 kW
$\dot{Q}_a$	0.86 kW	$\dot{Q}_c$	0.63 kW
$\dot{Q}_g$	0.91 kW	$\dot{Q}_e$	0.58 kW
Q_{SHX}	0.45 kW	$\dot{m}_4$	0.0042 kg/s
$\dot{m}_7$	0.0003 kg/s	P_{low}	1.92 kPa
P_{high}	37 kPa	$X_{1,2,3}$	54.4%
$X_{4,5,6}$	57.75%	$T_{1,2}$	47.5° C.
T_3	95° C.	$T_{4,7}$	120.4° C.
$T_{5,6}$	67.9° C.	T_8	74° C.
$T_{9,10}$	16.8° C.	T_{11}	400° C.
T_{12}	197.6° C.	T_{13}	70.1° C.
T_{14}	51° C.	T_{17}	20.9° C.

[0067] In each of the models, the segment in the system's flow cycle in which the low pressure concentrated solution leaves the solution heat exchanges and prior to entering the absorber is referred to as state point X. For example, in FIG. **2**, state point X is disposed between the expansion valve **290** and the absorbent inlet **242**.

[0068] The Pressure-Temperature diagrams of both comparative and exemplary flow configurations are shown in FIG. **5**. The process water inlet temperature for the system is set to 25° C. in both models, e.g. the temperature entering absorber **240** for the exemplary model (Point A in FIG. **2**) and the temperature entering the condenser for the conventional model. For the conventional model (solid line in FIG. **5**), the solution concentration and pressure of state point X are 69.48% and 1.82 kPa, respectively. This condition corresponds to supersaturation, i.e. crystallization will occur at state point X. For the exemplary model (dashed line in FIG. **5**), the solution concentration and pressure of state point X are 57.75% and 1.92 kPa, respectively. The exemplary process conditions are far from the crystallization curve (Bold Line). This is a result of process water flowing into the absorber (e.g. at Point A in FIG. **2** or **147** in FIG. **1**) at a lower temperature for the exemplary model (25° C.) compared to the conventional model (45.97° C.).

[0069] Lower temperatures in the absorber require lower absorber solution concentration in order to avoid crystallization. However, higher process temperature entering the condenser will reduce the heating capacity and Coefficient of Performance (COP). As shown in FIG. **6**, the COP is reduced by 3.30% and the heating capacity is reduced by 4.05% from the conventional model to the exemplary model. This drop is insignificant since it produces an absorption cycle useful for residential applications, e.g., water heating.

[0070] FIG. **7** shows the low pressure concentrated solution at state point X, which is vulnerable to crystallization, pressure and concentration combination versus process water inlet temperature, e.g. temperature at absorbent inlet **242**, varied from 10° C. to 60° C. for both comparative and exemplary models. The star symbol corresponds to the maximum allowable operating conditions beyond which the system will be prone to LiBr crystallization. The results shown in FIG. **7** indicate that the exemplary model enables a wider span of inlet process water temperature compared to the conventional model. The lithium bromide solution of an absorption heat pump system with the conventional flow configuration cycle begins to crystallize when the process water inlet temperature is 14° C. However, the salt solution of an absorption heat pump system with the exemplary flow configuration does not begin to crystallize until the process water inlet temperature increases above 53° C. These simulation results are based on the operating and design parameters of Table 1 while only varying the process water inlet temperature from 10° C. to 60° C.

[0071] FIG. **8** depicts the trends for outlet process water temperature variation with inlet water conditions for the two models. Higher COP and capacity of the conventional model resulted in higher outlet process water temperature. The average difference in outlet temperature between the different models is about 2° C. However, the conventional model experiences crystallization over most of the simulation design space. The results shown in FIG. **8** depict that the maximum water outlet temperature for the conventional model is 64.75° C., whereas that for the exemplary model is 88.53° C.

[0072] FIGS. **9***a* and **9***b*, show the dependences of the low pressure strong solution (state point X) concentration for a conventional system (FIG. **9***a*) and an exemplary system (FIG. **9***b*), respectively. First, the strong LiBr solution concentration strongly depends on the process water inlet temperature. A lower process water inlet temperature results in a lower strong LiBr solution concentration. Second, the strong solution concentration is influenced by the ambient air temperatures. Higher ambient air temperatures result in a lower strong LiBr solution concentration. The areas above dash lines in FIGS. **9***a* and **9***b* represent operating conditions that should be avoided in order to avoid crystallization. The comparison between FIGS. **9***a* and **9***b* shows that the exemplary model has a much larger feasible area of operation than the conventional model.

[0073] The comparison of performance of the two models discussed above shows that reversing the process water flow direction resulted in a safer operating conditions and larger area of feasible operating conditions. This crystallization control strategy results in performance degradation of less than 5% in efficiency and capacity.

We claim:

1. An absorption heat pump system comprising:

a first assembly comprising a condenser and an evaporator, wherein a refrigerant outlet of said condenser is in fluid communication with a refrigerant inlet of said evaporator;

a second assembly comprising an absorber, a desorber, and a heat exchanger, wherein a solution outlet of said absorber is in fluid communication with a solution inlet of said desorber, an absorbent outlet of said desorber is in fluid communication with an absorbent inlet of said absorber, and said heat exchanger is disposed in fluid communication between said absorber and said desorber; and

a thermal coupler comprising a first gas inlet, a second fluid inlet, and a heated fluid outlet,

wherein a refrigerant outlet of said evaporator is in fluid communication with a refrigerant inlet of said absorber, a refrigerant outlet of said desorber is in fluid communication with a refrigerant inlet of said condenser, and wherein a first gas outlet of said desorber is in fluid communication with said first gas inlet of said thermal coupler, and said heated fluid outlet of said thermal coupler is in fluid communication with a heated fluid inlet of said evaporator.

2. The absorption heat pump system according to claim **1**, wherein said thermal coupler comprises a mixer.

3. The absorption heat pump system according to claim **1**, wherein said thermal coupler comprises a heat exchanger.

4. The absorption heat pump system according to claim **1**, wherein

said absorber further comprises a coolant absorber inlet and a coolant absorber outlet,

said condenser further comprises a coolant condenser inlet and a coolant condenser outlet, and

wherein said coolant absorber outlet is in fluid communication with said coolant condenser inlet and a pump driving a process fluid from said absorber coolant outlet to said condenser coolant inlet.

5. The absorption heat pump system according to claim **1**, further comprising

a refrigerant fluid comprising water, and

an absorbent fluid comprising a liquid comprising lithium bromide (LiBr).

6. The absorption heat pump system according to claim **1**, wherein said evaporator has an operating temperature greater than 5° C.

7. A method of using an absorption heat pump comprising:

providing an absorption heat pump system;

receiving a first gas from a desorber of said absorption heat pump system;

forming a third fluid comprising said exhaust gas and a second gas; and

delivering said third fluid to an evaporator of said absorption heat pump system.

8. The method according to claim **7**, wherein said first gas comprises exhaust from said desorber.

9. The method according to claim **7**, wherein said second gas comprises air.

10. The method according to claim **7**, further comprising:

introducing a process fluid to an absorber of said absorption heat pump system before passing said process fluid to a condenser of said absorption heat pump system,

wherein a temperature of said process fluid exiting said condenser is greater than a temperature of said process fluid exiting said absorber.

11. The method according to claim **7**, further comprising

circulating a refrigerant fluid from said evaporator through an absorber of said absorption heat pump system then through said desorber then through a condenser of said absorption heat pump system;

circulating an absorbent fluid between said absorber and said desorber; and

wherein said refrigerant fluid comprises water, and

said absorbent fluid comprises LiBr.

12. The method according to claim **11**, further comprising:

receiving refrigerant fluid comprising a vapor phase in said absorber;

receiving absorbent fluid in said absorber;

forming a solution comprising said refrigerant fluid comprising a vapor phase and said absorbent fluid, wherein said solution has a concentration of less than 65% LiBr immediately after exiting said absorber.

13. The method according to claim **7**, further comprising operating said evaporator at a temperature greater than 5° C.

14. The method according to claim **7**, further comprising operating said absorption heat pump system without forming LiBr crystals proximate said absorber.

15. A method of using an absorption heat pump comprising:

providing an absorption heat pump system;

coupling an exhaust gas from a desorber of said absorption heat pump system with a second fluid to form a second heated fluid; and

delivering said second heated fluid to an evaporator of said absorption heat pump system.

16. The method according to claim **15**, wherein said coupling comprises mixing said exhaust gas and said second fluid to form said second heated fluid.

17. The method according to claim **15**, wherein said coupling comprises heat transfer from said exhaust gas to said second fluid through at least one solid surface to form said second heated fluid.

18. The method according to claim **15**, further comprising:

circulating a refrigerant fluid from an evaporator of said absorption heat pump system through said absorber then through a desorber of said absorption heat pump system then through said condenser;

circulating an absorbent fluid between said absorber and said desorber; and

wherein said refrigerant fluid comprises water, and

said absorbent fluid comprises LiBr.

19. The method according to claim **15**, farther comprising operating said evaporator at a temperature greater than 5° C.

20. The method according to claim **15**, farther comprising operating said absorption heat pump system without forming LiBr crystals proximate said absorber.

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