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Mueller et al.(10) **Pub. No.: US 2007/0209380 A1**(43) **Pub. Date: Sep. 13, 2007**(54) **THERMAL SUPERCONDUCTOR
REFRIGERATION SYSTEM****Publication Classification**(76) Inventors: **Lynn Mueller**, Richmond (CA); **John
Graham**, Vancouver (CA)(51) **Int. Cl.**
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CHICAGO, IL 60661(57) **ABSTRACT**

A superconductor refrigeration system incorporates thermal superconducting heat transfer. The system includes an intensifying heat exchanger, a refrigerating heat exchange coil formed from thermal superconductor material, and a dissipating heat exchange coil formed from thermal superconductor material. The system can also include a switch connected to condenser and evaporator heat exchange segments, a refrigeration switch segment and a dissipating switch segment such that in a first switch position a refrigerating mode is provided and in a second switch position a defrost mode is provided. Additional embodiments include thermostat controllers and blowers for enhanced control. Heat exchange and reuse is described for multiple heat exchangers coupled by thermal superconductors. A defrosting element is described for refrigeration heat exchangers.

(21) Appl. No.: **11/619,493**(22) Filed: **Jan. 3, 2007**(30) **Foreign Application Priority Data**

Jan. 3, 2006 (CA) 2,530,621

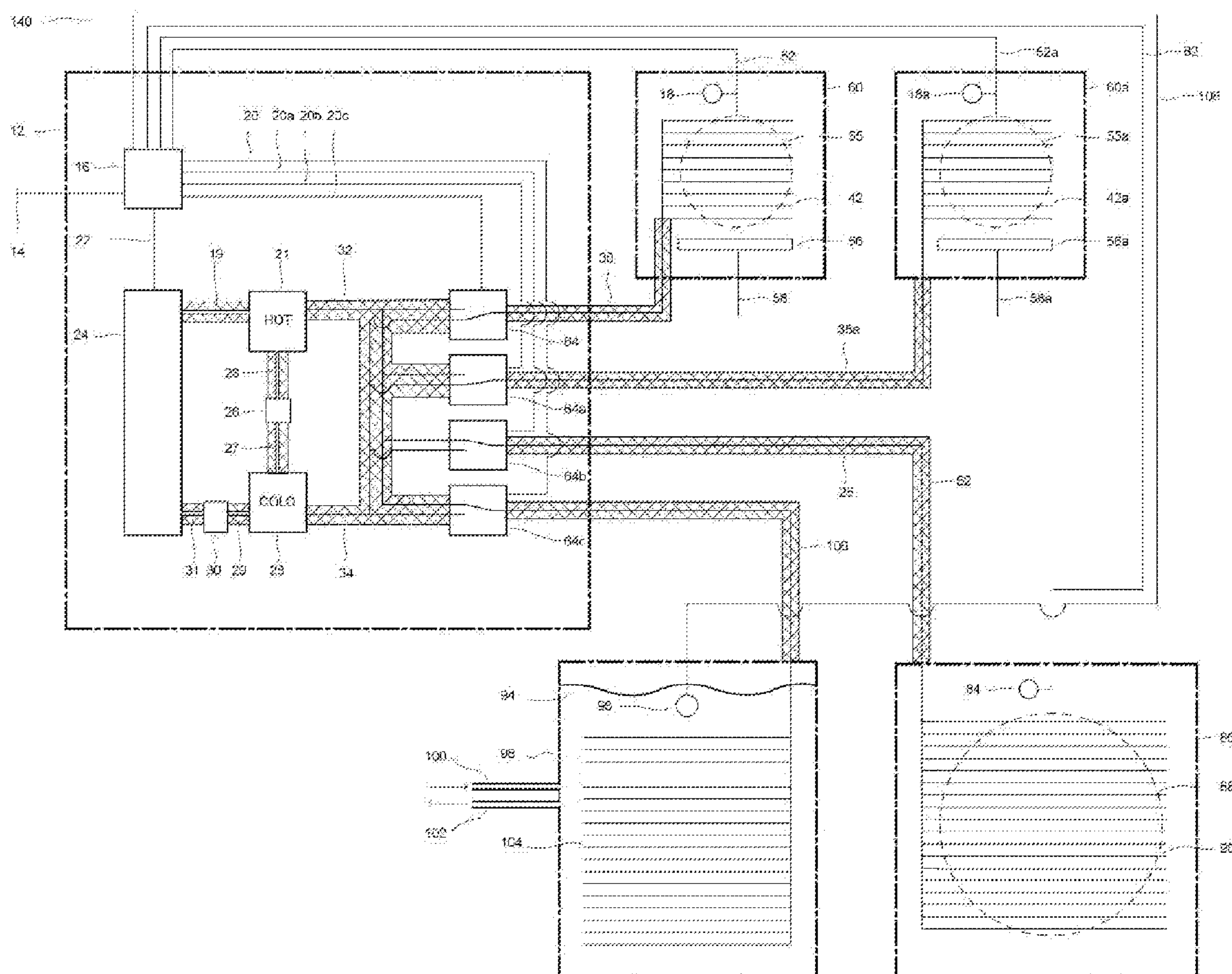


Figure 1a

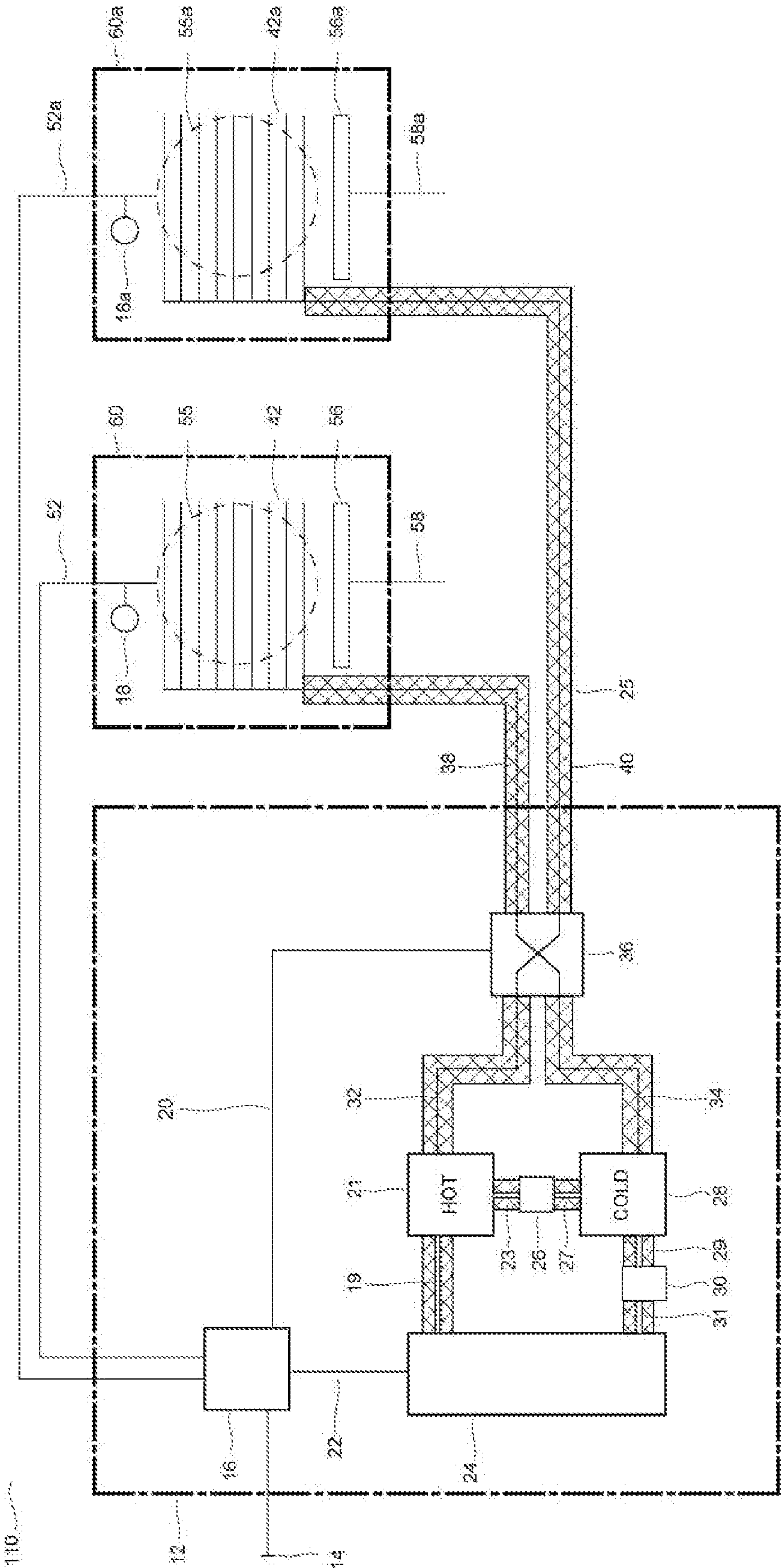


Figure 1b

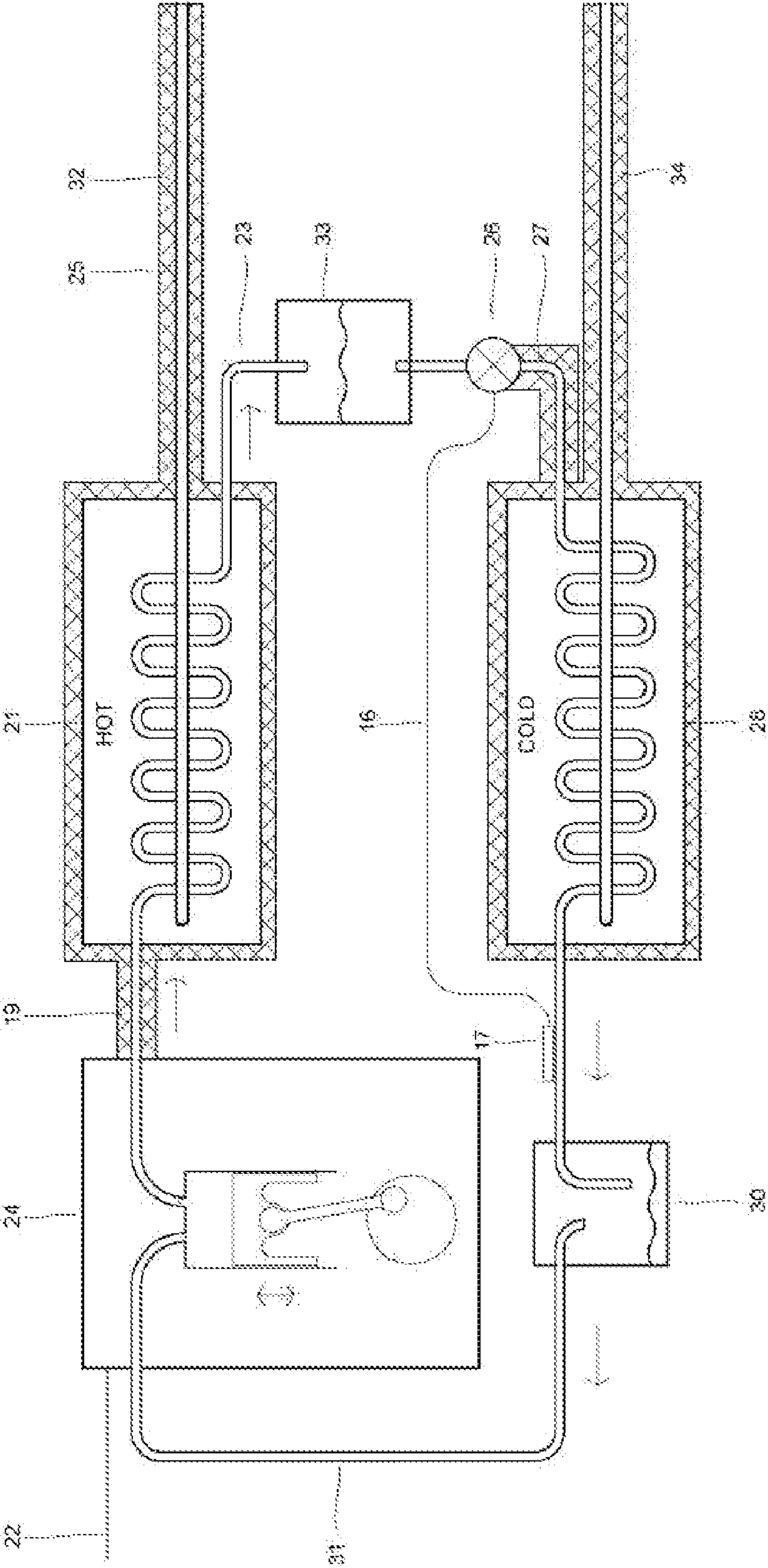


Figure 2

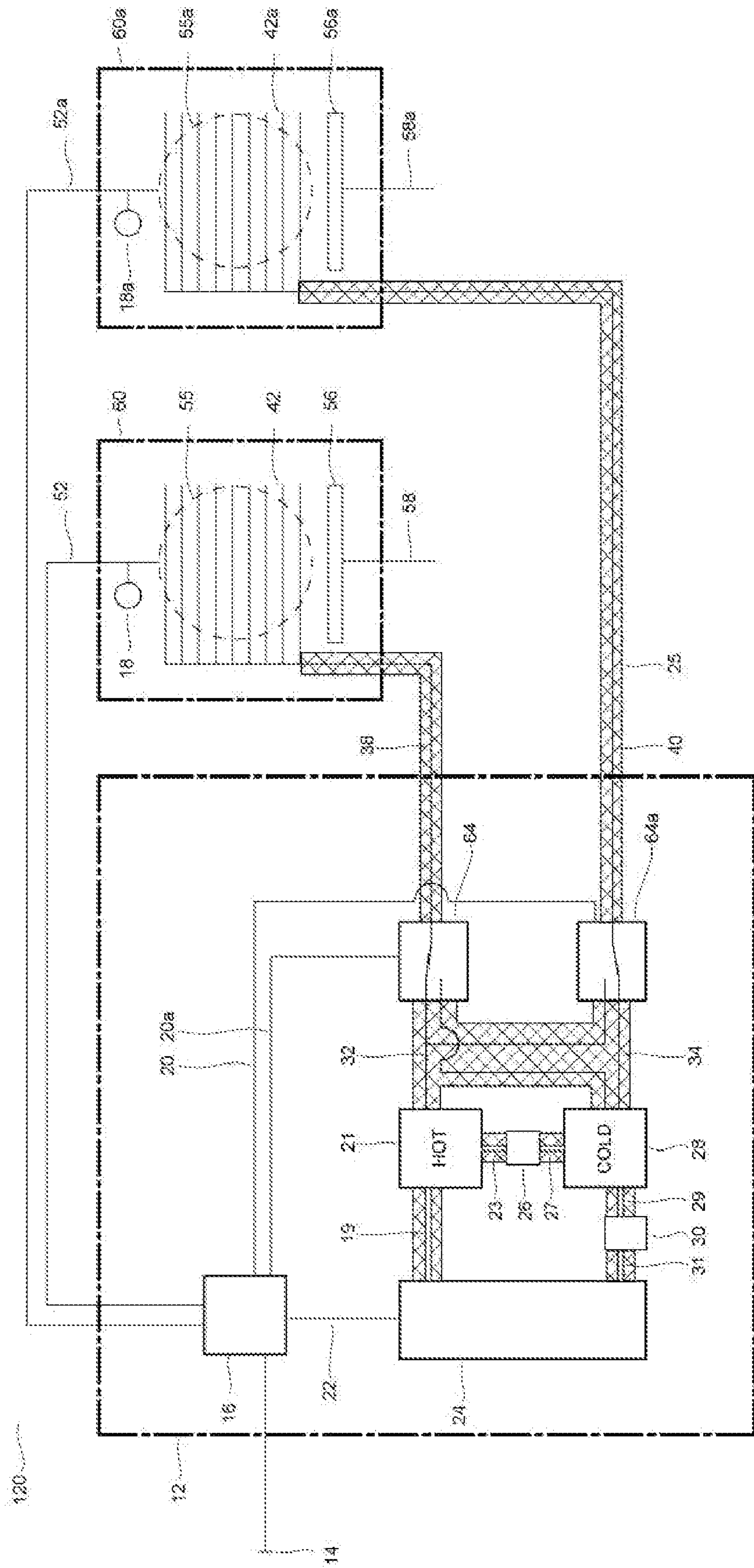


Figure 3

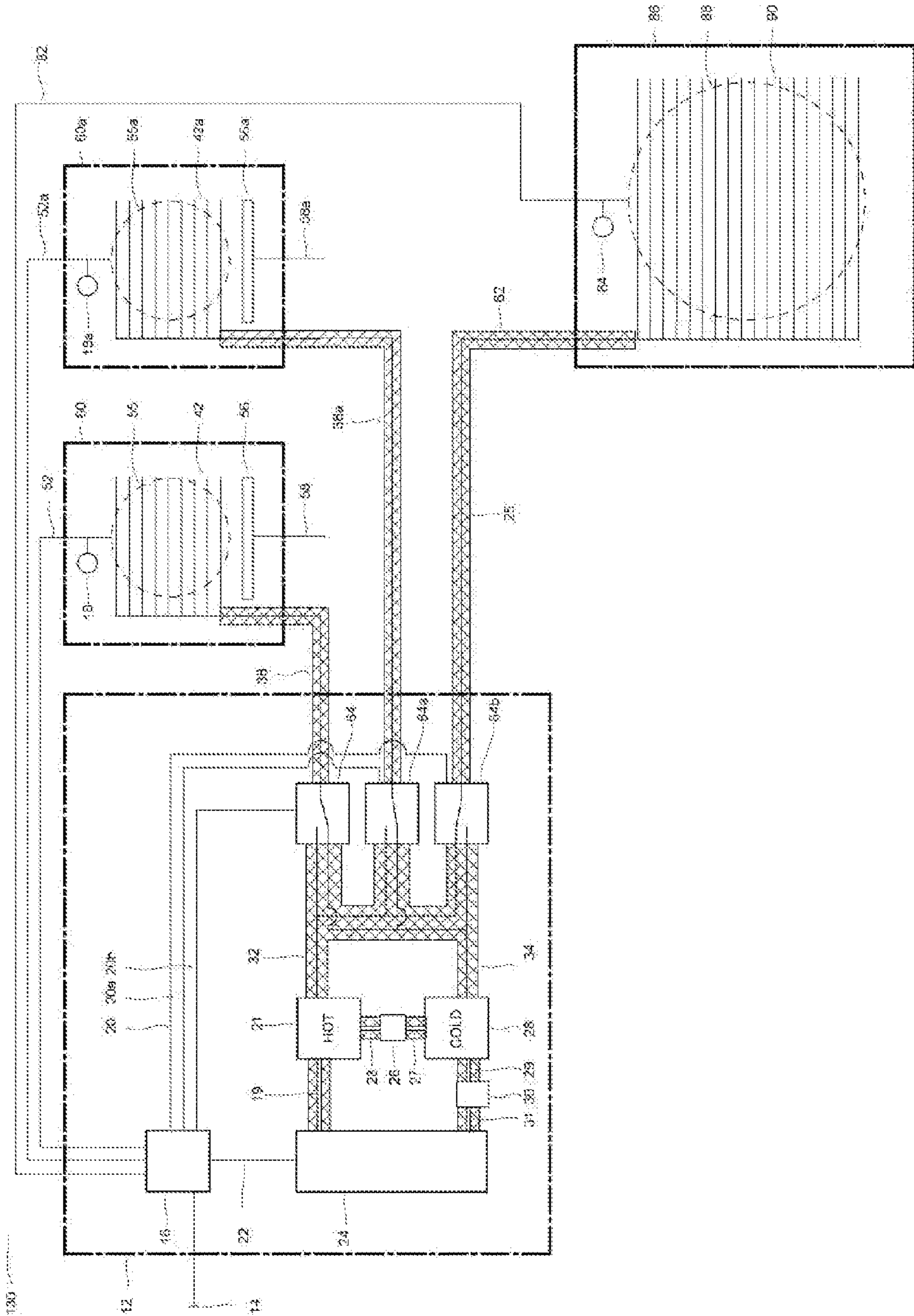


Figure 4

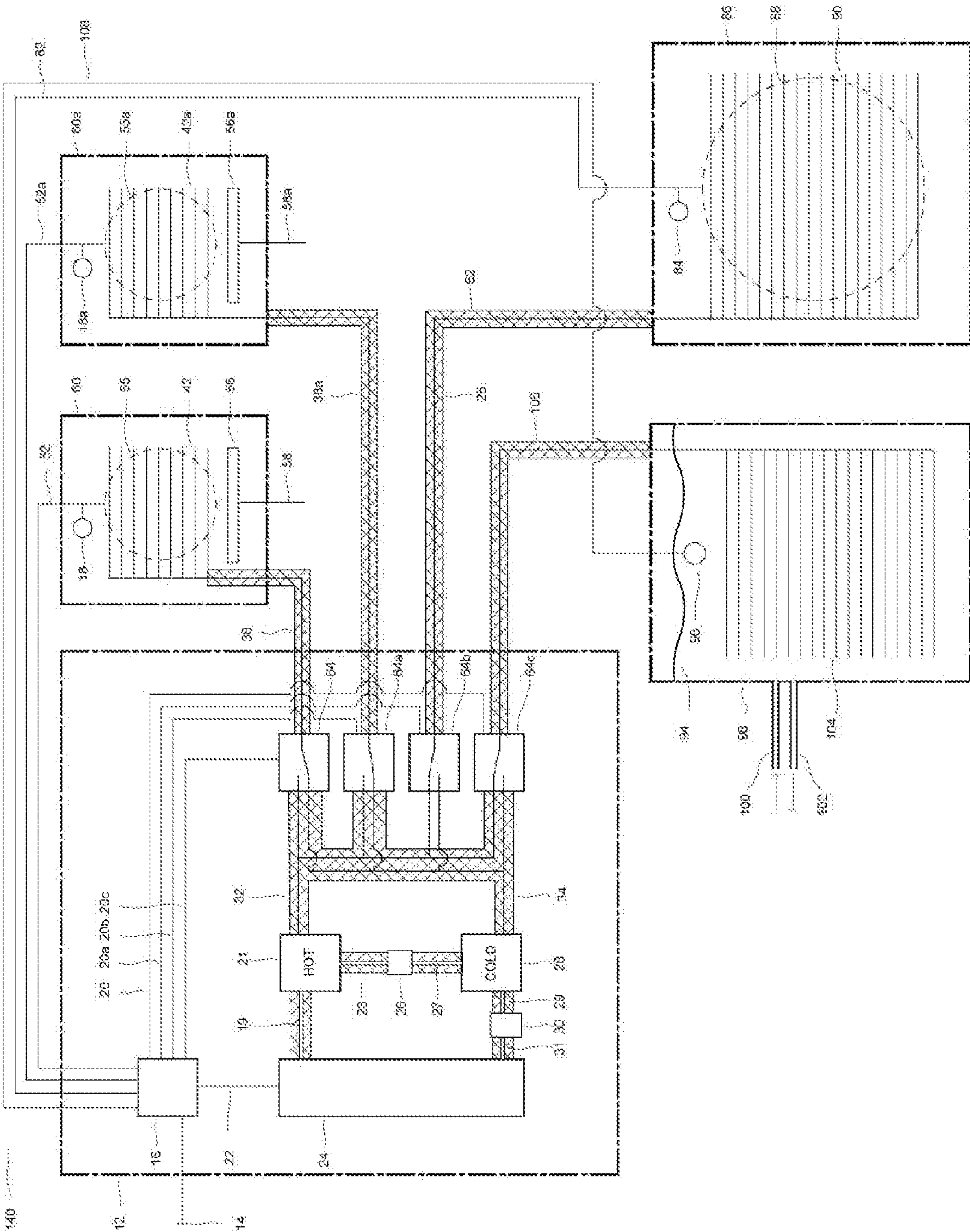


Figure 5

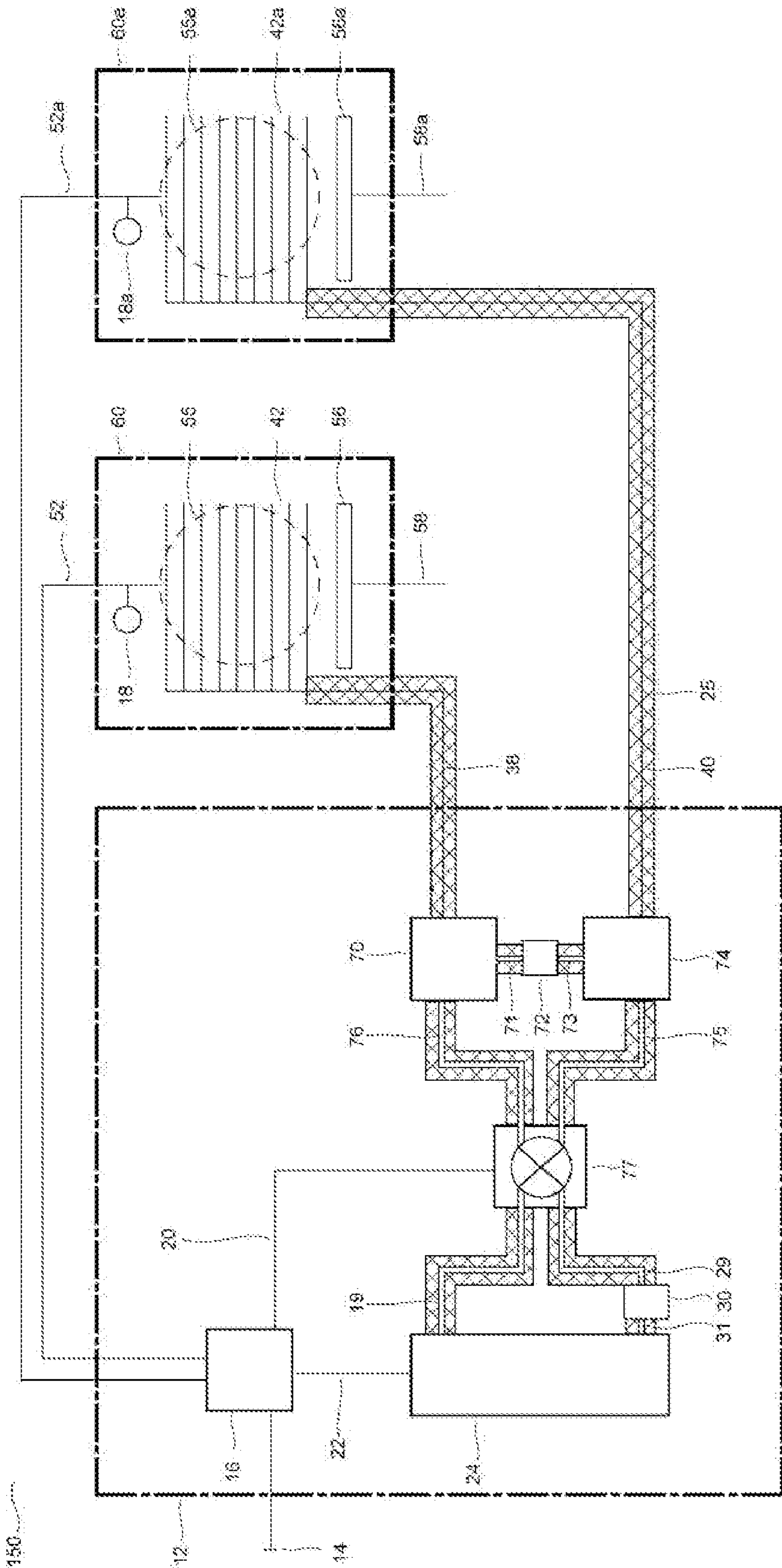


Figure 6

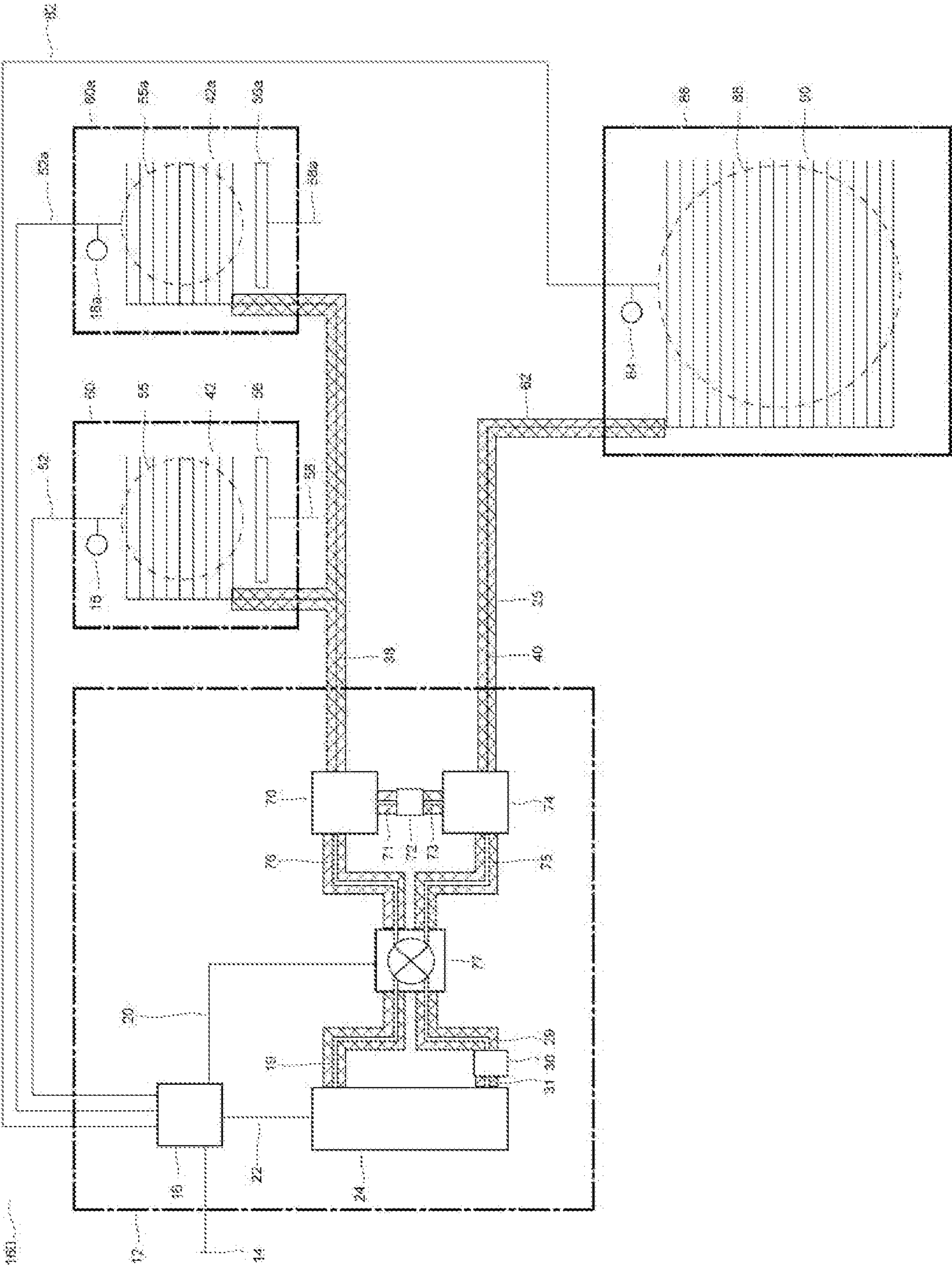


Figure 7

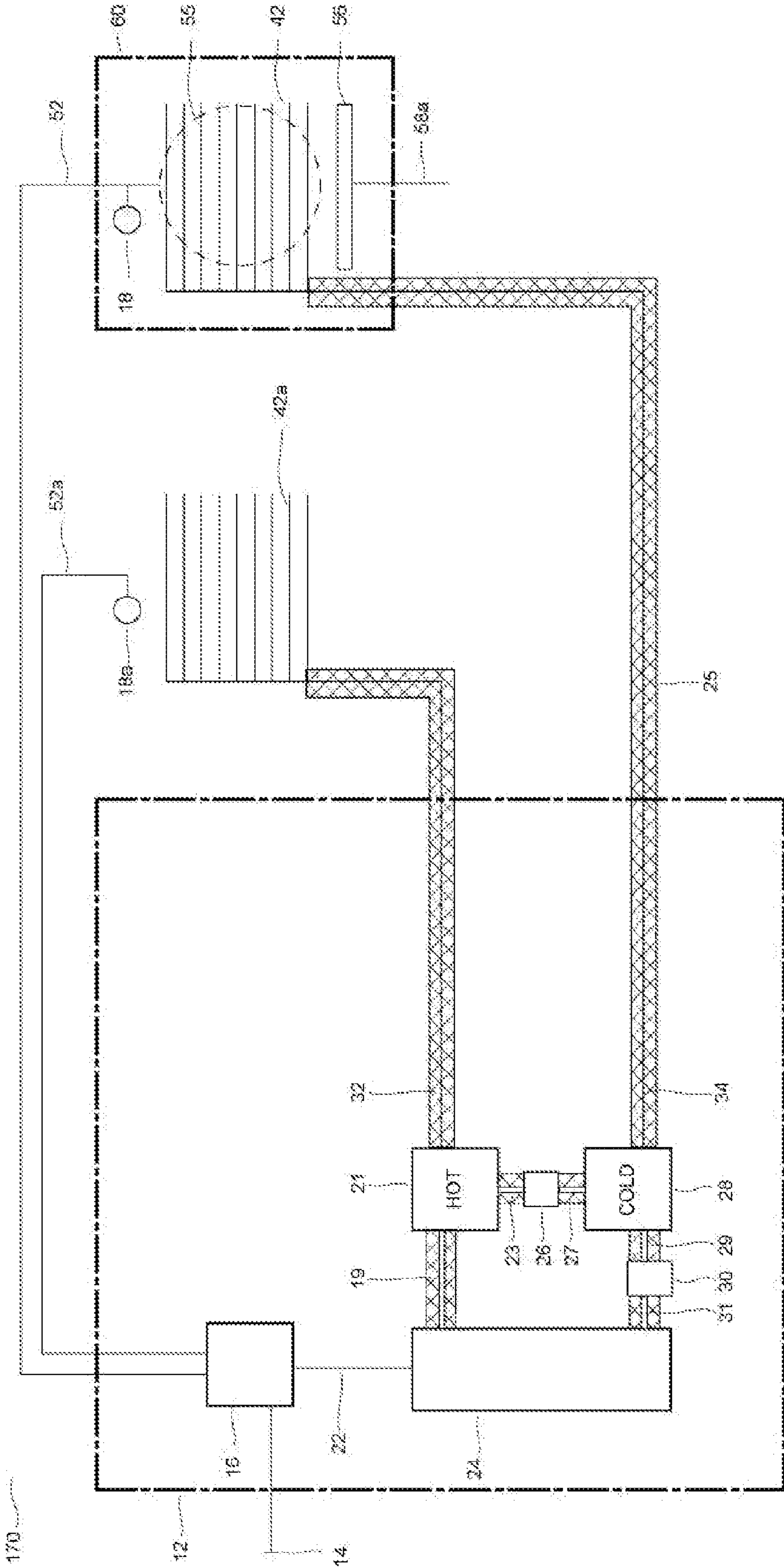


Figure 8a

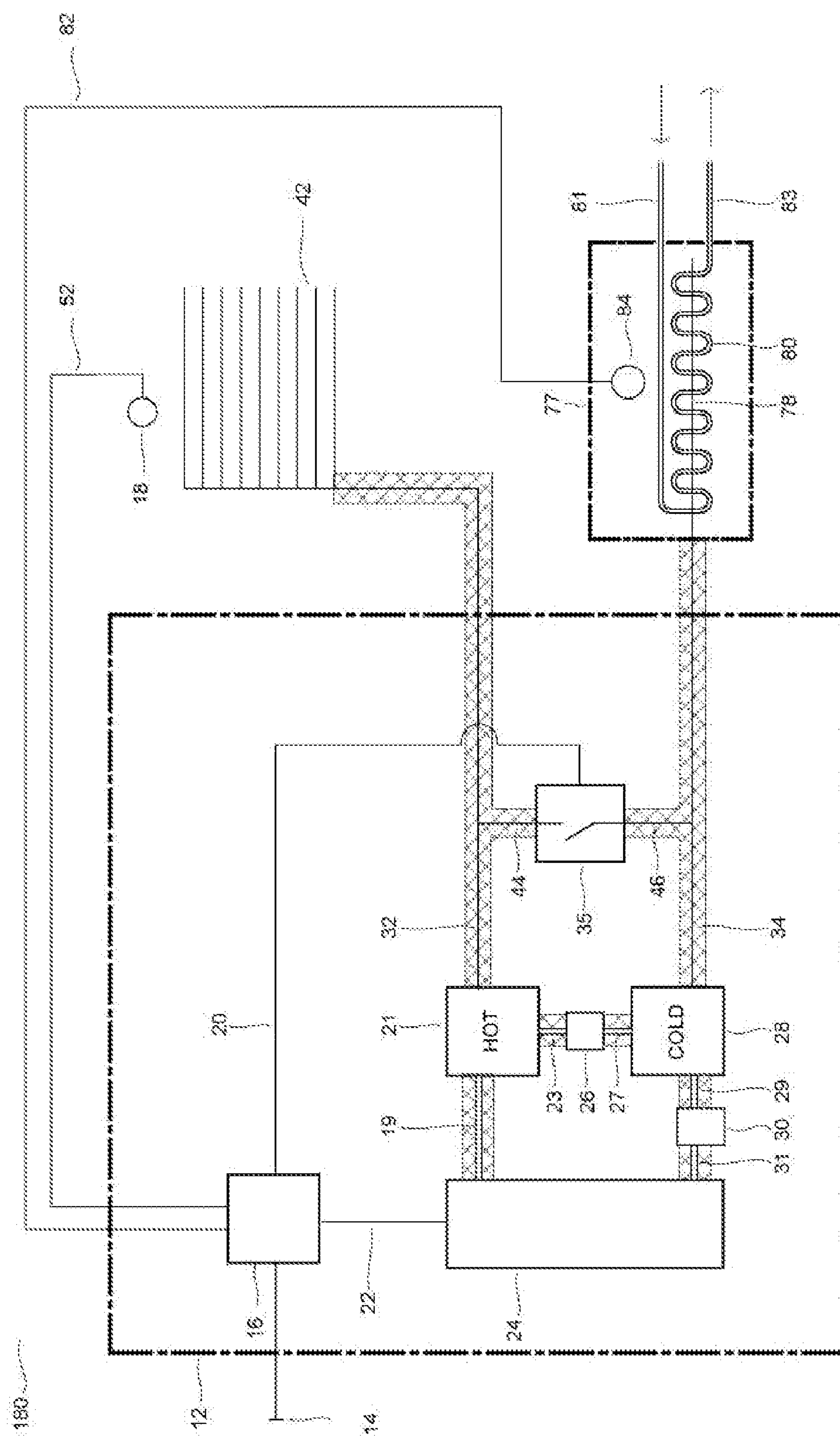


Figure 8b

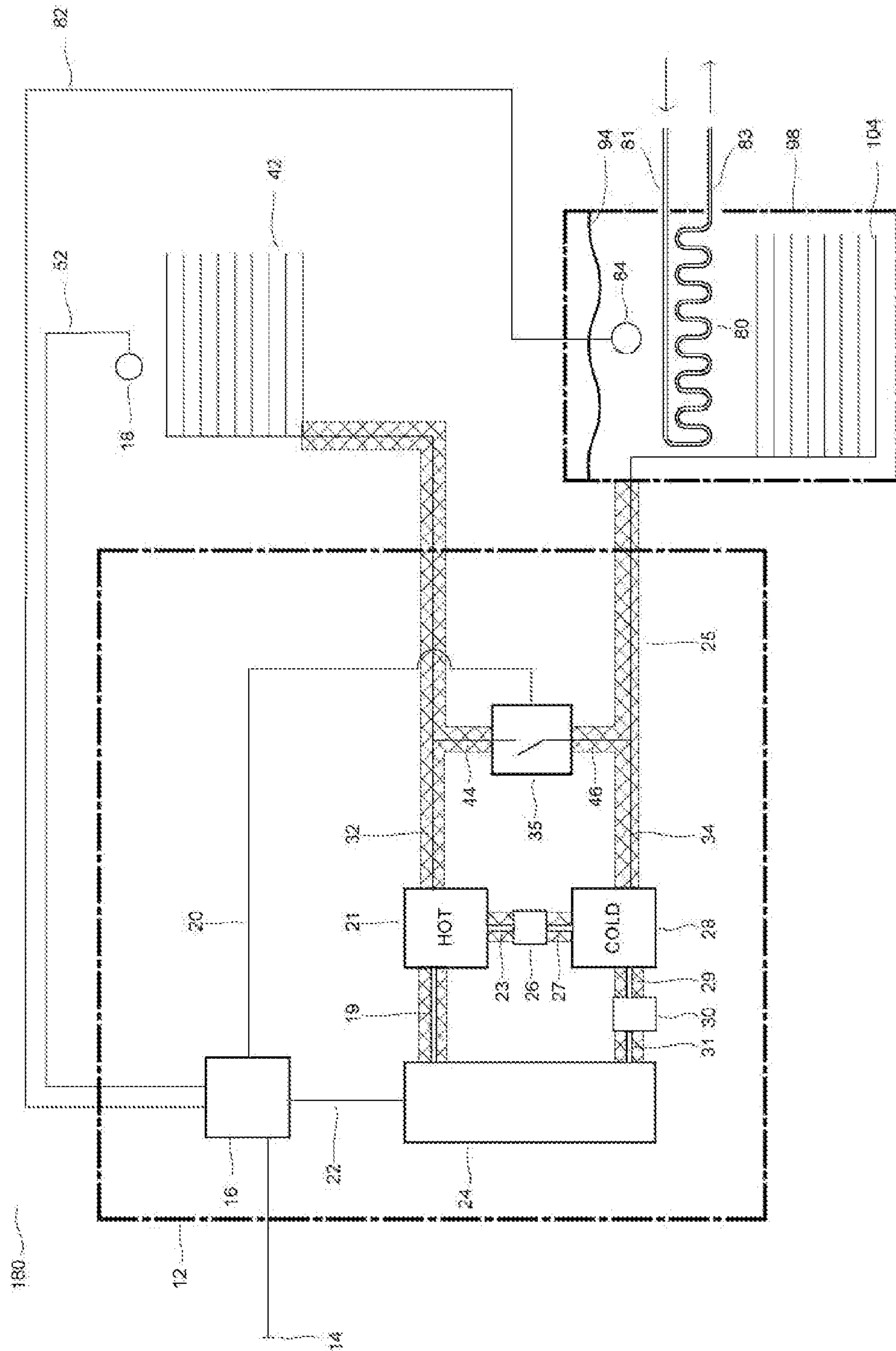
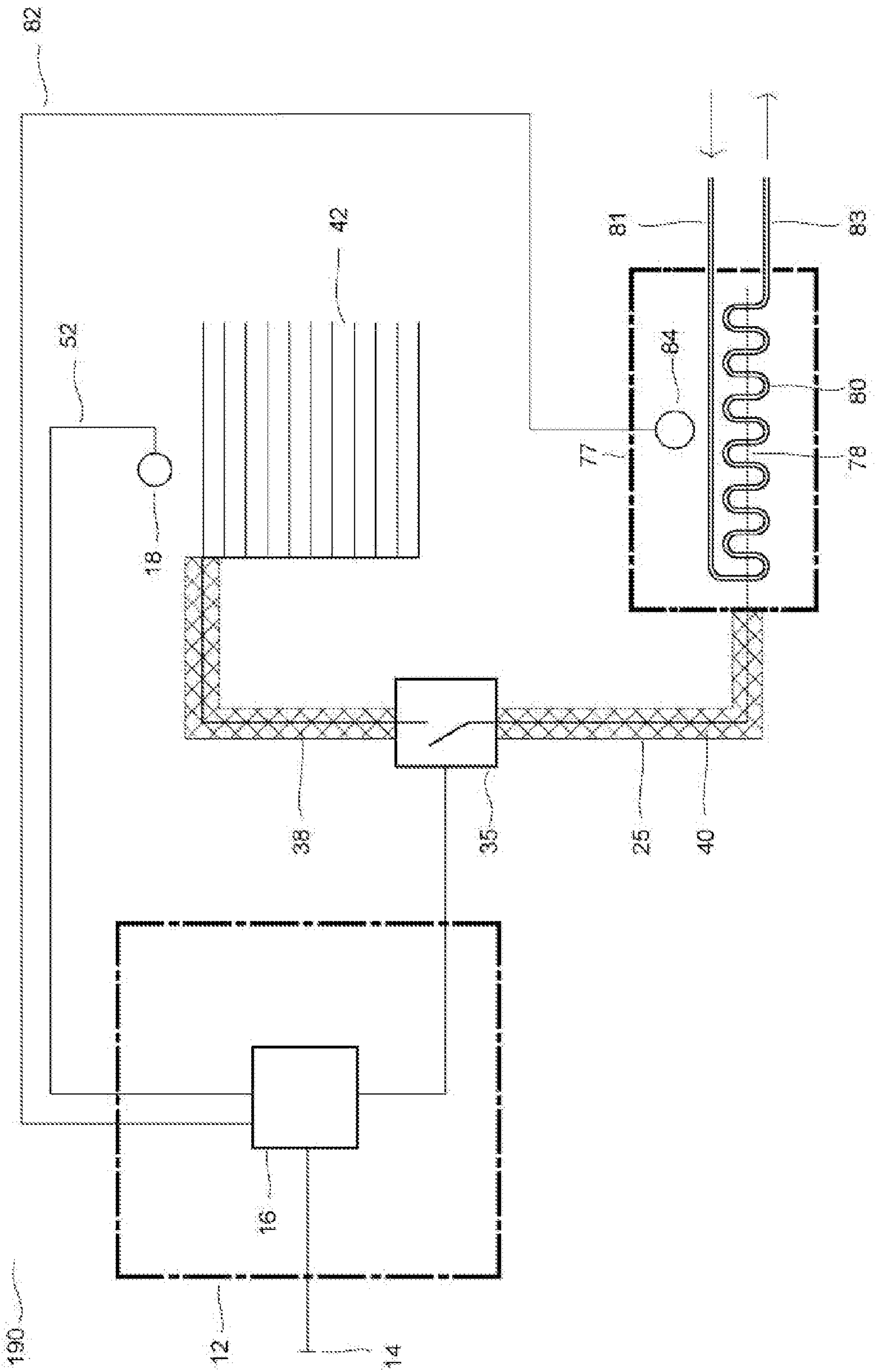


Figure 9



REPLACEMENT SHEET

Figure 9a

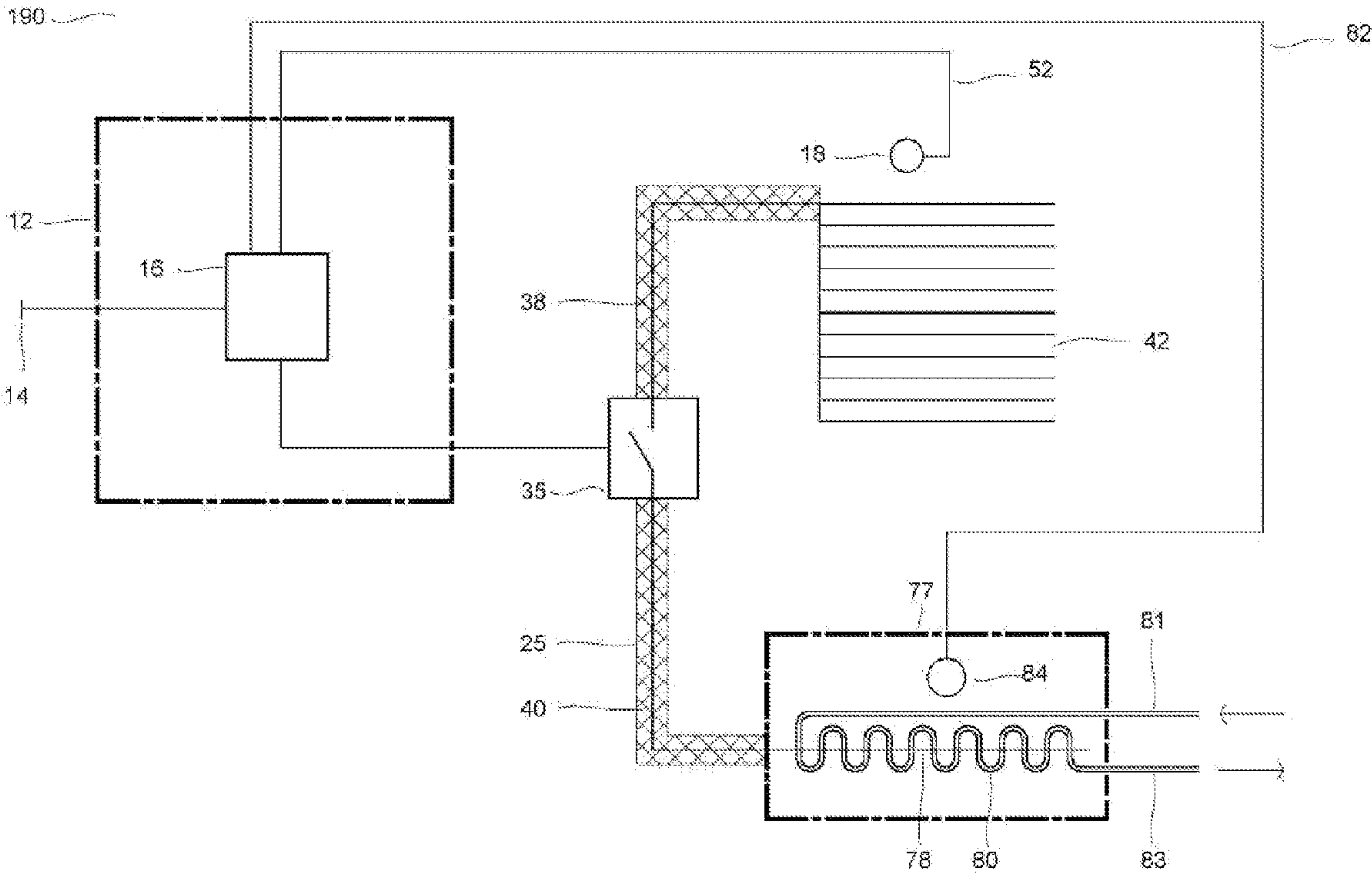


Figure 9b

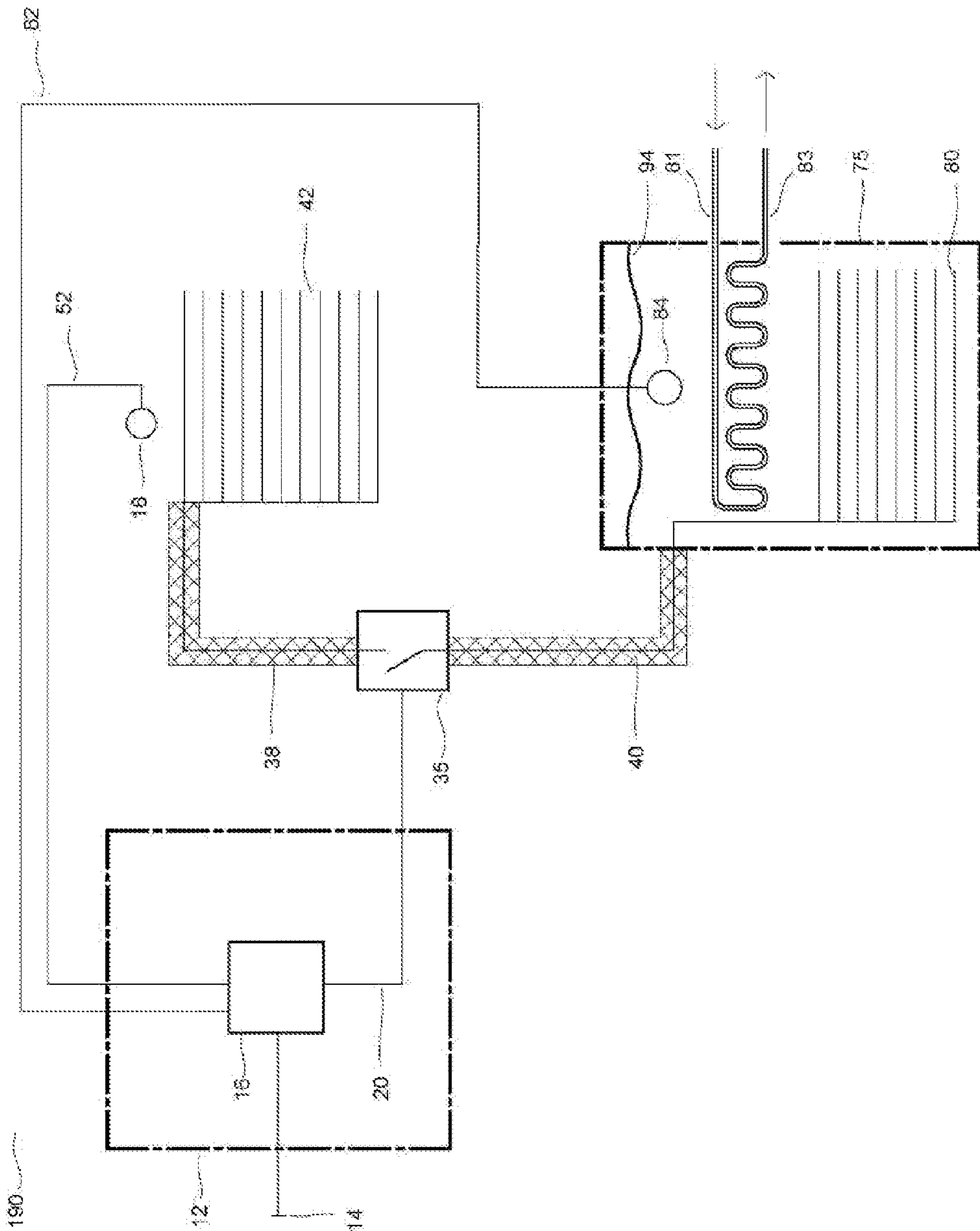


Figure 10

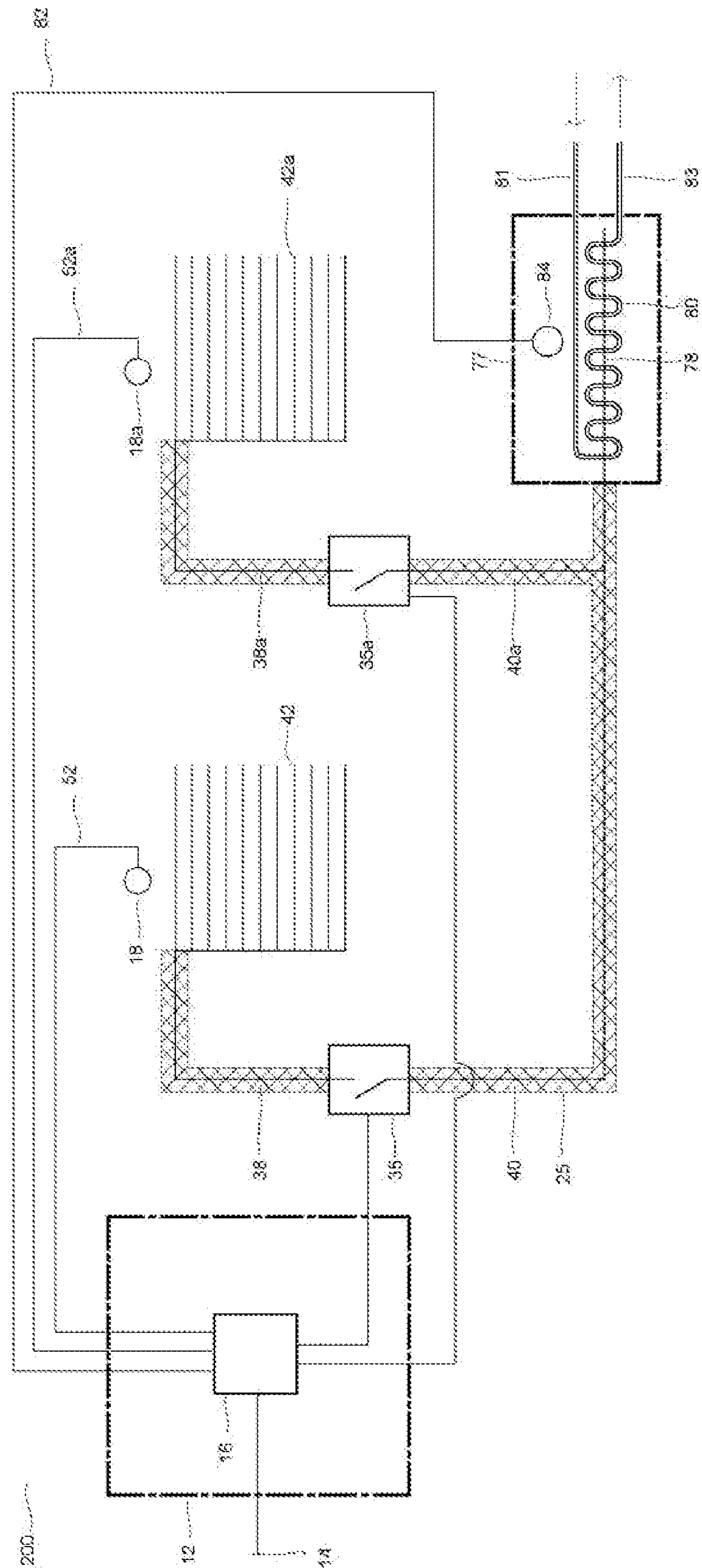


Figure 11

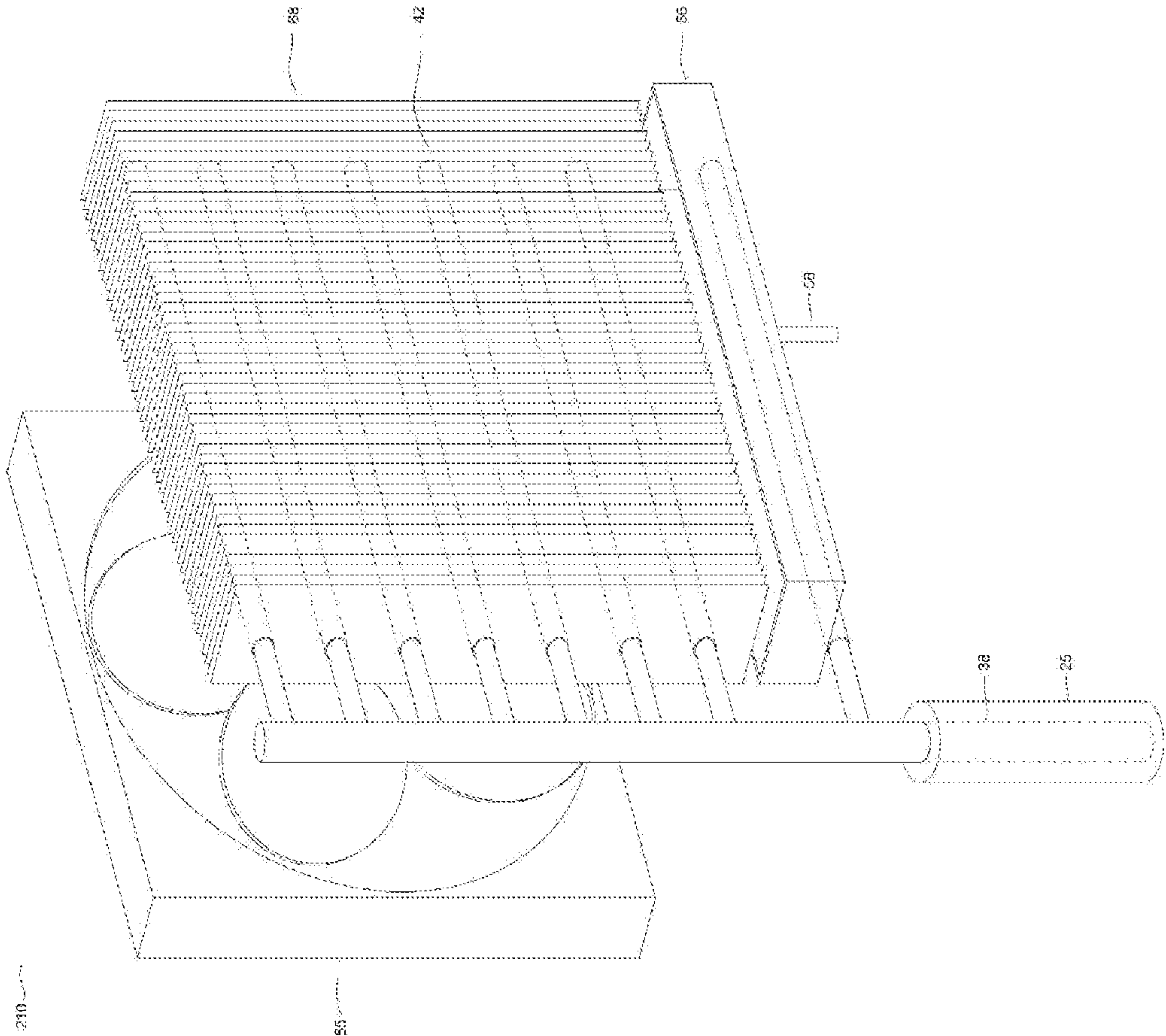


Figure 12a

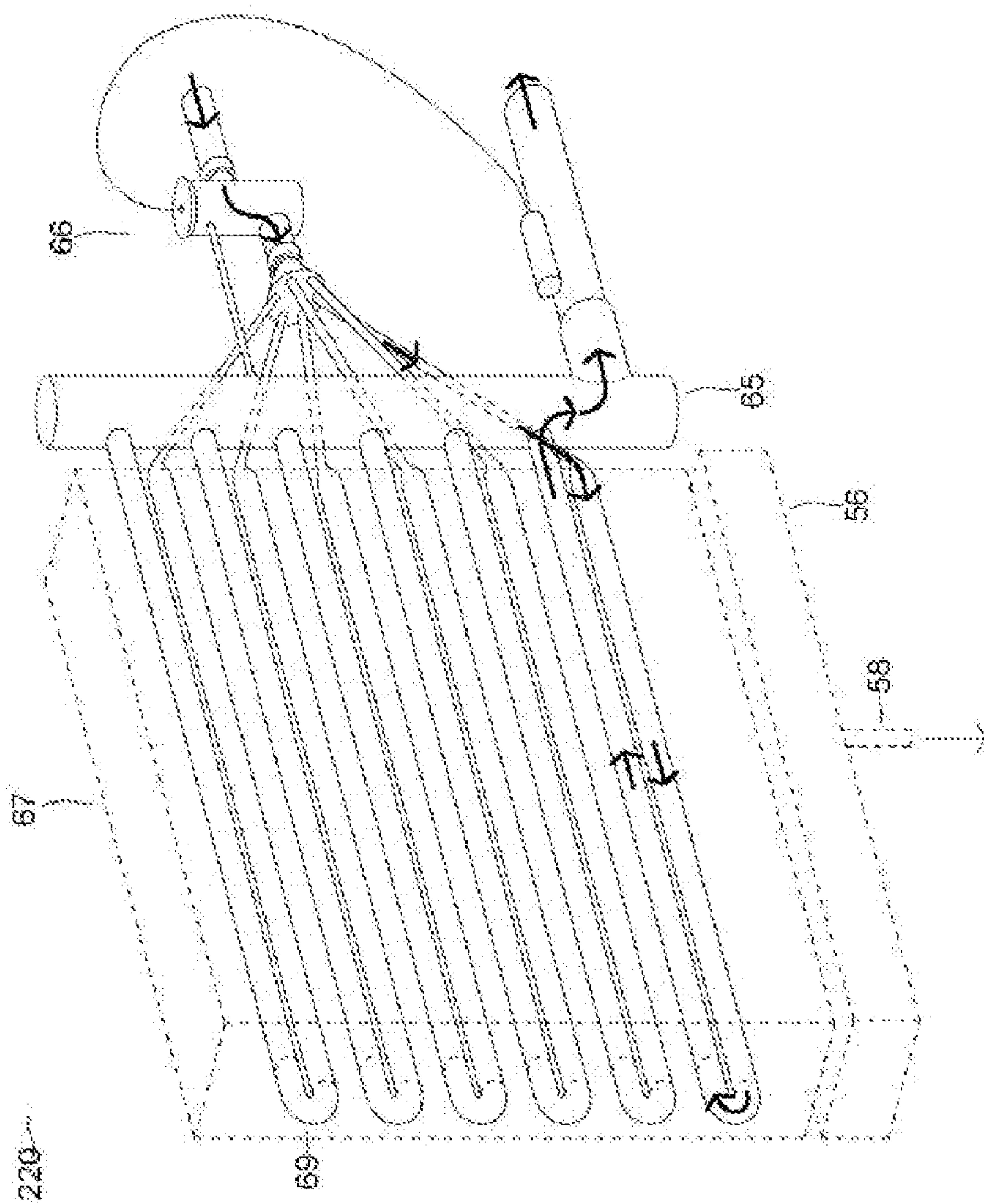


Figure 12b

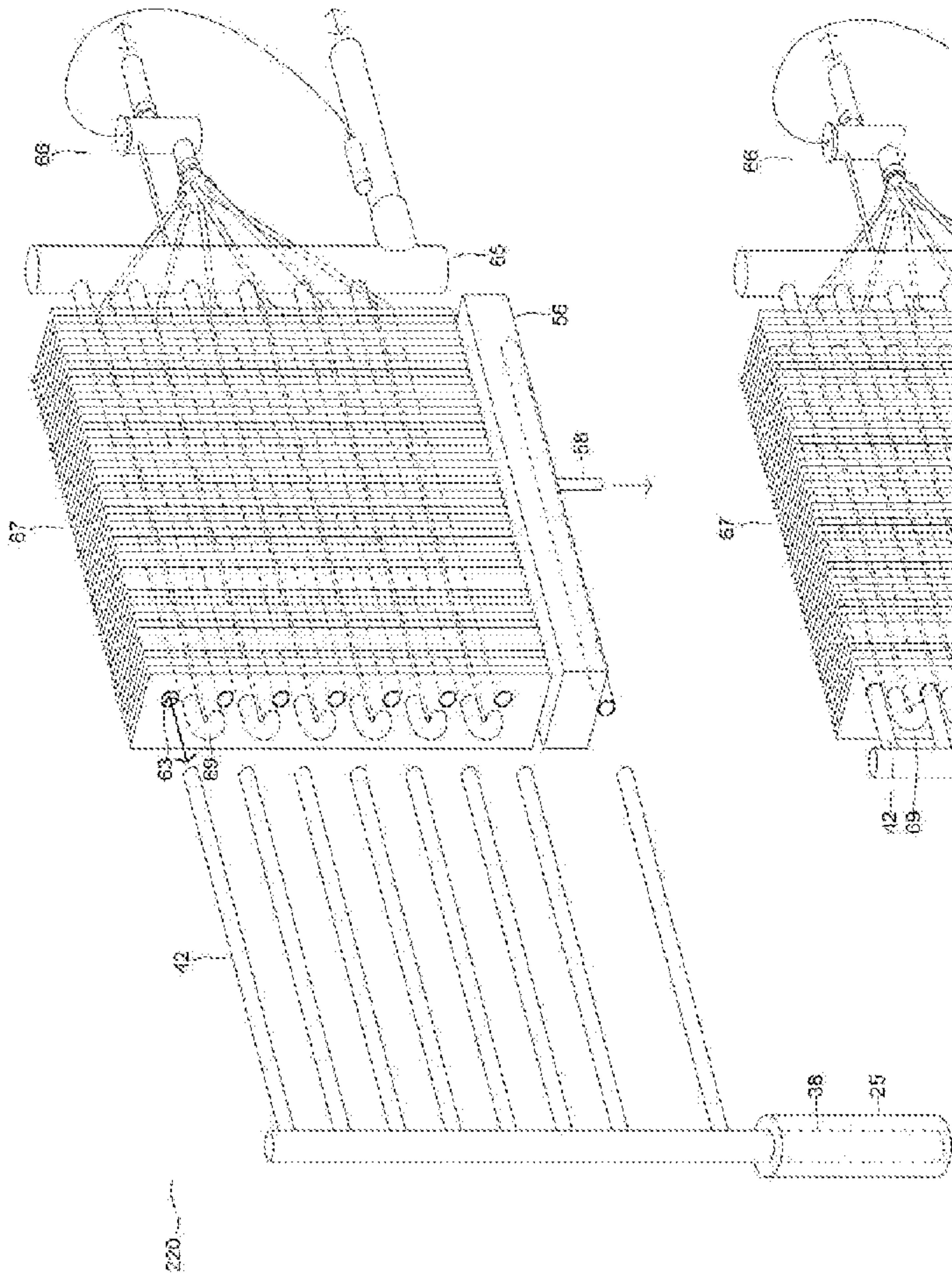


Figure 12c

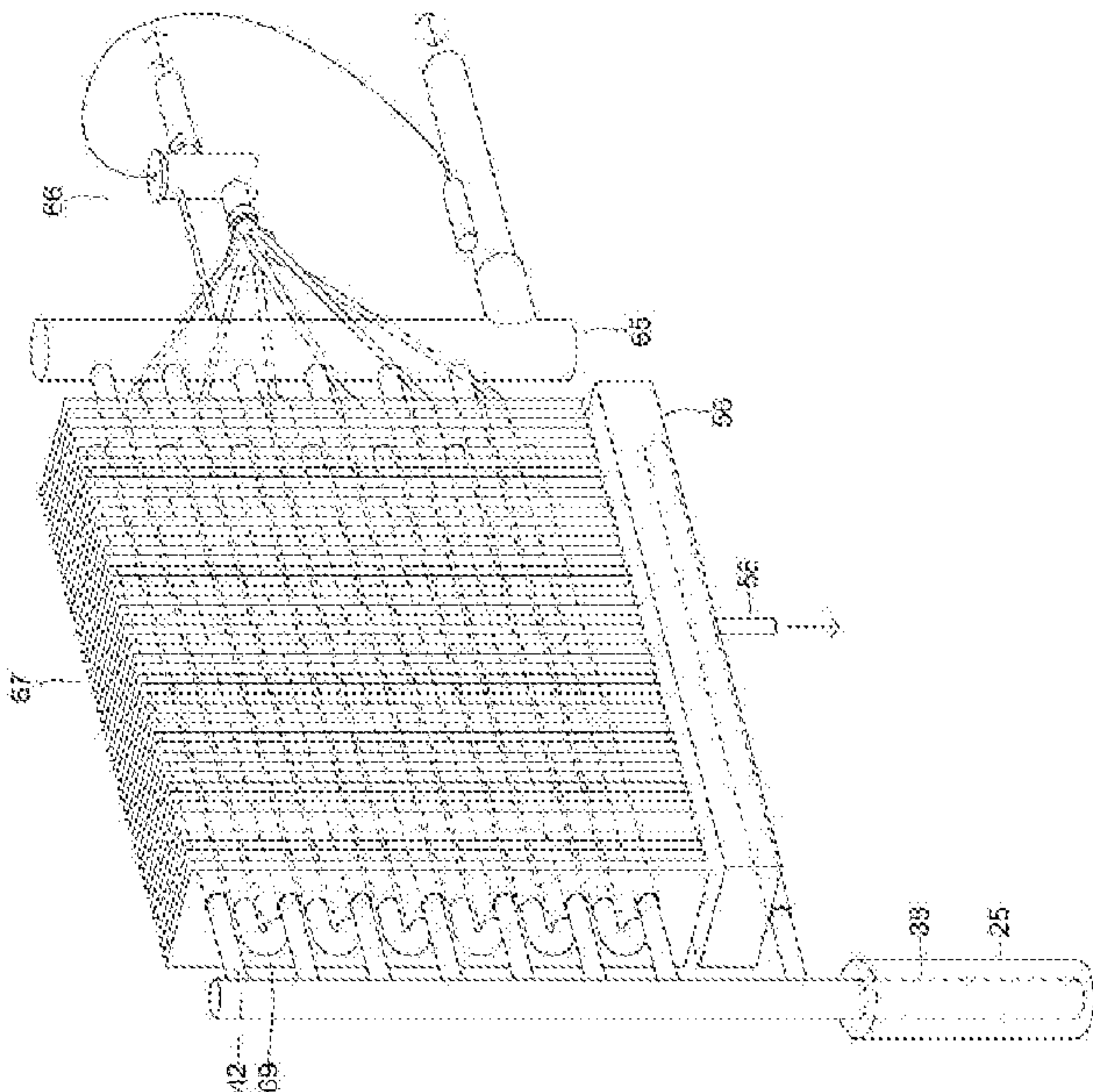
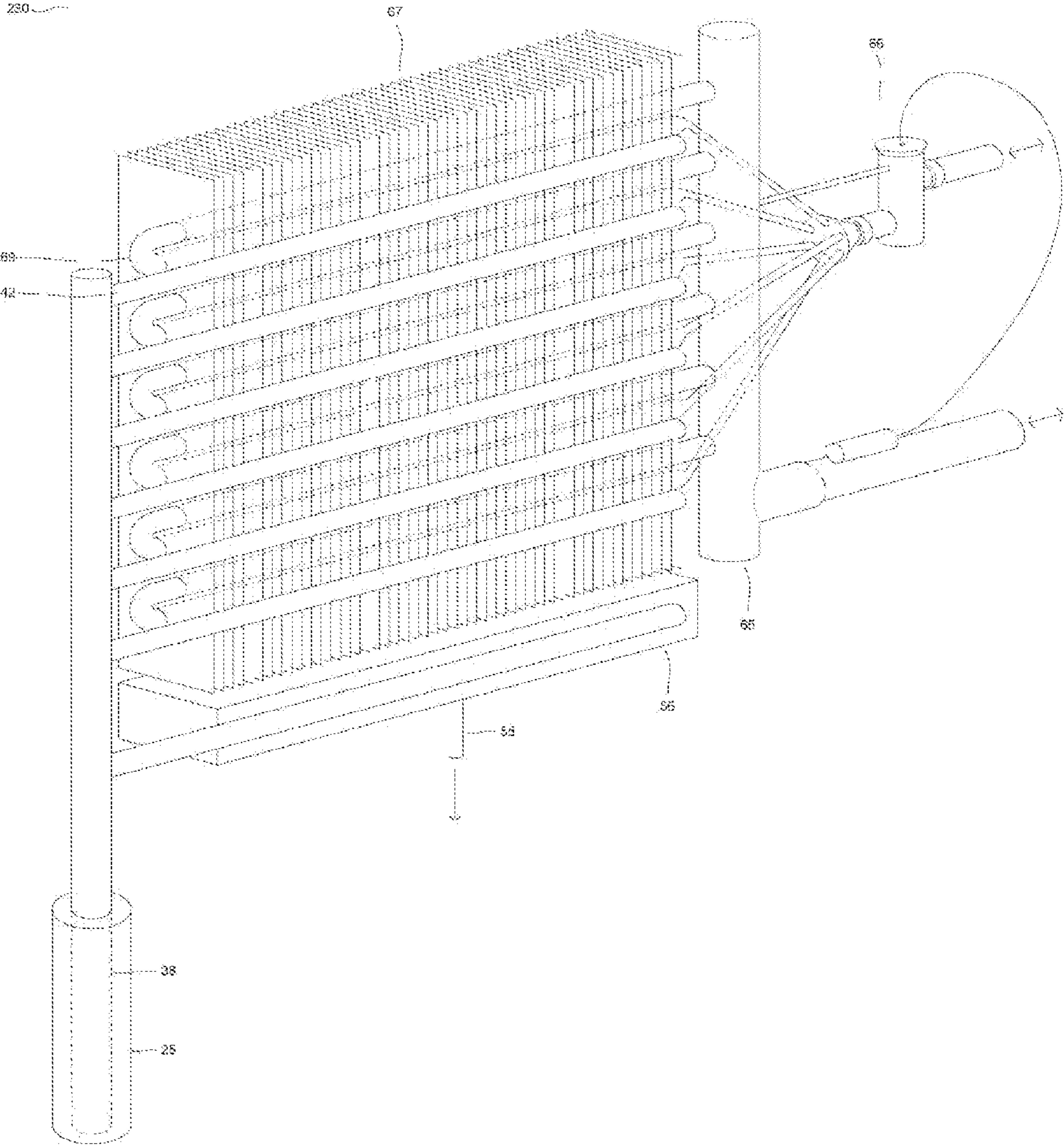


Figure 13



THERMAL SUPERCONDUCTOR REFRIGERATION SYSTEM

FIELD OF THE INVENTION

[0001] The present invention relates generally to refrigeration systems, and more particularly to a refrigeration heat exchanger having a superconducting heat transfer element.

BACKGROUND OF THE INVENTION

[0002] Commercial refrigeration systems typically use a phase-change refrigerant to absorb heat from an interior space and move it to an exterior space where it can be rejected. The refrigerant in these typical systems is circulated in a refrigerant loop connecting a refrigerating heat exchanger (or “evaporator”) which absorbs heat from a space to be cooled, a compressor which intensifies this heat, and a heat dissipating heat exchanger (or “condenser”) which dissipates the heat either into the outside environment or into a building mechanical system that requires heat, such as a domestic hot water system.

[0003] In a typical application such as a walk-in freezer with a roof-top heat dissipating heat exchanger, the refrigeration process works in the following manner. Liquid refrigerant flows through the refrigerant loop and into the evaporator where it rapidly drops in temperature as it expands to fill the larger volume of the evaporator, becoming a supercooled partial liquid. As the droplets in the partial liquid contact the inner surfaces of the evaporator coil they absorb heat and rapidly evaporate, cooling the surfaces of the evaporator to a temperature lower than the air in the freezer. The cooled surfaces then absorb heat from the air as it is drawn across the surfaces by a fan. The cooled air then returns to the space, cooling the space. The evaporated refrigerant then flows out of the evaporator, through the refrigerant loop, and into the compressor where it is compressed, causing the heat contained in the vapor to be intensified. The hot vapor then flows through the loop to the roof-top condenser which becomes hot. Air drawn across the outer surfaces of the condenser absorbs this heat and carries it off into the atmosphere. This loss of heat causes the refrigerant vapor to condense into a liquid. The liquid refrigerant then flows back to the evaporator to begin the heat removal process again.

[0004] Many variants of this process have been developed to serve different refrigeration requirements, but the process remains similar. In some systems, the roof-top heat dissipating heat exchanger is replaced with a heat exchanger inside the building, with air ducts coming into and going out of the building for the purpose of rejecting heat into the outside atmosphere. In other systems, the roof-top heat exchanger is replaced with a refrigerant-to-water heat exchanger inside the building, which transfers heat from the refrigerant loop to a water loop, such that heat can be rejected into an outdoor evaporation pond or employed by a building mechanical system to provide hot water for space heating or domestic hot water purposes. Similarly, the refrigerating heat exchanger can absorb heat from a liquid such as water in an ice making machine instead of from the air in a space. In these variations, the method of heat exchange at the refrigerating and dissipating heat exchangers varies, but the refrigeration circuit remains the same. Typically, the characteristic rating of the refrigerant is matched to the application.

[0005] In large refrigeration systems, this process has a number of inherent problems and inefficiencies.

[0006] Commercial refrigerators are often large and far away from the refrigeration plants that serve them, so the loops are often very long and have large volumes of refrigerant and large numbers of connections and valves, which makes them vulnerable to leaks and causes them to require frequent maintenance of components.

[0007] The complexity of large circulating refrigerant systems makes it difficult for the heat absorbed in one refrigerator to be employed to defrost the heat exchanger in another or to supplement other building mechanical systems requiring heat. This results in low energy efficiency.

[0008] The movement of refrigerant over long distances requires significant pumping energy, which decreases system energy efficiency.

[0009] In the refrigeration cycle, cold refrigerant passes through loops in the evaporator, absorbing heat from the evaporator as it passes through. As a result, each loop naturally has a temperature gradient—colder at the refrigerant inlet and warmer at the refrigerant outlet. This means that parts of the evaporator are warmer than others, making them less able to absorb heat from the air, resulting in lower evaporator efficiency, and requiring an increase in heat exchanger size to compensate.

[0010] In air-to-refrigerant heat exchangers operated in the refrigeration mode, the cooling process causes moisture from the air to condense and freeze on the surfaces of the closely packed fins and tubes that make up the evaporator. Eventually this ice build-up blocks air-flow through the evaporator, reducing efficiency. When efficiency drops below an acceptable level, the ice is removed through a defrost cycle, most commonly achieved by reversing the refrigeration system to provide heating instead of cooling to the refrigerating heat exchanger.

[0011] Defrosting results in three problems. First, the reversing valves employed to reverse the flow of refrigerant in the system are inefficient and prone to failure. Second, the reversal of the system from refrigeration to defrost causes refrigerant to behave differently from its prior phase at a location in the loop, condensing where it previously evaporated, evaporating where it previously condensed; compensating for these changes in behavior requires additional system complexity, cost and maintenance. Second, frequent cycling from cold to hot causes stress on connections which causes leaks. Third, the defrost cycle requires the whole refrigeration system to be stopped, gradually reversed to decrease heat stress, operated in reverse long enough to defrost the refrigerating heat exchanger, stopped, and then gradually reversed to decrease heat stress before returning to the refrigerating mode; this creates a transition time, and during this time the space is not being refrigerated, leading to a rise in space temperature that can be compensated for with high levels of refrigeration energy when the refrigeration mode becomes operational again, causing the whole refrigeration system to require higher refrigerating capacity. Other systems have been developed to achieve shorter defrost times but each has inherent problems. Electrical resistance strip heaters for example, have been mounted to the face of evaporator coils, allowing the primary refrigeration system to simply stop while the secondary electrical

system provides defrost energy. These strip heaters are prone to burning out, requiring frequent replacement which can be done if the strips are mounted to the accessible face of the evaporator unit. This causes them to be inefficient because they are far away from the ice mass, which at the core of the evaporator.

[0012] There is a need for a refrigeration system that operates without a refrigerant transfer loop, utilizes much less power than conventional refrigerators, has smaller heat exchangers, has an extended lifetime due to fewer parts, uses less refrigerant, has a shorter and more efficient defrost cycle and provides enhanced refrigeration efficiency per unit power. There is further a need for a non-refrigerant based defrosting element for use in combination with a conventional refrigeration system.

SUMMARY OF THE INVENTION

[0013] A refrigeration system incorporates thermal superconducting heat transfer. The system includes an intensifying heat exchanger, a refrigerating heat exchange coil formed from thermal superconductor material, and a dissipating heat exchange coil formed from thermal superconductor material. The system can include a switch connected to condenser and evaporator heat exchange segments, a refrigeration switch segment and a dissipating switch segment such that in a first switch position a refrigerating mode is provided and in a second switch position a defrost mode is provided. Additional embodiments include thermostat controllers and blowers for enhanced control. Heat exchange and reuse is described for multiple heat exchangers coupled by thermal superconductors. A defrosting element is described for refrigeration heat exchangers.

[0014] In one embodiment, a refrigeration system having thermal superconducting heat transfer includes a reversible intensifying heat exchanger, having a compressor, a refrigerating heat exchange coil formed from thermal superconductor material, and a dissipating heat exchange coil formed from thermal superconductor. The refrigeration system also has a reversing valve that can be configured to provide corresponding refrigerating or defrosting modes of the superconductor refrigeration system. The refrigerating or defrosting modes can be selected by a thermostat controller for the purpose of operating in a refrigerating or defrosting mode to refrigerate a space.

[0015] In a further embodiment, a defrosting system having thermal superconducting heat transfer includes an intensifying heat exchanger, a defrosting heat exchange coil formed from thermal superconductor material, an absorbing heat exchange coil formed from thermal superconductor material, and a controller programmable to a desired set point and further having a thermostat controller connected to the thermal switch and compressor.

[0016] In a further embodiment, a superconductor refrigeration exchange element includes a plurality of evaporator refrigerant conduits suitable for receiving refrigerant; an evaporator coupled to ends of each of the plurality of refrigerant coils, a condenser conduit coupled to opposing ends of each of the plurality of refrigerant coils; a plurality of cooling plates formed of a thermally conductive material arranged in an approximately co-planar stack, and having at least one conduit opening through each of the plates corresponding to each refrigerant conduit such that the conduits

are seated in thermal contact within the cooling plate stack for the purpose of exchanging heat with air; a thermal superconductor heat transfer pipe arranged such that a coupling portion is coupled on at least one side of the cooling plate stacks such that thermal contact is created between the cooling plates and the heat transfer pipe. The location of the coupling portion relative to the seated conduits is arranged to increase available air flow through the plates, and a transfer portion extends away from the stack of plates. In addition, insulation surrounds at least part of the extended transfer portion to reduce heat transfer loss. Heat is transferred from the cooling plates by the refrigerant conduits for the purposes of cooling the air flow and heat is transferred to cooling plates by the thermal superconductor heat transfer pipe for defrosting ice build up on the cooling plates such that the air flow is approximately maintained.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1a is a schematic diagram of a refrigeration system with thermal superconductor heat exchangers and a reversible superconductor transfer switch enabling the system to switch from refrigeration to defrost. FIG. 1b is an enlarged view of the intensifier heat circuit.

[0018] FIG. 2 is a schematic diagram of a refrigeration and defrost system with thermal superconductor transfer segments coupled to a heat intensification circuit by independent thermal transfer switches.

[0019] FIG. 3 is a schematic diagram of a refrigeration and defrost system with multiple thermal superconductor heat exchangers coupled with independent thermal transfer switches to a single heat intensification circuit.

[0020] FIG. 4 is a schematic diagram of a refrigeration and defrost system using a liquid heat exchanger as a heat source or heat sink.

[0021] FIG. 5 is a schematic diagram of a refrigeration and defrost system using superconductor heat exchangers with blowers and a reversing valve to switch the system from refrigeration to defrost.

[0022] FIG. 6 is a schematic diagram of a refrigeration and defrost system using multiple superconductor heat exchangers with blowers and a reversing valve to switch the system from refrigeration to defrost.

[0023] FIG. 7 is a schematic diagram of a defrost system using superconductor heat exchangers.

[0024] FIG. 8a is a schematic diagram of a defrost system using a heat intensification circuit and a superconductor heat exchanger to draw waste heat from the hot vapor line of a conventional refrigeration system.

[0025] FIG. 8b is a schematic diagram of a defrost system using waste heat indirectly from the hot vapor line of a conventional refrigeration system through a liquid heat exchange fluid.

[0026] FIG. 8c is a schematic diagram of a defrost system using waste heat from a circulating fluid from another heat generating system.

[0027] FIG. 9a is a schematic diagram of a defrost system using a superconductor heat exchanger to draw waste heat

directly from the hot refrigerant line of a conventional refrigeration system without the assistance of a heat intensification circuit.

[0028] FIG. 9b is a schematic diagram of a defrost system using waste heat indirectly from the hot vapor line of a conventional refrigeration system through a liquid heat exchange fluid, without the assistance of a heat intensification circuit.

[0029] FIG. 10 is a schematic diagram of a defrost system using a superconductor heat exchanger to draw waste heat directly from the hot refrigerant line of a conventional refrigeration system without the assistance of a heat intensification circuit.

[0030] FIG. 11 is a schematic diagram of a heat exchanger with superconductor heat exchange segments.

[0031] FIG. 12a is a cut-away view of a conventional refrigerating heat exchanger showing the fluid flow path. FIG. 12b is a schematic diagram of a modified refrigerating heat exchanger with couplable superconductor defrost heat exchange elements. FIG. 12c is a schematic diagram of a modified refrigerating heat exchanger with integrated superconductor defrost heat exchange elements.

[0032] FIG. 13 shows superconductor defrost heat exchange elements applied to the face of a conventional heat exchanger.

[0033] FIG. 14 shows an elevation of a refrigeration and defrost system installed in a building where the refrigerated space, the refrigeration plant and the dissipating heat exchangers are separated from each other.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT(S)

[0034] With reference to the drawings, new devices and systems for improved refrigeration and defrosting will be described, embodying the principles and concepts of the present technology.

[0035] Recent advances in thermal superconducting materials can now be considered for use in novel energy transfer applications. For example, U.S. Pat. Nos. 6,132,823, 6,916,430 and 6,911,231 and continuations thereof, disclose examples of a heat transfer medium with extremely high thermal conductivity and methods of manufacture, and are included herein by reference. Specifically the following disclosure indicates the orders of magnitude improvement in thermal conduction; "Experimentation has shown that a steel conduit 4 with medium 6 properly disposed therein has a thermal conductivity that is generally 20,000 times higher than the thermal conductivity of silver, and can reach under laboratory conditions a thermal conductivity that is 30,000 times higher than the thermal conductivity of silver." Such a medium is thermally superconducting, and when suitably configured for refrigeration, its application results in many significant advantages. The available product sold by Qu Energy International Corporation is an inorganic heat transfer medium provided in a vacuum sealed heat conducting tube. The term superconductor can interchangeably mean thermal superconductor. For illustrative purposes, this superconductor can be in the form of a sealed metal tube as currently available from Qu Corporation and will be considered to be in tube form. Alternatively, other available

thermal superconductors could be similarly substituted that can have various forms and cross sections such as flexible conduits, thin laminate, thin film coated metal etc. Optionally, the superconducting transfer segments can be formed from discontinuous discrete sections of superconducting material separated by small gaps of a non-superconducting material.

[0036] An embodiment of the present technology is a refrigeration system comprised of two subsystems. The first subsystem is a refrigeration loop which serves to intensify heat energy so it can be moved. The second subsystem is a heat distribution system that uses thermal superconductor elements to absorb and dissipate heat and to move heat through the system without moving parts. These subsystems can include:

[0037] a) two heat exchangers, one hot and one cold, which can be for example, located in the refrigeration plant area, to transfer heat energy between the phase change refrigeration subsystem and the superconductor distribution subsystem;

[0038] b) two or more blowers to draw air across the heat exchangers to achieve the transfer of heat energy to or from the heat exchangers;

[0039] c) one or more thermal superconductor switches to allow heat to be directed to or from an individual heat exchange component or to allow individual heat exchange components to be isolated from the system;

[0040] d) superconductor distribution components to transfer heating and cooling energy between the switches and the individual heat exchange components;

[0041] e) superconductor heat exchangers to absorb heat from spaces to be cooled

[0042] f) superconductor heat exchangers to dissipate excess heat into the atmosphere or transfer excess heat to other building systems which can use this heat; and

[0043] g) thermostats and programmable controllers to enable the system to sense and respond to conditions in the refrigeration system.

[0044] The embodiment of the refrigeration system operates in the following general manner. The phase-change refrigerant subsystem operates as a local heat intensification circuit, with a "cold" heat exchanger or "evaporator" which absorbs heat from the heat distribution subsystem, a compressor which intensifies this heat, and a "hot" heat exchanger or "condenser" which transfers this heat back into the distribution subsystem. In a refrigeration mode, the "cold" heat exchanger is connected by a superconducting heat transfer element to a superconducting heat exchanger in a space selected to be cooled (the "refrigeration space"), while the "hot" heat exchanger is connected by superconducting heat transfer elements to a superconducting heat exchanger located or coupled for external heat transfer such as outside a building, by thermal routing using a superconducting thermal switch in a refrigeration mode setting. Air from the refrigeration space is drawn by a blower across the superconducting heat exchanger where heat from the air is absorbed by the heat exchanger's cold surfaces. The air returns to the space colder, cooling the space. The heat absorbed from the air is transferred by the superconducting transfer elements to the "cold" heat exchanger, then trans-

ferred to the refrigerant loop, intensified and transferred to the “hot” heat exchanger and back to the thermal switch. The heat is then transferred by superconducting thermal transfer elements to the dissipating superconducting heat exchanger. A fan blows air across the heated surfaces of the superconducting heat exchanger, causing the heat to be absorbed by the air and dissipated into the atmosphere.

[0045] In a defrost mode, the thermal switch is reversed, connecting the “hot” heat exchanger to the superconducting heat exchanger in the refrigeration space, and the “cold” heat exchanger to the external superconducting heat exchanger outside the refrigeration space. Heat is absorbed from the external or outside air by the outside heat exchanger, transferred to the “cold” heat exchanger, absorbed by the refrigerant loop, intensified, transferred to the “hot” heat exchanger and then transferred to the superconducting heat exchanger in the cooled space, heating it up and melting the ice that has built up on its surfaces.

[0046] Replacing the circulating fluid components of conventional heat distribution systems with thermal superconductor components has a number of advantages that overcome the limitations described in the background. First, thermal superconductors as described herein have no moving parts, except as configured as thermal switches for routing heat. Second, thermal superconductors have the capacity to transfer heat over relatively long distances with limited energy loss and without the assistance of mechanical pumping. Third, the superconductors transfer heat bi-directionally so the system can be changed quickly from refrigeration to defrost with limited stress on system components and without changing the direction of the circulation of the conventional refrigeration loop. Fourth, they can be arranged to allow heat to be transferred more uniformly across heat exchangers, making these heat exchangers more efficient and therefore potentially smaller than conventional circulating phase change heat exchangers.

[0047] Limiting the function of the conventional phase change refrigeration loop to the intensification of heat has several advantages. First, it allows the phase change refrigeration subsystem to be contained within the refrigeration plant area of a building, making it smaller and less complicated than in a conventional refrigeration system because large volumes of refrigerant are not required to be circulated over long distances. Second, in the preferred embodiment, it allows the phase change refrigeration subsystem to operate in the same direction in both refrigeration and defrost cycles, eliminating reversing valves, many of the thermostatic expansion metering valves, most of the circulating refrigerant in the system and most of the reservoirs required in a reversing system to handle excess liquid refrigerant. Third, it eliminates refrigerant leaks outside the central refrigeration plant area and makes the system easier to service. Fourth, the elimination of unreliable components, extends system lifetime and reduces system maintenance.

[0048] In addition to the foregoing technical advantages, this refrigeration system (in its various embodiments) shows significant operational advantages over conventional refrigeration systems. First, it allows heat energy to be moved from one heat exchanger to another in the system so that waste heat produced by a refrigeration unit can be employed to defrost the heat exchanger in another refrigeration unit. Second, it allows waste heat to be moved to and from other

building mechanical systems such as air heat, floor heat, snow melt, domestic hot water and grey water. And third, with correct switching, this system allows refrigeration units to provide space cooling without the use of mechanical compression whenever outdoor temperatures are low enough to be practicable.

[0049] FIG. 1a illustrates an embodiment of refrigeration system 110 in which heat is transferred bi-directionally using a thermal superconducting medium in the manner described generally above.

[0050] Specifically, an intensifier heat circuit forms a refrigerant transfer path which includes a compressor 24 having outlet connected by refrigerant conduit 19 to a condenser heat exchanger 21 connected to an evaporator conduit 23 connected to an expander 26 connected via conduit 27 to an evaporator heat exchanger 28 connected to a return conduit 29 and an optional accumulator 30 connected by a return conduit 31 to the inlet of the compressor 24. The compressor is controllable through control line 22 connected to controller 16. As is well known in the art, the condenser heat exchanger gives up heat and the evaporator heat exchanger absorbs heat, referred to, respectively, as hot and cold intensifier exchangers, for the purpose of delivering higher grade heat. The compressor 24 compresses a gaseous refrigerant to intensify its heat content, circulates it through conduit 19 to the condenser heat exchanger 21 where it gives up heat and condenses to a liquid or partial liquid, and then passes through conduit 23 to expander 26 which rapidly expands the liquid in a pressure drop causing the refrigerant to become a supercooled partial liquid which absorbs heat and evaporates in the evaporator heat exchanger 28 before passing through return conduit 29 to optional accumulator 30 (where excess remaining liquid is trapped and evaporated) and remaining refrigerant passes through conduit 31 to complete the loop at the compressor inlet. This heat intensifier circuit is for the purpose of converting low grade heat to high quality heat such that heat is transferred at a faster rate. An apparatus for intensifying heat can equivalently substitute for the refrigerant based heat intensifier circuit illustrated. When the refrigerant loop as described is filled with a suitable amount of refrigerant, the intensifier circuit is operated by turning the compressor on. This creates a temperature differential between condenser heat exchanger 21 and evaporator heat exchanger 28. In the preferred case, the intensifier heat exchangers are isolated by insulation 25. Superconductor segment 32 is coupled to condenser heat exchanger 21 and superconductor segment 34 is coupled to evaporator heat exchanger 28, and both superconductor segments terminate on an input side of 2x2 thermal switch 36 connected to control line 20.

[0051] The thermal switch functions to selectively couple the intensifier heat exchangers to refrigeration space heat exchanger 42 (associated with a partially or fully closed space to be refrigerated) and external heat exchanger 42a (in an environment external to the refrigerated space.) A high efficiency thermal switch design is described in a related United States Patent Application “Geothermal Exchange System Using a Thermally Superconducting Medium,” filed Sep. 14, 2006, incorporated herein for reference. Alternately, the thermal switch can be made of other thermally conductive material such as copper or silver alloys with resulting higher losses. For short transfer distances, segments 32 and 34 can equivalently be a non-superconducting heat transfer

medium with a resulting small loss in overall efficiency. In the preferred embodiment the thermal superconductor pipes **32** and **34** are coupled to heat exchangers **21** and **28** respectively by direct contact including spot welding the two components side by side along a suitable “transfer length” or forming both such that a substantial contact areas of the two components can be clamped or joined. The heat intensifier circuit is for the purpose of converting low grade heat to high quality heat such that heat is transferred at a faster rate. An apparatus for intensifying heat can equivalently substitute for the refrigerant based heat intensifier circuit illustrated.

[0052] The first of two remaining inputs of the thermal switch **36** is connected to thermal superconductor transfer segment **38**, which is connected to refrigeration space heat exchange coil **42** within a space to be cooled. A thermal sensor **18** is associated with the air to be conditioned by refrigeration space heat exchange coil **42**. A controller **16** is powered by power line **14** and provides power to compressor **24** and thermal switch **36**, as well as control data to and from thermal switch **36**, blowers **55** and **55a** and thermal sensors **18** and **18a** through respective control lines **52** and **52a**. As will be appreciated, variations of this example can include independently connected compressor or blower power or multiple control systems without changing functionality. Refrigerating heat exchange coil **42** can be configured in a geometric arrangement to improve heat transfer to a specific medium. Insulation **25** preferably covers superconductor transfer segments outside of coupling connections and heat exchange sections, to reduce thermal transfer losses. The last remaining input of the thermal switch **36** is connected to thermal superconductor transfer segment **40** which is connected to external heat exchanger **42a**. A thermal sensor **18a** is associated with the air to which external heat exchanger **42a** transfers heat. Controller **16** provides control data to and from thermal sensor **18**. External heat exchange coil **42a** can be configured in a geometric arrangement to improve heat transfer to the air.

[0053] The refrigeration heat exchange system **110** is operated in either a refrigeration or a defrost mode. The refrigeration mode operation can be determined in proportion to the difference between a refrigeration set point and the measured temperature from sensor **18**. Defrost mode can be programmed for periodic maintenance based on empirical understanding of ice buildup, or an additional ice buildup sensor (not shown) can be added with a set point that triggers defrost mode, for example an optical displacement sensor or air pressure sensor common in the industry. In refrigeration mode, thermal switch **36** is controlled to couple superconductor **38** to cool segment **34** and to couple superconductor **40** to hot segment **32**. Controller **16** operates compressor **24** which comprises part of a heat intensification circuit. Blower **55** draws air across the cold surfaces of refrigeration space exchanger **42** causing heat to be absorbed from the air. Thermal superconductor transfer segment **38** then transfers this heat to the intensifier circuit where it is intensified and then transferred by superconductor transfer segment **40** to external superconductor heat exchange coil **42a**. Blower **55a** then draws air across the heated surfaces of heat exchange coil **42a** causing heat to be absorbed into the air and dissipated into the atmosphere outside the space to be cooled. The blower can be local and dedicated to the refrigeration system shown, or can alternatively be shared or provided as a separate room circulating system having the

refrigeration space heat exchanger positioned suitably in the flow path, for example fans embedded in a wall pushing air past suspended heat exchangers.

[0054] In defrost mode, thermal switch **36** is controlled to reverse the thermal couplings and heat transfer such that refrigeration space heat exchanger becomes heated and external heat exchanger absorbs heat, i.e. they reverse functions compared to refrigeration mode. Superconductor **38** is coupled to hot segment **32** and superconductor **40** is coupled to cold segment **34**, and controller **16** operates compressor **24**, which comprises part of a heat intensification circuit. Heat is then absorbed from air drawn by blower **55a** across the cooled surfaces of external heat exchange coil **42a** and then transferred through superconductor transfer segment **40** to the intensifier circuit and intensified, then transferred through superconductor transfer segment **38** to refrigeration space exchange coil **42**, causing it to heat up and melt ice that has built up on its surfaces. Melted water is then collected in drip tray **56** and drained away through condensate drain line **58** to a suitable location. Sensor **18** can be located for effective monitoring of degree of melted ice on the heat exchanger, or an additional defrost sensor (not shown) can be included and connected to controller **16**. The modes can simply switch on/off or alternatively oscillate between refrigerating and defrosting based on programming of controller **16**, however as is evident from FIG. 1, the modes are mutually exclusive as relates to a system with a single refrigeration space heat exchanger and a single external heat exchanger.

[0055] The intensifier circuit can have additional components as required to scale for larger energy applications, for example where the refrigeration space is very large and partially open for storage access. As shown in FIG. 1b for an expanded alternate arrangement of a large scale intensifier circuit, such larger systems can have receivers **33**, suction accumulators **30**, bulb sensors **17**, thermostatic expansion metering valves **15** and the like to manage refrigerant flow through the heat intensification circuit, as known in the art of conventional heat pump systems.

[0056] Using the preferred thermal superconducting tubes, it is preferred to have insulation **25** along the length of superconductor segments except heat exchanger coil segments or thermal transfer couplings to other components, to limit heat loss and condensation buildup. However alternate thermal superconductor embodiments can have integrated insulating layers or have acceptable transfer loss such that the refrigerating heat exchange system **110** is operable with less or no external insulation.

[0057] The refrigerating heat exchange system **110** can be enclosed a number of ways, depending on application. The components can be housed inside one enclosure to comprise a unit refrigerator. Alternatively, as shown in FIG. 1, the heat intensifier circuit, switch and controller can be housed in a housing **12** (such as a room in a building), and superconductor heat exchange coils **42** and **42a** can be housed in separate enclosures **60** and **60a** respectively, as would typically be found in a large industrial refrigeration application where the refrigeration plant, the space to be cooled and the outdoor location for the dissipation of heat are at a significant distance from each other. In another alternative embodiment, the heat intensifier circuit can be enclosed in either enclosure **60** or **60a** with superconductor heat exchange

coils **42** or **42a** respectively, such as is found in conventional “split” systems. As is well known in the art of controlling mechanical systems, controller **16** and sensors **18** and **18a** can be equally enclosed within enclosures **12**, **60** or **60a**, or located outside these enclosures and connected either wirelessly or by wires to other associated components in refrigerating heat exchange system **110**. Similarly controller **16** can be remotely programmed through wired or wireless communications.

[0058] FIG. 2 illustrates an embodiment of the present technology in which discrete two state superconducting thermal switches **64** and **64a** replace the function of reversing switch **36** of FIG. 1, shown as refrigeration system **120**. Each thermal switch **64** and **64a** can couple to both of the hot or cold intensifier heat exchangers **21** and **28**, dependent on control signals sent via control lines **20** and **20a** from the controller. In refrigerating mode, thermal switch **64** is set so that one of the two illustrated branches of cold superconductor transfer segment **34** is coupled with superconductor transfer segment **38** such that heat absorbed from a space by refrigeration space exchanger **42** is transferred to cold heat exchanger **28**, and thermal switch **64a** is set so that one of the two illustrated branches of hot superconductor transfer segment **32** is coupled with superconductor transfer segment **40** such that heat absorbed from hot heat exchanger **21** by superconductor transfer segment can be transferred to external heat exchanger **42a** and dissipated into the atmosphere. In defrost mode, thermal switches **64** and **64a** are set in reverse position such that heat absorbed by dissipating heat exchanger **42a** can be transferred through the system to refrigeration space exchanger **42** for the purpose of melting built-up ice. For system **120** to operate, switches **64** and **64a** can be set oppositely, so that one couples to hot heat exchanger **21** and one couples to cold heat exchanger **28**, as controlled by controller **16**. Refrigeration system **120** can be similarly housed and programmed for response to the associated thermal sensors, as system **110**, with the additional modification of the switching arrangement.

[0059] Typical industrial refrigeration applications require distributed cooling and shared dissipation configurations, which are easily enabled by the teachings of the superconductor refrigeration system **130** shown in FIG. 3. FIG. 3 illustrates an embodiment of the present technology in which a plurality of refrigeration space exchangers **42**, **42a**, are coupled to a plurality of thermal switches **64**, **64a** respectively, and external heat exchanger **90** is coupled to additional thermal switch **64b**. In this embodiment, switches **64**, **64a** and **64b** can be independently configured so that each of heat exchangers **42**, **42a** and **90** operate as either heat absorbing or heat dissipating, subject to at least one of the heat exchangers being coupled to hot heat exchanger **21** and at least one being coupled to cold heat exchanger **28** to provide a limited thermal balance. Thermal switches are controlled through control lines **20**, **20a** and **20b** as shown, to couple heat to and from the superconductor transfer segments **38**, **38a** and **62** respectively. External heat exchanger **90** includes blower **88** and thermal sensor **84** connected to control line **82** and enclosed in housing **86**. In this embodiment for a refrigerating mode, refrigeration system **130** can be set so that heat exchangers **42** and **42a** operate as refrigeration space exchangers and heat exchanger **90** operates as a external heat exchanger. Alternatively, heat exchanger **42** can be set to operate as a refrigeration space exchanger with heat exchangers **42a** and **90** set to operate as

dissipating heat exchangers such that heat exchanger **42** refrigerates while heat exchanger **42a** defrosts. Note that in this previous case the terminology external has dropped and the term dissipating heat exchanger is used, since within this context heat can be exchanged with another refrigeration space heat exchanger operating in defrost mode rather than an external heat dissipation in ambient atmosphere. In this mode of operation, heat absorbed by heat exchanger **42** is transferred to the heat intensification circuit and then to heat exchanger **42a** for the purpose of defrosting build up of ice. This enables refrigeration system **130** to reuse waste heat produced by at least one refrigeration space exchanger. In another mode of operation, one of heat exchangers **42**, **42a** can be disconnected from the heat intensification circuit by positioning corresponding switch **64** or **64a** in an off position, allowing the disconnected heat exchanger to be serviced or inoperable while the connected heat exchanger continues to refrigerate or defrost. The modes of operation can, as before, be programmed to respond to periodic timing, or in response to environmental temperature changes in the associated thermal sensors, or by external controls or stimulus as required to improve the refrigeration and defrost cycles, and overall system efficiency. The flexibility of this system configuration represents a significant advance over conventional systems, by reducing mode switching response times through elimination of refrigerant reversal and reusing transferred energy not recovered otherwise, and permitting simultaneous concurrent defrost and refrigeration using the same intensifier circuit.

[0060] As shown in refrigeration system **140** in FIG. 4, the integrated multiple heat exchangers illustrated in system **130** can have extended functionality by adding a thermal storage or ballast with heat exchange functionality. A plurality of air-to-superconductor heat exchangers are independently coupled through thermal switches **64**, **64a** and **64b** to a heat intensification circuit, and fluid-to-superconductor heat exchanger **104** is also coupled to the circuit by thermal switch **64c** through superconductor transfer segment **106** such that the heat exchangers can independently operate to absorb or dissipate heat, subject to at least two of the heat exchangers being coupled to the heat intensification circuit, and at least one of the coupled heat exchangers being set in heat absorption mode and at least one of the coupled heat exchangers being set in heat dissipation mode. Fluid to superconductor heat exchanger **104** is configured within a liquid storage tank **98** filled with liquid **94** such as water or a solution with high heat capacity, and having associated temperature sensor **96** connected to controller **16** by line **108**, to provide feedback on the temperature of the stored liquid. In the preferred embodiment, one of the heat exchangers, for example heat exchanger **90**, is external to the refrigeration space. In a heat storage mode selected by controller **16** in response to programming and/or temperature measurements, excess heat absorbed by one or more air-to-superconductor heat exchangers **42**, **42a** and **90** can be transferred to fluid-to-superconductor heat exchanger **104** for transfer to fluid **94**, either for storage in tank **98** or for use by a separate mechanical system (not shown) which circulates fluid **94** into tank **98** through fluid inlet **100** and out of tank **98** through fluid outlet **102**. In a heat recovery mode, thermal switches of refrigeration system **140** can be set so that heat in fluid **94** can be absorbed by fluid-to-superconductor heat exchanger **104** and transferred to the heat intensification circuit and then transferred to one or more of

the air-to-superconductor heat exchangers for the purpose of defrosting or alternatively for space heating. The refrigeration system with heat storage functionality is well-suited for time varying non-uniform utilization of one or more refrigeration spaces, and is enabled by bi-directional heat transfer using thermal superconductors.

[0061] The embodiments shown in FIGS. 1 to 4 are preferred implementations for systems that both refrigerate and defrost. However, there is a key substitution that could be made that would still be improved over existing refrigeration systems but have fewer operating modes with the tradeoff of using a less reliable component—a reversing valve. The refrigeration systems in FIGS. 1 to 4 can be modified by adding reversing valve 77 in the intensifier circuit and eliminating thermal switches as shown in the refrigerating heat exchange system 150 of FIG. 5, to create a reversible heat intensifying loop as is well known in the art. In this embodiment, refrigerant vapor is compressed by compressor 24 and then flows through conduit 19 to reversing valve 77. The reversing valve, controlled by controller 16 through control line 20, then directs this vapor to either of heat exchanger 70 or 74, according to whether heating or cooling is required.

[0062] If refrigeration is required for refrigerating heat exchanger 42, controller 16 sends an instruction to reversing valve 77 to actuate to a position such that heated refrigerant vapor is transferred from conduit 19 to conduit 75. The refrigerant then flows to heat exchanger 74, which functions as a condensing heat exchanger. Heat exchanger 74 gives up heat to superconducting heat transfer segment 40 which transfers it to external heat exchanger 42a in heat dissipating mode, located outside the space to be cooled. The refrigerant gas flowing through heat exchanger 74 condenses in the process of giving up heat, forming a liquid or partial liquid which is transferred through conduit 73 to bidirectional expansion element 72 which causes liquid refrigerant to become a supercooled partial liquid before flowing through conduit 71 to heat exchanger 70, where it absorbs heat from superconducting transfer segment 38 which transfers heat from refrigeration space heat exchanger 42. The design of expansion element 72 for use in both circulation directions is well-known. The warmed refrigerant gas then passes through conduit 76 and then through reversing valve 77 which, in the selected position for this mode, transfers it through conduit 29 to optional accumulator 30 which traps and then allows to evaporate excess remaining liquid refrigerant before the refrigerant vapor returns through conduit 31 to compressor 24 to begin the heat intensification cycle again. As described previously controller 16, controls operation of refrigeration mode through feedback from temperature sensor 18 and/or 18a, or associated external stimulus, by operating the compressor and reversing valve.

[0063] If defrost is required, controller 16 sends an instruction to reversing valve 77 to actuate to a position such that heated refrigerant vapor is transferred from conduit 19 to conduit 76. The refrigerant is then transferred to heat exchanger 70 which then functions as the condensing heat exchanger. Heat exchanger 70 gives up heat to superconductor heat transfer segment 38 which transfers heat to refrigeration space heat exchanger 42 where this heat melts ice built up on the surfaces of the heat exchanger. The refrigerant gas flowing through heat exchanger 70 condenses in the process of giving up heat, forming a liquid or partial

liquid which is transferred through conduit 71 to bidirectional expansion element 72 which causes liquid refrigerant to become a supercooled partial liquid before flowing through conduit 73 to heat exchanger 74, where it absorbs heat from superconducting transfer segment 40 connected to external heat exchanger 42a which absorbs heat from the air drawn across it by blower 55a. The heated refrigerant vapor then passes through conduit 75 and then through reversing valve 77 which, in the selected position for this mode, transfers it through conduit 29 to optional accumulator 30 which traps and then allows to vaporize excess remaining liquid refrigerant before the refrigerant vapor returns through conduit 31 to compressor 24 to begin the heat intensification cycle again. This system has the advantages of using well known components for switching modes in the intensification circuit; however it is noted that for larger intensification circuits designed for large scale heat capacity, the volume of refrigerant inhibits reversal and creates a delay time during which the system is inoperable or inefficient. This effect is reduced relative to a full conventional circulation.

[0064] Refrigeration system 160 in FIG. 6 expands system 150 to include a plurality of refrigeration space heat exchangers 42 and 42a. In this embodiment, superconductor transfer segment 38 becomes a thermal bus which, in the refrigerating mode, transfers heat from refrigerating heat exchangers 42 and 42a to heat exchanger 70, and in the defrost mode transfers heat from heat exchanger 70 to refrigeration space heat exchangers 42 and 42a for the purpose of melting build up of ice. Superconductor external heat exchanger 90 is directly connected to intensifier heat exchanger 74 by superconductor thermal transfer pipe 40 and operates in dissipating or absorbing modes depending on direction of the intensifier circuit.

[0065] This embodiment provides the basic operational modes of refrigeration and defrost such that the bussed refrigeration space heat exchangers 42 and 42a are fixed in identical modes. Therefore, because refrigerating heat exchanger 42 and heat dissipating heat exchanger 42a are not separately switched as shown in FIGS. 1 to 4, no other operating modes described for FIGS. 1 to 4 are enabled.

[0066] All refrigerating systems shown in FIGS. 1 to 6 operate in both refrigeration and defrost modes, and in some cases mixed modes. In some applications a system will not have both refrigerating and defrost modes. One such application is in the retrofitting of existing conventional phase-change refrigerant systems, where complete replacement would be economically inefficient. In such an application, some of the most difficult problems of reversing phase change systems could be eliminated by the addition of a separate system to handle defrost only. FIG. 7 illustrates such a defrost only system 170. Defrost heat exchanger 42a is permanently coupled by superconducting heat transfer segment 32 to hot heat exchanger 21, and heat absorbing heat exchanger 42 is permanently coupled by superconducting heat transfer segment 34 to cold heat exchanger 28. The coupling of the defrost heat exchanger to the evaporator is further described in FIGS. 11-13.

[0067] When controller 16 receives a signal from defrost sensor 18a that ice has built up on an associated evaporator coil (not shown) of a separate refrigerating system (not shown) or determines that a programmed periodic defrost

cycle is due, controller **16** operates compressor **24** to activate a heat intensification circuit. Heat is absorbed from the atmosphere by external heat exchanger **42** and transfers it by superconductor heat transfer segment **34** to the heat intensification circuit, which intensifies it and transfers heat by superconducting heat transfer element **32** to defrost heat exchanger **42a** for the purpose of melting ice that has built up on the associated evaporator coil. As will be obvious to one skilled in the art of conventional refrigeration systems, sensor **18a** can be alternatively an infrared sensor, a sensor that detects changes in static pressure of the air being drawn across the evaporator coil by its associated blower (not shown), or another kind of ice sensor. Alternatively, the defrost cycle can be initiated by a timer or other programmed control sequence or by manual switching. The superconductor defrost exchanger system **170** represents an advance by enabling a conventional refrigerant system to remain in one operating mode instead of reversing valve position, eliminating reversing the trouble prone reversing valve and increasing reliability and overall operating efficiency.

[0068] FIGS. **8a,b,c** illustrates several alternate embodiments showing superconductor defrost system **180**. In these embodiments, the defrost heat source substitutes a fluid loop **80** connected to a remote thermal system in place of the external heat exchanger using air exchange. In a preferred embodiment FIG. **8a**, the fluid loop is the hot refrigerant loop of a conventional refrigeration system. In this embodiment, the remote conventional refrigeration system (not shown) operates to remove heat from at least one refrigerating heat exchanger (not shown). This heat is then transferred through heat exchanger **77** to the defrost intensifier subsystem by thermal superconductor pipe **78** which is coupled with low thermal losses. Heat is then intensified and transferred to defrost heat exchange segment **42** where it is then transferred to the associated evaporator coil (not shown) of a conventional refrigerating heat exchanger for the purpose of melting build up of ice. As will be obvious to one skilled in the art of conventional refrigeration systems, the evaporator coil (not shown) receiving the heat from superconductor defrost system **180** can equally be part of the remote conventional refrigeration system providing the heat, or part of a second, separate conventional refrigeration system. In this process, hot refrigerant gas flows into heat exchanger **77** through refrigerant inlet **81**, gives up heat to superconductor heat exchange element **78** as the refrigerant passes through condenser coil **80**, condensing in the process, and then flows out of heat exchanger **77** through refrigerant outlet **83**. The heat absorbed by superconductor heat exchange element **78** is transferred by superconductor transfer segment **34** to the heat intensification circuit where it is intensified and transferred by superconductor transfer segment **32** to defrost heat exchanger **42**. Controller **16** initiates the operation of the defrost cycle in response to defrost sensor **18**, or as programmed by periodic timing, and operates the compressor until programmed desired sensor setting is reached, or programmed defrost duration is reached. For the case of large industrial refrigeration plants with many dissipating heat exchangers in proximity to refrigeration spaces, this defrost embodiment solves the problem of reusing dissipated heat near its source without increasing ambient temperatures, rather than transporting it and wast-

ing it. This is of particular value where high external or internal ambient temperatures make heat dissipation inefficient.

[0069] Also included in FIG. **8a** is an optional thermal transfer bypass route, comprised of superconductor thermal transfer segments **44**, **46** and thermal switch **35**, which enables superconductor transfer segments **32** and **34** to be directly thermally coupled as shown, such that heat is not required to pass through the heat intensification circuit to transfer between the superconductor transfer segments. When controller **16** determines by way of heat flow sensor **84** that the heat content of fluid **94** is sufficient without intensification for the purpose of melting ice at greater than a programmed threshold de-icing rate determined by the approximate volume of ice, evaporator configuration and refrigeration space temperature, at the refrigerating heat exchanger (not shown) associated with superconductor defrost segment **42**, the controller causes compressor **24** to be stopped if operating, and switch **35** to be set in an "on" position, causing superconductor transfer segments **32** and **34** to be thermally coupled, transferring heat directly from superconductor heat exchange segment **107** to defrost heat exchange segment **42**.

[0070] FIG. **8b** shows a variant of the defrost system **180** in which a fluid **94** stores and transfers heat but remains contained within tank **98**. In a preferred embodiment, a separate system (not shown) causes a heated refrigerant to flow through refrigerant inlet **81** into tank **98**, passing through condenser coil **80**, giving up heat to fluid **94** before condensing and flowing out of the tank through refrigerant outlet **83**. Similar to FIG. **4**, heat is absorbed by superconductor heat exchange segment **104** positioned in storage tank **98** and transferred to the heat intensification circuit. Alternatively, the separate system (not shown) can equally be a circulating fluid heat transfer system and condenser coil **80** can equally be a heat exchange coil suited to the purpose of transferring heat from one fluid to another. A temperature sensor **84** can provide an optional feedback to controller **16** for information on the heating state and cycle of the fluid **94**. A bypass switch **35** is optionally provided as described previously.

[0071] FIG. **8c** illustrates an alternative embodiment of the defrost system **180** which uses a directly exchanged fluid such as grey water, sea water, pond water or the like as the heat source. In this embodiment, a fluid **94** from a separate system (not shown) flows into tank **98** through fluid inlet **101** and flows out through fluid outlet **102**. Superconductor heat exchange segment **104** is located in the storage tank **98** and absorbs heat from the fluid **94** and transfers it by way of superconductor transfer segment **34** to the heat intensification circuit, where the heat is intensified before being transferred to defrost heat exchange element **42**. A temperature sensor **96** can provide an optional feedback to controller **16** for information on the heating state and cycle of the fluid **94**. A bypass switch **35** is optionally provided as described previously.

[0072] The rapid defrost cycle enabled by the defrost systems shown in FIGS. **1-8**, allows for more frequent defrost cycles for shorter durations which leads to an increased average air flow path over the evaporator fins, resulting in improved effective cooling rates over existing conventional systems which can tradeoff air flow restriction versus longer defrost downtime.

[0073] FIG. 9a illustrates a simplified alternative embodiment of the defrost system illustrated in FIGS. 8a, which is operable when the heat content of the remote hot refrigerant gas flowing through condenser coil 80 is sufficient, without intensification, for the purpose of melting ice at the refrigerating heat exchanger (not shown) associated with superconductor defrost segment 42. During operation of defrost system 190, heat is absorbed from condenser coil 80 by superconductor heat exchange segment 78 and transferred by superconductor transfer segment through thermal switch 35 to superconductor transfer segment 38 which transfers it to superconductor defrost segment 42. In operation, controller 16 determines (by timer program or through a signal from ice sensor 18) that defrost heat is required by superconductor defrost segment 42, and closes thermal switch 35, causing heat to flow from heat exchanger 77 to defrost segment 42. In this embodiment, controller 16 can be located on its own or can be integrated into the controller of the refrigeration system (not shown) as a separate function of the refrigeration controller. In an alternate version, enclosure 12 can be modified to enclose also thermal switch 35, and have optional fastening features to be mounted to or in the remote heat exchange module housing 77a. The simplified superconductor defrost system represents an advance in retrofitting existing refrigeration systems with limited additional electrical power required, through operation of a heat exchange system to reuse available heat, and through very compact installation. Alternate embodiments of system 190 could of course use the liquid exchange configurations described in FIGS. 8b, c, including the indirect liquid heat transfer system shown in FIG. 9b.

[0074] FIG. 10 illustrates an alternative embodiment of the defrost system, having multiple discrete defrost exchangers. Defrost system 200 shows two defrost exchangers 42 and 42a coupled through discrete thermal switches 35 and 35a, to the common superconductor heat exchange pipe 40/40a which terminates in coupling 78 to the remote heat exchanger 77. In defrost operation, heat absorbed by superconductor heat exchange segment 78 is transferred by way of superconductors 40 and 40a to a plurality of thermal switches 35, 35a and then to a plurality of superconductor transfer segments 38, 38a, and finally to a plurality of superconductor defrost segments 42, 42a for the purpose of defrosting ice from evaporator coils associated with each defrost exchange (not shown). When controller 16 determines by way of heat flow sensor 84 that the heat content of fluid 94 is sufficient without intensification for the purpose of melting ice at greater than a programmed threshold de-icing rate determined by the approximate volume of ice, evaporator configuration and refrigeration space temperature, at the refrigerating heat exchanger (not shown) associated with superconductor defrost segment 42. There can be two thresholds, one suitable for a single defrost mode operation, and a second higher heat flow threshold to allow simultaneous heat flow to multiple defrost exchangers. In an alternate version, enclosure 12 can be modified to enclose also both thermal switches 35 and pipes 40 and 40a, and have optional fastening features to be mounted to or in the remote heat exchange module housing 77a. In this embodiment, controller 16 operates switches 35 and 35a independently so that the defrost segments can be independently coupled to or decoupled from heat exchanger 77, and the rate and quality of heat exchanged at heat exchanger is preferably above a threshold for simultaneous defrosting.

[0075] FIG. 11 illustrates an expanded drawing of one embodiment of the superconducting heat exchanger 210, as shown in FIGS. 1 to 7. In this embodiment, refrigeration space heat exchanger 42 is configured as a superconductor array coupled to optional heat transfer fins 68 to distribute heat across a larger surface area in order to transfer heat to the air being drawn across the heat exchanger by blower 55. In an alternative embodiment, refrigeration space heat exchanger 42 can be configured with sufficient surface area such that it can transfer heat as required without the addition of heat transfer fins. The heat exchanger 42 can be operated in defrost mode as previously described. An optional drip tray 56 and drip line 58 is illustrated, including an optional superconductor branch positioned in the drip tray to defrost the drip tray. It will be appreciated that the superconductor heat exchanger can be configured differently from the illustration for specific installations without changing the functionality. Transfer segment 38 is shown with thermal insulation 25.

[0076] FIG. 12a-c, illustrate a conventional phase change refrigeration evaporator with the addition of a superconducting defrost component, as described previously for FIGS. 8 to 10, to form refrigerating and defrosting heat exchange unit 220. The evaporator operates in the conventional manner as part of a refrigeration system. Liquid refrigerant supply subsystem 66 causes liquid refrigerant to expand and become a super-cooled partial liquid as it flows into evaporator loops 69, absorbing heat from heat transfer fins 67 before flowing out of evaporator loops 69 into refrigerant vapor return subsystem 65 and then back to the remainder of the refrigeration system (not shown). The heat transfer fins 67 have additional sleeves 63 enabling superconductor defrost segment 42 to be inserted for the purpose of delivering heat to melt ice that has built up on surfaces of the evaporator assembly. Water produced by the melting of ice is collected in drip tray 56 (which is also heated by superconductor defrost segment 42) and is drained away to a suitable location through drain line 58. FIG. 12a illustrates the conventional evaporator assembly with other components removed for clarity. FIG. 12b illustrates a superconducting defrost array 42 couplable and ready for insertion into sleeves 63 to complete the refrigerating/defrosting heat exchange unit 220. FIG. 12c illustrates an evaporator unit with superconducting defrost array 42 permanently installed, or alternatively, with removable superconducting defrost array 42 inserted for operation. As will be obvious to one skilled in the art, there are various coupling methods to couple the metal superconductor pipe to the typically metal fins. The defrost transfer element 42 represents an increase in the heat transfer efficiency so that a wide range of couplings and tolerances with various retrofitted evaporator designs still allows the defrost system to be enabled. Specifically, the thermal superconductor may not require bonding, welding or other processes but can simply be press-fit.

[0077] FIG. 13 illustrates an alternative embodiment of the modified conventional evaporator system of FIG. 12, configured as superconductor defrost evaporator system 230. In this embodiment, superconducting defrost segment 42 is mounted to one side of the evaporator assembly such that heat from superconducting defrost segment 42 is transferred to heat transfer fins 67 for the purpose of melting ice that has built up on the surface of heat transfer fins 67 and evaporator loops 69. Superconducting defrost segment 42 can alternatively be mounted to both sides of the evaporator

assembly for additional defrost capacity. Superconducting defrost segment **42** can alternatively be configured to be removable from the face of the evaporator assembly so as to decrease the wind resistance to air being blown through the assembly. This example allows for convenient in-situ installation within the refrigeration space, without alteration of the conventional refrigeration heat exchanger.

[0078] FIG. **14** illustrates a typical configuration of refrigeration system **130** in a building **116**. A space to be refrigerated is enclosed by room **118**, having access door **117** such that materials can be transported in and out. The internal average temperature is shown as **T1**. Also within building **130** is a refrigeration plant enclosed in housing **12**, of the type described herein, the internal temperature outside room **118** is **T2**. Suspended in refrigerated room **118** are refrigerating heat exchanger housings **60** and **60a** which house refrigerating heat exchange segments, blowers, sensors and other associated equipment (all not shown) of the superconductor refrigeration systems. Superconducting heat transfer segments **38** and **38a** thermally couple the refrigerating heat exchange segments with thermal switches **64a** and **64b** in refrigeration room **12**, having internal temperature **T4**. Thermal switches are in turn coupled to both condensing heat exchanger **21** and evaporating heat exchanger **28**, which are part of a heat intensification circuit with a phase change refrigerant fluid (not shown) circulated by compressor **24**, which receives control signals from thermostat controller **16**. Heat absorbed by the refrigerating heat exchange segments (not shown) is transferred to evaporator heat exchanger **28**, intensified by the heat intensification circuit, transferred by condensing heat exchanger **21** to thermal switch **64b** and then by superconducting thermal transfer segment **40** to external heat exchanger in housing **86** outside building **116**, where this heat is then dissipated into the atmosphere, having temperature **T3**. Not shown are additional refrigeration plants or remote heat exchangers that the illustrated refrigeration plant can couple to. As previously described, refrigeration system operates in a refrigerating mode when **T1** is above a programmed thermostat set point. The higher external temperature **T3** is, the blower (not shown) speed can be increased by controller **16** to adjust the corresponding heat transfer rate to external air. The external dissipation of heat, maintains internal temperature **T2** at acceptable limits.

[0079] Further, the blower associated with the refrigerating heat exchanger can be a variable speed controller with speed controlled by the thermostat controller in response to the difference between a desired temperature set point and measured temperature of the refrigeration space. Additionally, the variable speed blower can be connected to the thermostat controller to enable this control.

[0080] In these examples and embodiments described, insulation has been shown on superconductor segments designed for low thermal loss transfer (i.e. not the ends of the superconductor segments), and is the preferred example, whether or not explicitly stated in figure descriptions or numbered on drawings. However, as noted previously, the superconductor geothermal exchange systems described will operate with no insulation or with some transfer lines insulated or a combination of insulated or un-insulated portions of the superconductors thereof.

[0081] In these examples housing has been described as split housing in a preferred case, however it will be appre-

ciated that the various embodiments can be integrated into existing structures or enclosed in a single housing.

[0082] Although particular embodiments of the present technology have been described by way of example, it will be appreciated that additions, modifications and alternatives thereto can be envisaged. The scope of the present disclosure includes a novel feature or combination of features disclosed therein either explicitly or implicitly or generalization thereof irrespective of whether or not it relates to the claimed invention or mitigates one or more of the problems addressed by the present invention. The applicant hereby gives notice that new claims can be formulated to such features during the prosecution of this application or of such further application derived there from. In particular, with reference to the appended claims, features from dependent claims can be combined with those of the independent claims and features from respective independent claims can be combined in an appropriate manner and not merely in the specific combinations enumerated in the claims.

What is claimed is:

1. A superconductor refrigeration system having thermal superconducting heat transfer, the system comprising:

- (a) a reversible intensifying heat exchanger, having
 - i. a compressor;
 - ii. a first heat exchanger and a second heat exchanger, each of said heat exchangers adapted to function interchangeably as an evaporator and a condenser, wherein said first heat exchanger is operable as an evaporator and said second heat exchanger is operable as a condenser when said system is operating in cooling mode, and wherein said first heat exchanger is operable as a condenser and said second heat exchanger is operable as an evaporator when said system is operating in heating mode;
 - iii. at least one first conduit in communication with said compressor and each of said heat exchangers and adapted for carrying refrigerant through said system to each of said heat exchangers, said at least one conduit including a return conduit for carrying refrigerant gas back to said compressor;
 - iv. a reversing valve in communication with said at least one conduit and configured to reverse the flow of refrigerant from said compressor to said heat exchangers depending upon whether said system is operating in said cooling mode or said heating mode;

whereby when said intensifier heat exchanger is operating in heating mode, said valve is activated to direct refrigerant pumped from said compressor through said at least one conduit to said first heat exchanger where said refrigerant gas is condensed into liquid, through said return conduit to said second heat exchanger where said liquid is vaporized into gas and heat is transferred from earth source through said thermal superconductor, and back to said compressor via said return conduit;

and whereby when said intensifier heat exchanger is operating in cooling mode, said valve is activated to direct refrigerant pumped from said compressor through said at least one conduit to said second heat exchanger where said refrigerant gas is condensed into liquid and heat is transferred to earth source through

said thermal superconductor, through said return conduit to said first heat exchanger wherein said liquid is vaporized into gas, and back to said compressor via said return conduit;

(b) a refrigerating heat exchange coil formed from thermal superconductor material, having a transfer segment terminating at opposing ends at a refrigerating heat exchange segment and a refrigerating heat exchange segment coupled to one of said first or second heat exchangers; and

(c) a dissipating heat exchange coil formed from thermal superconductor material, having a transfer segment terminating at opposing ends at a dissipating heat exchange segment and a dissipating heat exchange segment coupled to the other one of said first or second heat exchangers,

wherein said reversing valve can be configured to provide corresponding refrigerating or defrosting modes of said superconductor refrigeration system.

2. The superconductor refrigeration system of claim 1, further comprising a thermostat controller associated with a location proximal to said refrigerating heat exchange segment, programmed with a desired temperature set point and for measuring temperature of said space and further connected to said reversing valve and said compressor, wherein both said compressor is operated and said reversing valve position controlled in response to one of the difference between said temperature set-point and said measured temperature and a preset timer.

3. The superconductor refrigeration system of claim 2, further comprising a blower positioned to circulate air over said refrigerating heat exchange segment, and connected to said controller, wherein said blower is operated in response to one of the difference between said temperature setpoint and said measured temperature and a preset timing.

4. The superconductor refrigerating system of claim 3, further comprising a second blower positioned to circulate air over said dissipating heat exchange segment, and wherein said thermostat controller is connected to said blower to operate said blower in response to difference between said measured temperature and said setpoint for the purpose of dissipating heat.

5. The superconductor refrigerating system of claim 1, wherein said thermal superconductor material is an inorganic high heat transfer medium

6. The superconductor refrigerating system of claim 5, wherein said high heat transfer medium is applied in a sealed heat transfer pipe.

7. The superconductor refrigerating system of claim 6, wherein said thermal superconductors are heat transfer pipes containing said high heat transfer medium, and insulated along at least a portion of heat transfer segment, said heat transfer pipes having thermal conductivity greater than 100 times the thermal conductivity of silver and approximately negligible heat loss along said heat transfer segment.

8. The superconductor refrigerating system of claim 4, wherein said refrigerating and dissipating heat exchange segments are arranged as condenser arrays having area approximately corresponding to said blower area for increased air heat exchange.

9. The superconductor refrigerating system of claim 1, wherein at least a portion of said thermal superconductors

are formed in discrete segments joined by approximately short thermally conducting joiners.

10. The superconductor refrigerating system of claim 2, further comprising a plurality of refrigerating heat exchange segments coupled to a to said condenser heat exchange segments.

11. The superconductor refrigerating system of claim 10, further comprising a plurality of blowers positioned proximal to each of said refrigerating heat exchange segments and said dissipating heat exchange segments and connected to said thermostat controller.

12. The superconductor refrigerating system of claim 10, further comprising a plurality of temperature sensors associated with said plurality of heat exchange coils providing independent temperature measurement, and said plurality of heat exchange switches are switchable in response to respective differences between said individual temperature measurements and corresponding associated temperature set points.

13. The superconductor refrigerating system of claim 1, further comprising an auxiliary fluid loop coupled to said dissipating exchange segment and having a fluid pump, for the purpose of exchanging heat from or to said superconductor refrigerating system.

14. The superconductor refrigerating system of claim 13, wherein said fluid is water.

15. The superconductor refrigerating system of claim 14, wherein said auxiliary water loop is for the heating of water.

16. The superconductor refrigerating system of claim 14, wherein said auxiliary water loop uses heat from waste water.

17. The superconductor refrigerating system of claim 13 wherein said fluid is refrigerant and said fluid pump is a compressor.

18. The superconductor refrigerating system of claim 17 wherein heat is exchanged between the refrigerant loop and the superconductor heat exchange segments through direct thermal contact.

19. The superconductor refrigerating system of claim 17 wherein heat is exchanged between the refrigerant and the superconductor heat exchange segment through an intermediating fluid.

20. The superconductor refrigerating system of claim 19 wherein said intermediating fluid acts as a thermal storage mass.

21. The superconductor refrigerating system of claim 1, further comprising a receiver connected to said thermostat controller and a remote control in communications with said receiver such that thermostat setpoints and operations can be controlled wirelessly.

22. The superconductor refrigerating system of claim 1 further comprising a programmable timer connected to said thermostat controller such that defrost cycles can be activated at time-controlled intervals.

23. The superconductor refrigerating system of claim 11, further comprising thermostat controller to vary the operating speed of said blowers separately, such that the cooling or heating characteristics of said refrigerating and heat dissipating heat exchangers can be individually controlled.

24. The superconductor refrigerating system of claim 1, further comprising an ice buildup sensor located approximately at said refrigerating heat exchange segment and

connected to said controller, wherein said switch position is selected for defrosting mode upon said sensor reaching a programmed setpoint

25. The superconductor refrigerating system of claim 24, further comprising an optical sensor to detect ice build up on heat exchangers.

26. The superconductor refrigerating system of claim 24, further comprising an air pressure sensor to detect ice build up on heat exchangers.

27. The superconductor refrigerating system of claim 3, further comprising:

- (a) a plant enclosure which houses said compressor, said controller, said intensifying heat exchanger and said reversing valve; and
- (b) a heat exchange enclosure which houses said refrigerating heat exchange segment and blower and thermal sensor, and having venting near said blower suitable for circulation of air through an inlet and outlet,

wherein said plant enclosure and said heat exchange enclosures are at least connected by one end of said refrigerating heat exchange segment and communications control to said blower and said thermal sensor.

28. The superconductor refrigerating system of claim 27, wherein said heat exchange enclosure is configured to be suspended in a space to be refrigerated.

29. The superconductor refrigerating system of claim 11, further comprising

- (a) a plant enclosure which houses said compressor, said controller, said intensifying heat exchanger and said thermal switches; and
- (b) a plurality of heat exchange enclosures, each of which houses one of corresponding said refrigerating heat exchange segment, blower and thermal sensor, said enclosure having venting near said blower,

wherein said plant enclosure and said plurality of heat exchange enclosures are connected by at least said corresponding refrigerating switch segments and communications controls to said blowers.

30. A superconductor defrosting system having thermal superconducting heat transfer, the system comprising:

- (a) an intensifying heat exchanger, having
 - i. a refrigerant coil which receives refrigerant in the heating and cooling cycle;
 - ii. a first condenser heat exchange segment of said coil;
 - iii. a first evaporator heat exchange segment of said coil;
 - iv. an evaporator to expand liquid refrigerant to partial liquid and located between said exchange segments; and
 - v. a compressor for compressing and circulating a refrigerant in said refrigerant coil;

- (b) a defrosting heat exchange coil formed from thermal superconductor material, having a transfer segment terminating at opposing ends at a defrosting heat exchange segment and a second condenser heat exchange segment;

- (c) an absorbing heat exchange coil formed from thermal superconductor material, having a transfer segment terminating at opposing ends at an absorbing heat exchange segment and a second evaporator heat exchange segment; and

- (d) a controller programmable to a desired set point and further having a thermostat controller connected to said thermal switch and said compressor.

31. The superconductor defrosting system of claim 30, further comprising a blower positioned to circulate air over said defrosting heat exchange segment, and connected to said controller.

32. The superconductor refrigerating system of claim 31, further comprising a second blower positioned to circulate air over said absorbing heat exchange segment.

33. The superconductor defrosting system of claim 30, wherein said thermal superconductor material is an inorganic high heat transfer medium.

34. The superconductor defrosting system of claim 33, wherein said high heat transfer medium is applied in a sealed heat transfer pipe.

35. The superconductor defrosting system of claim 34, wherein said thermal superconductors are heat transfer pipes containing said high heat transfer medium, and insulated along at least a portion of heat transfer segment, said heat transfer pipes having thermal conductivity greater than 100 times the thermal conductivity of silver and approximately negligible heat loss along said heat transfer segment.

36. The superconductor defrosting system of claim 32, wherein said defrosting and absorbing segments are arranged as condenser arrays having area approximately corresponding to the areas of said blowers for increased air heat exchange.

37. The superconductor defrosting system of claim 30, wherein at least a portion of said thermal superconductors are formed in discrete segments joined by approximately short thermally conducting joiners.

38. The superconductor defrosting system of claim 30, wherein said defrosting heat exchange segment is arranged as a thermal conductor bus extending to a plurality of said defrosting heat exchange coils, and said absorbing heat exchanger segment is arranged as a thermal conductor bus extending to a plurality of said absorbing heat exchanger coils, to provide a corresponding heat transfer capacity.

39. The superconductor defrosting system of claim 38, further comprising a plurality of blowers positioned proximal to each of said defrosting heat exchange segments and said absorbing heat exchange segments and couplable to said thermostat controller.

40. The superconductor defrosting system of claim 30, further comprising a receiver connected to said thermostat controller and a remote control in communications with said receiver such that controller setpoints and operations can be controlled wirelessly.

41. The superconductor defrosting system of claim 30, further comprising a programmable timer connected to said controller such that defrost cycles can be activated at time-controlled intervals.

42. The superconductor defrosting system of claim 39, further comprising a thermostat controller to vary the operating speed of said blowers separately, such that the cooling or heating characteristics of said defrosting and heat absorbing heat exchangers can be individually controlled.

43. The superconductor defrosting system of claim 30, further comprising an ice buildup sensor located approximately at said defrosting heat exchange segment and connected to said controller, wherein said switch position is selected for defrosting mode upon said sensor reaching a programmed setpoint

44. The superconductor refrigerating system of claim 43, further comprising an optical sensor to detect ice build up on said refrigerating heat exchange coils.

45. The superconductor refrigerating system of claim 43, further comprising an air pressure sensor to detect ice build up on heat exchanger coils.

46. The superconductor refrigerating system of claim 32, further comprising:

- (a) a plant enclosure which houses said compressor, said controller, said intensifying heat exchanger and said thermal switch; and
- (b) a defrosting heat exchange enclosure which houses said defrosting heat exchange segment and and thermal sensor and said blower
- (c) a absorbing heat exchange enclosure which houses said heat absorbing heat exchange segment and and thermal sensor and said blower

wherein said plant enclosure is connected to said defrosting heat exchanger enclosure and said heat absorbing heat exchange enclosure by at least said condenser heat exchange segment and said evaporator heat exchange segment and communications control to said blowers.

47. The superconductor refrigerating system of claim 44, wherein said heat exchange enclosure is configured to be suspended in a space to be refrigerated.

48. The superconductor refrigerating system of claim 39, further comprising

- (a) a plant enclosure which houses said compressor, said controller, said intensifying heat exchanger; and
- (b) a plurality of heat exchange enclosures, each of which houses one of corresponding said defrosting heat exchange segment and said blower, said enclosure having venting near said blower,

wherein said plant enclosure and said plurality of heat exchange enclosures are connected by at least said corresponding condenser heat exchange segments and communications controls to said blowers.

49. A superconductor refrigeration exchange element for use in an air flow path, comprising:

- (a) a plurality of evaporator refrigerant conduits suitable for receiving refrigerant;
- (b) an evaporator coupled to ends of each of said plurality of refrigerant coils;
- (c) a condenser conduit coupled to opposing ends of each of said plurality of refrigerant coils;
- (d) a plurality of cooling plates formed of a thermally conductive material arranged in a approximately co-planar stack, and having at least one conduit opening through each of said plates corresponding to each refrigerant conduits such that said conduits are seated in thermal contact within said cooling plate stack for the purpose of exchanging heat with air;

(e) a thermal superconductor heat transfer pipe arranged such that a coupling portion is coupled on at least one side of said cooling plates stacks such that thermal contact is created between said cooling plates and said heat transfer pipe, the location of said coupling portion relative to said seated conduits is arranged to increase available air flow through said plates, and a transfer portion extends away from said stack of plates; and

(f) insulation surrounding at least part of said extended portion to reduce heat transfer loss;

wherein heat is transferred from said cooling plates by said refrigerant conduits for the purposes of cooling said air flow and heat is transferred to cooling plates by said thermal superconductor heat transfer pipe for defrosting ice build up on said cooling plates such that said air flow is approximately maintained.

50. The superconductor defrosting element of claim 49, further comprising a blower positioned to circulate air over said defrosting heat exchange segment.

51. The superconductor defrosting element of claim 49, wherein said thermal superconductor material is an inorganic high heat transfer medium.

52. The superconductor defrosting element of claim 49, wherein said high heat transfer medium is applied in a sealed heat transfer pipe.

53. The superconductor defrosting element of claim 52, wherein said thermal superconductors are heat transfer pipes containing said high heat transfer medium, and insulated along at least a portion of heat transfer segment, said heat transfer pipes having thermal conductivity greater than 100 times the thermal conductivity of silver and approximately negligible heat loss along said heat transfer segment.

54. The superconductor defrosting element of claim 50, wherein said defrosting heat exchange segment is arranged as a condenser array approximately conforming to the area of the blower.

55. The superconductor defrosting element of claim 49, wherein at least a portion of said thermal superconductors are formed in discrete segments joined by approximately short thermally conducting joiners.

56. The superconductor defrosting element of claim 49, further comprising a tray located below said defrosting element and a drainage line coupled to said tray for the collection and transfer of water produced by the defrosting of ice built up on said superconductor defrosting element.

57. The superconductor defrosting element of claim 49, further comprising an ice buildup sensor located approximately at said refrigerating heat exchange segment and connected to said controller, wherein a defrost cycle is selected upon said sensor reaching a programmed setpoint

58. The superconductor defrosting element of claim 57, further comprising an optical sensor to detect ice build up on heat exchangers.

59. The superconductor defrosting element of claim 57, further comprising an air pressure sensor to detect ice build up on heat exchangers.

60. The superconductor defrosting element of claim 57, further comprising thermal sensor to determine the rate of heat transfer to or from said element through said superconductor heat transfer pipe.

61. The superconductor refrigerating system of claim 50, further comprising an enclosure which houses said defrosting heat exchanger and said blower.