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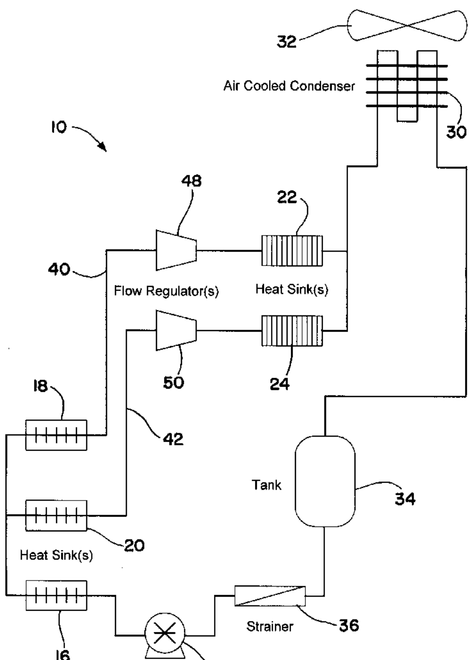

FIG. 1

(57) Abstract: A cooling system is used to cool heat-producing devices, such as ultra-capacitor cells. The cooling system is a two-phase system that pumps a cooling fluid through a closed loop. The fluid goes through tubing that cools cold plates that are coupled to heat-generating objects. The fluid goes through different parallel flow paths to cool different heat-generating objects. One or more of the parallel flow paths may have flow regulators for controlling flow through the parallel flow paths. The cooling system may be used to cool an array of ultra-capacitors, and associated electronics, for example.

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COOLING SYSTEM AND METHOD

FIELD OF THE INVENTION

[0001] The invention is in the general field of cooling systems and methods for cooling heat-generating components.

DESCRIPTION OF THE RELATED ART

[0002] Ultra-capacitors are being used as energy storage devices in various hybrid electric vehicles. Ultra-capacitors can provide more instantaneous power than a battery for a short amount of time, and so, are better suited for certain applications. One of the common size and shape of an ultra-capacitor cell is a cylinder with a diameter of about 6.4 cm (2.5 inches) and length of 8.3 cm (3.25 inches). To obtain sufficient energy and power capacity, the ultra-capacitor cells are often packaged together in series and form a complete module. During the ultra-capacitors' operation of repeated charging and discharging, the ultra-capacitor cells tend to build up heat and temperature. The cells must be cooled in some manner to prevent overheating and damage.

[0003] A cooling system for ultra-capacitors (or other electrical equipment) would need to be compatible with electrical equipment. Other desirable characteristics of a cooling system would be for the system to be lightweight and flexible, able to handle a large range of heat loads.

[0004] A prior cooling system is disclosed in U.S. Patent 6,519,955. In that system a pumped refrigerant is sent to cool a series of apparently identical cold plates. Such a system may not perform well when there are different heat loads on different types of heat sinks. Improvements would be desirable in cooling systems for ultra-capacitors in particular, and more generally for heat-producing devices.

SUMMARY OF THE INVENTION

[0005] According to an aspect of the invention, a two-phase flow cooling system includes parallel flow paths with a flow regulator in at least one of the flow paths.

[0006] According to another aspect of the invention, a cooling system includes: a pump that pumps cooling fluid; and a closed flow loop that is operably coupled to the pump; wherein the closed flow loop includes a pair of parallel flow paths thermally coupled to respective heat-generating objects; wherein at least one of the flow paths has a flow regulator therein; and wherein the flow regulators regulates two-phase flow of the cooling fluid through the parallel flow paths.

[0007] To the accomplishment of the foregoing and related ends, the invention comprises the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative embodiments of the invention. These embodiments are indicative, however, of but a few of the various ways in which the principles of the invention may be employed. Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The appended drawings show various features of embodiments of the invention.

[0009] Fig. 1 is a schematic diagram of a cooling system in accordance with an embodiment of the present invention.

[0010] Fig. 2 is an oblique view of parts of the cooling system of Fig. 1.

[0011] Fig. 3 is another oblique view of the parts of the cooling system that are shown in Fig. 2, with a cover removed for clarity.

[0012] Fig. 4 is an oblique view of other parts of the cooling system of Fig. 1, showing ultra-capacitors between cooling plates of the cooling system.

[0013] Fig. 5 is an oblique view showing the parts of Fig. 4, with one of the cooling plates removed.

[0014] Fig. 6 is an oblique view of still other parts of the cooling system of Fig. 1, focusing on the cooling plates used to cool electronic components.

[0015] Fig. 7 is an oblique view showing a flow regulator for use in the cooling system of Fig. 1.

[0016] Fig. 8 is a schematic diagram of a cooling system in accordance with an alternate embodiment of the present invention.

[0017] Fig. 9 is a schematic diagram of a cooling system in accordance with another alternate embodiment of the present invention.

[0018] Fig. 10 is a schematic diagram of a cooling system in accordance with still another alternate embodiment of the present invention.

DETAILED DESCRIPTION

[0019] A cooling system is used to cool heat-producing devices, such as ultra-capacitor cells. The cooling system is a two-phase system that pumps a cooling fluid through a closed loop. The fluid goes through tubing that cools cold plates that are coupled to heat-generating objects. The fluid goes through different parallel flow paths to cool different heat-generating objects. One or more of the parallel flow paths may have flow regulators for controlling flow through the parallel flow paths. The cooling system may be used to cool an array of ultra-capacitors, and associated electronics, for example.

[0020] Fig. 1 shows a cooling system 10 for cooling heat-generating objects. In the system 10 a pump 12 recirculates a cooling fluid through a closed loop to cool several heat sinks 16, 18, 20, 22, and 24, which represent cold plates that are coupled to heat-generating objects, in order to remove heat from (cool) those objects. The cooling system 10 is a two-phase cooling system, with the cooling fluid at least partially evaporating as it passes through the heat sinks 16-24, and then being condensed as it passes through a condenser 30. The condenser 30 is shown as an air-cooled condenser, for example cooled by a fan 32 blocking air across it, although other types of condensers may be used instead. After passing through the condenser 30, the liquid cooling fluid returns through an accumulator tank 34 and a strainer 36, before returning to the inlet of the pump 12. The accumulator 34 may alternatively be in branch off of the main tubing run between the condenser 30 and the strainer 36. The strainer 36 is a filter or mesh that strains out any extraneous solid objects from the cooling fluid, so as to avoid damaging the pump 12. A filter/dryer may also be used to remove moisture from the cooling fluid.

[0021] The cooling fluid (liquid refrigerant in the illustrated embodiment) is slightly subcooled as it leaves the pump 12. As the liquid refrigerant picks up heat from the heat sinks 16-24, it begins to boil, using some of the heat received from the heat sinks 16-24 to overcome the latent heat of the fluid. The refrigerant cooling fluid thus begins to flow as a two-phase fluid flow, partial liquid and partial vapor. As the cooling fluid picks up more heat as it passes through the heat sinks 16-24, the two-phase flow may pass through various flow regimes (flow states), such as bubbly flow, slug flow, churn flow, wispy/annular flow, and/or annular flow. An advantage of two-phase flow is that the cooling fluid may remain at a substantially constant temperature as it picks up heat. This allows its cooling ability to be maintained even near the downstream heat sinks 16-24. This advantage of two-phase flow contrasts with a single-phase cooling system, where a single-phase cooling fluid, such as water or oil, increases in temperature as it receives heat in passing through the heat sinks 16-24. This increase in temperature of an all-liquid cooling fluid decreases heat transfer performance at the downstream end of the heat sinks 16-24.

[0022] In the arrangement shown in Fig. 1, the heat sink 16 is immediately downstream of the pump 12, so that all of the outflow from the pump 12 passes through the heat sink 16. Downstream of the heat sink 16, the flow branches into two parallel flow paths 40 and 42. The flow path 40 includes the heat sinks 18 and 22, with a flow regulator 48 between them. The flow regulator 48 is downstream of the heat sink 18, and upstream of the heat sink 22. The flow path 42 includes the heat sinks 20 and 24, with a flow regulator 50 between them. The flow regulator 50 is downstream of the heat sink 20, and upstream of the heat sink 24.

[0023] The heat sinks 16, 18, and 20 may be used to cool relatively-constant-heat-flow heat-generating objects. The heat sinks 22 and 24, in contrast, may be for cooling objects that have any of a wide variety of heat loads. The heat sinks 16-20 may all impose substantially identical heat loads on the cooling system 10. The heat sinks 22 and 24 may impose heat loads that differ from each other. The flow regulators 48 and 50 are used to control the flow in the two flow paths 40 and 42, to make sure that there is sufficient cooling fluid flow in both of the paths 40 and 42 to handle all of the cooling needs of the system 10. Two flow regulators 48 and 50 are shown in the illustrated embodiment, but alternatively the flow may be regulated by having flow in only one of the flow paths 40 and 42. Without a flow regulator, an unbalanced heat load between the flow paths 40 and 42 could lead to all (or a substantial portion) of the cooling fluid in the high-heat-load flow path evaporating, because fluid flow is shifted to the other flow path (the one with the low heat load), because the low-heat-load path has a reduced pressure differential (it is the path of lesser resistance).

[0024] Figs. 2 and 3 show one possible layout of the cooling system 10. The pump 12 is controlled by a pump control board that is in a housing 54 on a frame 55. The pump control board controls the speed of pump 12, for example. The heat sinks 16, 18, and 20 are cold plates 56, 58, and 60, used to cool an array of heat-generating objects, which are ultra-capacitors 64 in the illustrated embodiment of the cooling system 10, as is shown in Fig. 4. The cold plates 56-60 in the illustrated embodiment are each a pair of aluminum plates with copper tubing sandwiched in between, although other materials may be used. The plates 56-60 are all mounted to a bracket 65 that is part of the housing or frame 54. Other components of the cooling system 10, such as the pump 12 and the accumulator 34, may also be mechanically mounted to the bracket or to other parts of the housing or frame 54. The surfaces of the cold plates 56-60 that are in contact with electricity-carrying parts of the ultra-capacitors 64 (or connectors linking the ultra-capacitors 64, such as bus bars 66 shown in Fig. 5), are electrically insulated. The cold plates 56-60 may be coated (covered) by an electrically-nonconductive film, an example of a suitable coating material is THERMFLOW T558, available from Chomerics, a division of Parker-Hannifin Corp.

[0025] The bus bars 66 engage the terminals of the ultra-capacitors 64 to electrically couple the ultra-capacitors 64 together. Molded plastic cell containers 68 may be used to hold the ultra-capacitors 64 in place in a desired array.

[0026] From the pump 12 the cooling fluid flow is directed through the cold plates 56-60, first through one of the plates, and then branching in different flow paths through the other two cold plates. Rigid tubing 70, such as tubing made out of the copper, steel, aluminum, or titanium, may be used to route the flow from the pump 12 to the cold plates 56-60, and between the cold plates 56-60. Since the cooling system 10 is a two-phase flow system, the cold plates 56-60 are all at substantially the same temperature, and thus are able to provide substantially the same amount of cooling to each layer of the ultra-capacitors (or other heat-generating objects).

[0027] After exiting the cold plates 56-60, the fluid flow in the parallel flow paths passes through flexible hosing or hard tubing 72 and into the heat sinks 22 and 24, which are cold plates 76 and 78 for providing cooling to electrical or electronic components, such as electronic components like insulated gate bipolar transistor (IGBT) modules, microprocessor modules, or the like.

[0028] Figs. 6 and 7 show further details of the heat sinks 22 and 24 for electronic components 82 and 84, using the cold plates 76 and 78. The flow regulators 48 and 50 may be elastomer discs with orifices in them to provide a controlled pressure drop, such as the disc 90 shown in Fig. 7. The orifices for the flow regulators 48 and 50 for the two parallel lines 40 and 42 (Fig. 1) may have different diameters, to provide different pressure drops for the regulators 48 and 50. Inlet manifolds 92 and 94 distribute flow to different parts of the cold plates 76 and 78. The manifolds 92 and 94 divide incoming flow into each of the cold plates 76 and 78 into three flow channels, to spread the flow through different parts of the cold plates 76 and 78. The cold plates 76 and 78 may be brass plates, with finned interiors for good heat transfer, and copper lids in contact with the components 82 and 84. A thermal grease may be placed between the cold plates 76 and 78 and the components 82 and 84 to facilitate heat transfer. An outlet manifold 98 collets the exit flow from both of the cold plates 76 and 78, and routes the flow back toward the condenser 30 (Fig. 2), for eventual return to the pump 12 (Fig. 2).

[0029] The electronic components 82 and 84 may have different heat loads, and requires different levels of cooling. The flow regulators 48 and 50 may be configured differently, for example have differently-sized orifices, to maintain flow in the two flow paths 40 and 42 sufficient to cool adequately the electronic components 82 and 84. When the ratio of heat loads of the heat sinks in the parallel flow paths 40 and 42 is known to be constant, simple fixed orifices placed in the flow paths 40 and 42 downstream of the flow path split may be used to direct the correct proportion of flow to each of the paths 40 and 42. However, when the ratio of parallel heat loads is known not be constant, fixed orifices may not satisfactorily provide flow to all portions of the cooling system 10 at all times. In these cases more complicated flow regulators may be used to limit the flow in each path to the greatest amount of flow need in each of the paths 40 and 42 under its highest heat load condition.

[0030] The flow regulators 48 and 50 may be made of materials suitable for use with refrigerants or other cooling fluids. Suitable materials for use with refrigerants include neoprene or hydrogenated nitrile butadiene rubber (HNBR). The term "flow regulator" is used herein to refer to devices that allow no flow rate beyond a predetermined flow, even for increased pressure difference. A "flow regulator" is different from, and used in contrast to, a "flow restrictor," which as used herein refers to a device that provides resistance to fluid flow, while still allowing steadily increasing flow as the pressure difference across the device increases. Flow regulators described herein may be passive devices, not requiring any adjustment or feedback to operate. Elastomeric orifices are examples of flow regulators. A spring-and-ported-piston device is another example of a flow regulator.

[0031] The cooling system 10 provides many advantages over some prior systems, for example single-phase cooling systems using water as a cooling fluid. The cooling system 10 may use a dielectric refrigerant, such as R-134a or HFO-1234yf, which does not present a hazard to electrical or electronic components from leakage. Water also poses corrosion concerns, which are avoided in the cooling system 10. In addition the two-phase cooling provides for near-constant temperature throughout the flow paths removing heat from the various heat sinks 16-24 (Fig. 1). The system 10 would weigh less, require smaller tubing sizes, and need less pumping volume than a comparable single-phase system. The fluid flow speeds are also slower for two-phase flow systems, which may aid in avoiding erosion of cooling system components. The cooling system 10 is flexible in that it is able to handle a wide variety of possible variable heat loads, with only a change in the flow regulators needed to maintain balance in the flow between different parallel flow paths. The cooling system 10 cools only to a temperature that is slightly above ambient temperature, and so condensation is not a problem. Such condensation may pose a danger to electrical or electronic equipment.

[0032] The cooling system 10 is described above for cooling cylindrical energy-producing devices, such as ultra-capacitors, along with associated electrical or electronic equipment. However the cooling system 10 may be used to cool any of a large variety of heat-producing objects, having any of a wide variety of shapes and sizes. Batteries, such as lithium ion batteries, are one example of an alternative to the ultra-capacitor cells.

[0033] The cooling system may be used in vehicles, such as hybrid electric vehicles, to provide cooling for ultra-capacitor cells. The cooling system 10 may be parts of an energy storage system for a vehicle, such as a hybrid electric vehicle. The cooling system 10 advantageously 1) provides effective cooling; 2) does not require air (with possible contaminants such as dust) for cooling; 3) is inexpensive; 4) allows the cells to be sealed in a watertight enclosure or other enclosure; 5) provides even cooling due to the substantially constant temperature of the two-phase cooling fluid as it flows past the cold plates; and 6) is compact.

[0034] The cooling system 10 may have any of a wide variety of alternative configurations. There may be three or more parallel flow branches. Each of the branches may have a larger or smaller number of heat sinks. The order and arrangement of the heat sinks may be different from what is shown in the illustrated embodiment, although it would be advantageous to keep the flow regulators just upstream of the heat sinks that may have variations or differences in heat flow.

[0035] Fig. 8 shows an alternative configuration, a cooling system 110 in which a liquid-cooled condenser 130 in place of the air-cooled condenser 30 (Fig. 1) used in the cooling system 10 (Fig. 1). In other respects the cooling system 110 may be similar to the cooling system 10.

[0036] Fig. 9 shows another alternative configuration, a cooling system 150 that has all of its heat sinks 152-160 arranged in series, with the closed flow loop of the cooling system 150 following a single path that does not branch off into different parallel flow paths. The vapor created in passing through the heat sinks 152-160 is re-condensed in an air-cooled condenser 170. Other aspects of the cooling system 150 may be similar to those of the cooling system 110.

[0037] Fig. 10 shows yet another alternative, a cooling system 180. The cooling system 180 is similar to the cooling system 150 (Fig. 9) except that the cooling system 180 has a liquid-cooled condenser 184 in place of the air-cooled condenser 184 (Fig. 9) used in the cooling system 150.

[0038] Although the invention has been shown and described with respect to a certain preferred embodiment or embodiments, it is obvious that equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the above described elements (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to describe such elements are intended to correspond, unless otherwise indicated, to any element which performs the specified function of the described element (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one or more of several illustrated embodiments, such feature may be combined with one or more other features of the other embodiments, as may be desired and advantageous for any given or particular application.

CLAIMS

What is claimed is:

1. A cooling system comprising:

a pump that pumps cooling fluid; and

a closed flow loop that is operably coupled to the pump;

wherein the closed flow loop includes a pair of parallel flow paths thermally coupled to respective heat-generating objects;

wherein at least one of the flow paths has a flow regulator therein; and

wherein the flow regulators regulate two-phase flow of the cooling fluid through the parallel flow paths.

2. The cooling system of claim 1, wherein the cooling fluid is a refrigerant fluid.

3. The cooling system of claim 1 or claim 2,

further comprising another flow regulator;

wherein the parallel flow paths have respective of the flow regulators in them.

4. The cooling system of claim 3, wherein the heat-generating objects have variable heat loads.

5. The cooling system of claim 3 or claim 4, wherein the flow regulators include respective orifices.

6. The cooling system of claim 5, wherein the orifices have different respective diameters.

7. The cooling system of any of claims 3 to 6, wherein the parallel flow paths have respective heat sinks downstream of the flow regulators, to cool the heat-generating objects.

8. The cooling system of claim 7, wherein the heat sinks include respective cold plates.

9. The cooling system of claim 7 or claim 8, wherein the parallel flow paths have respective additional heat sinks.

10. The cooling system of claim 9, wherein the respective additional heat sinks include respective additional cold plates.

11. The cooling system of claim 10, wherein the additional heat sinks are upstream of the flow regulators.

12. The cooling system of any of claims 9 to 11, further comprising a further heat sink, upstream of the parallel flow paths.

13. The cooling system of claim 1,
further comprising a condenser downstream of the parallel flow paths;
wherein the condenser re-condenses vapor from the two-phase flow.

14. The cooling system of claim 13, wherein the condenser is an air-cooled condenser.

15. The cooling system of claim 13, wherein the condenser is a liquid-cooled condenser.

16. The cooling system of any of claims 1 to 15, further comprising an accumulator tank, upstream of the pump.

17. The cooling system of any of claims 1 to 16, wherein the heat-generating objects include cylindrical energy-producing objects.

18. The cooling system of claim 17, wherein the cylindrical energy-producing objects are ultra-capacitors.

19. The cooling system of claim 17 or claim 18, wherein the heat-generating objects also include electrical or electronic devices operatively coupled to the energy-producing objects.

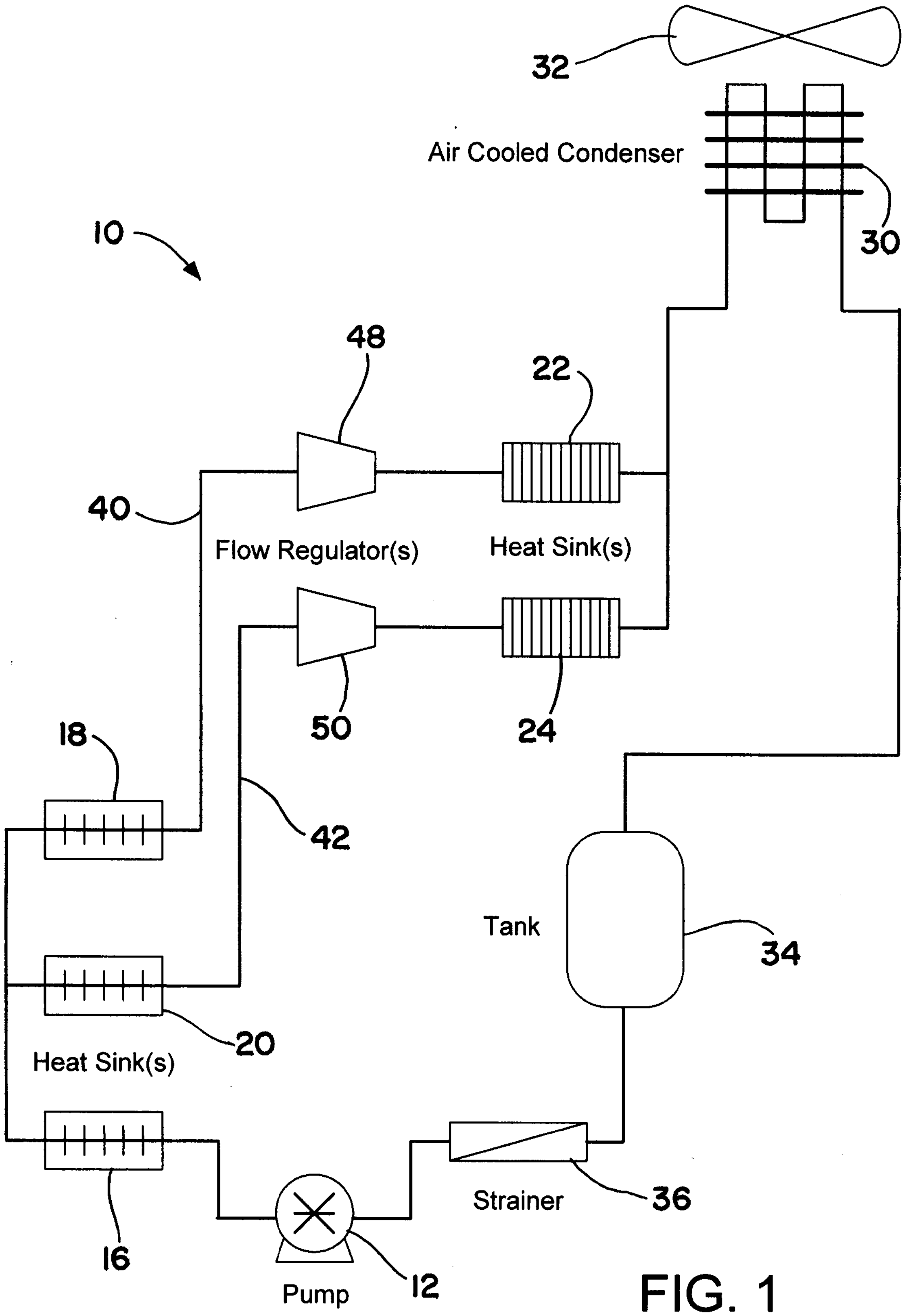
32
Air Cooled Condenser
30
10
48
22
40
Flow Regulator(s)
Heat Sink(s)
50
24
18
42
Tank
34
20
Heat Sink(s)
Strainer
36
16
Pump
12

FIG. 1

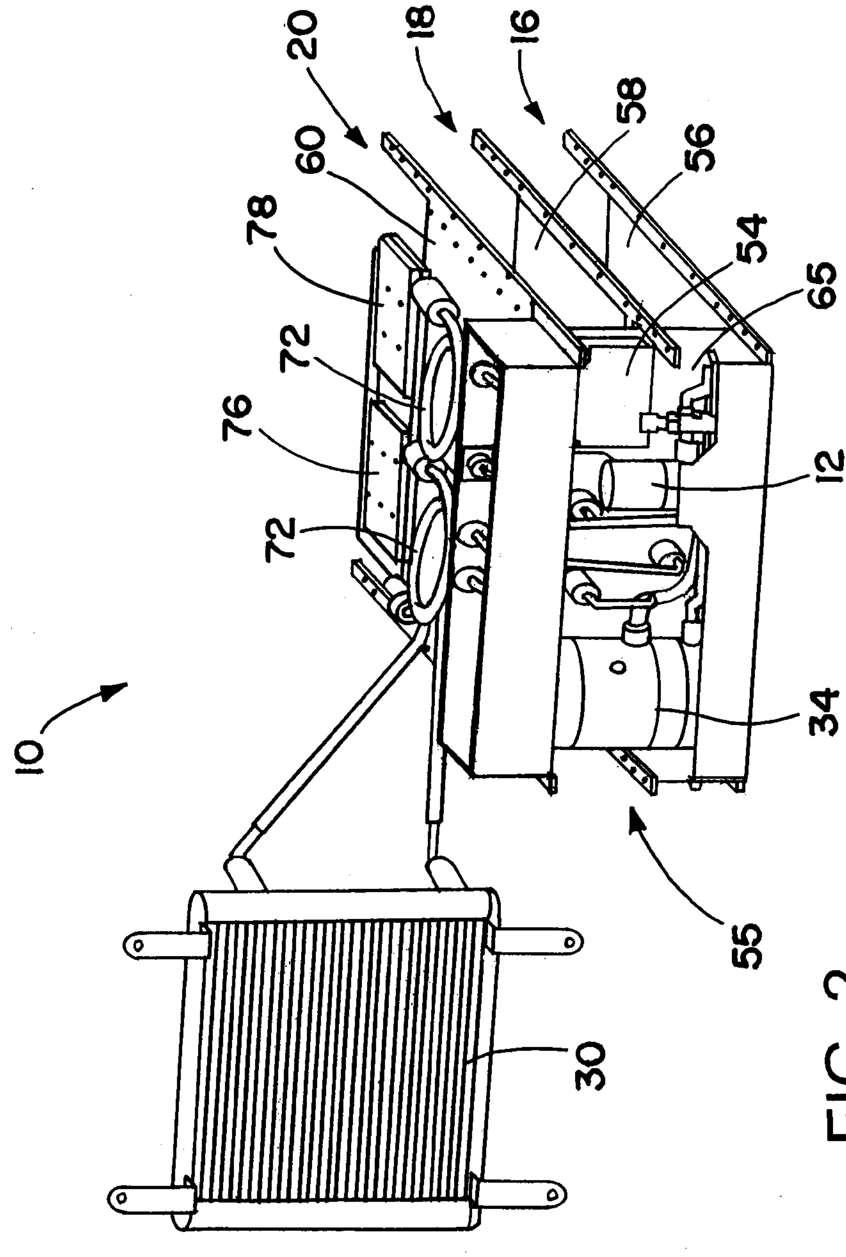

FIG. 2

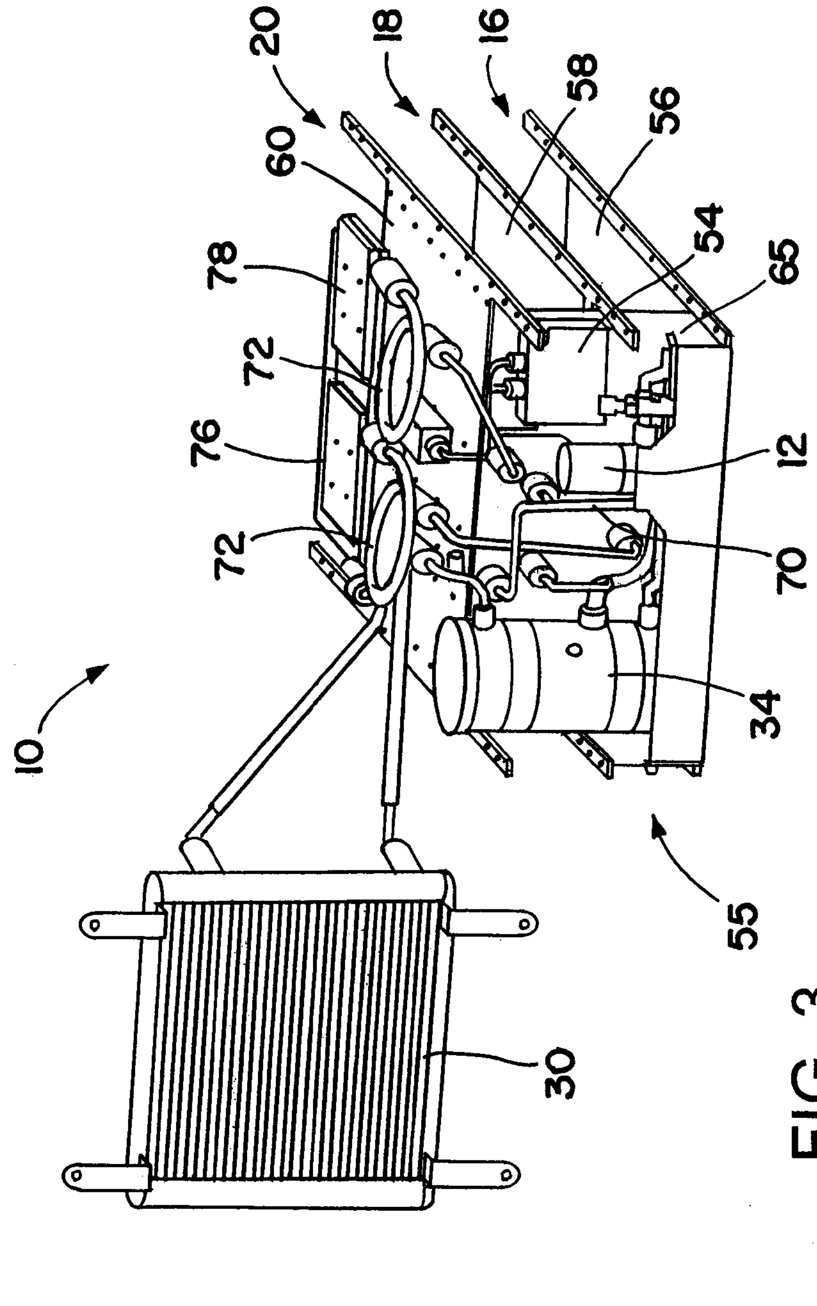

FIG. 3

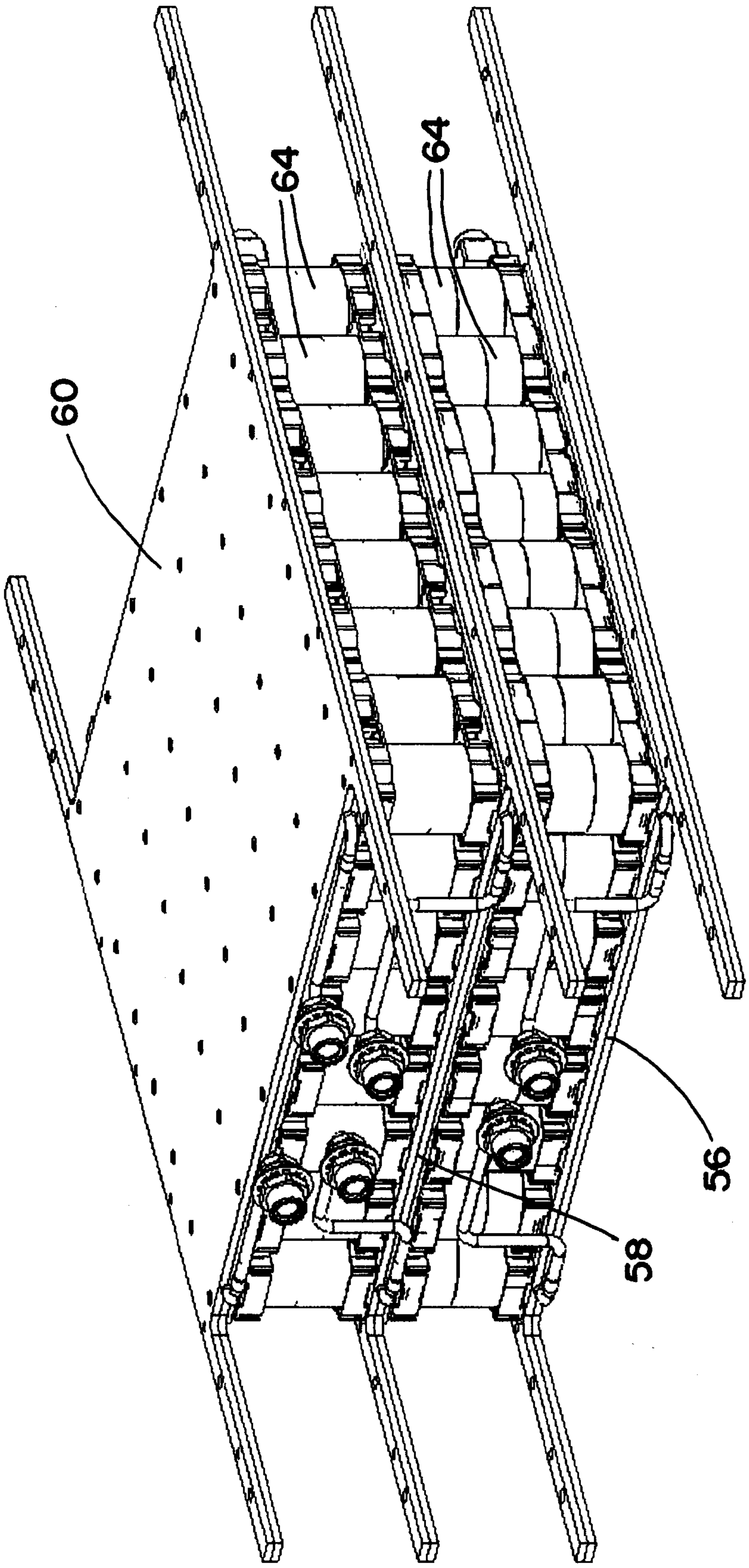

FIG. 4

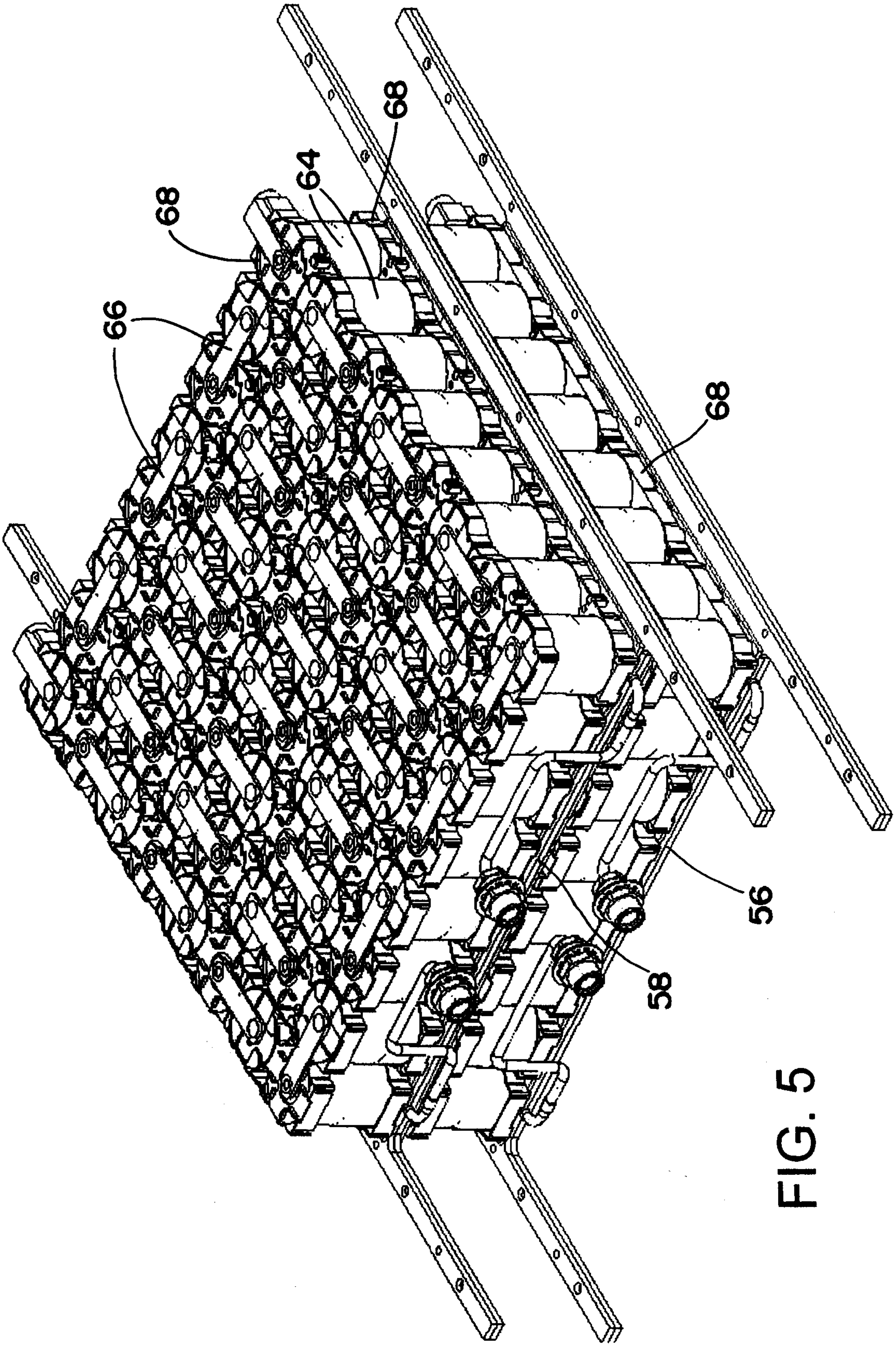

FIG. 5

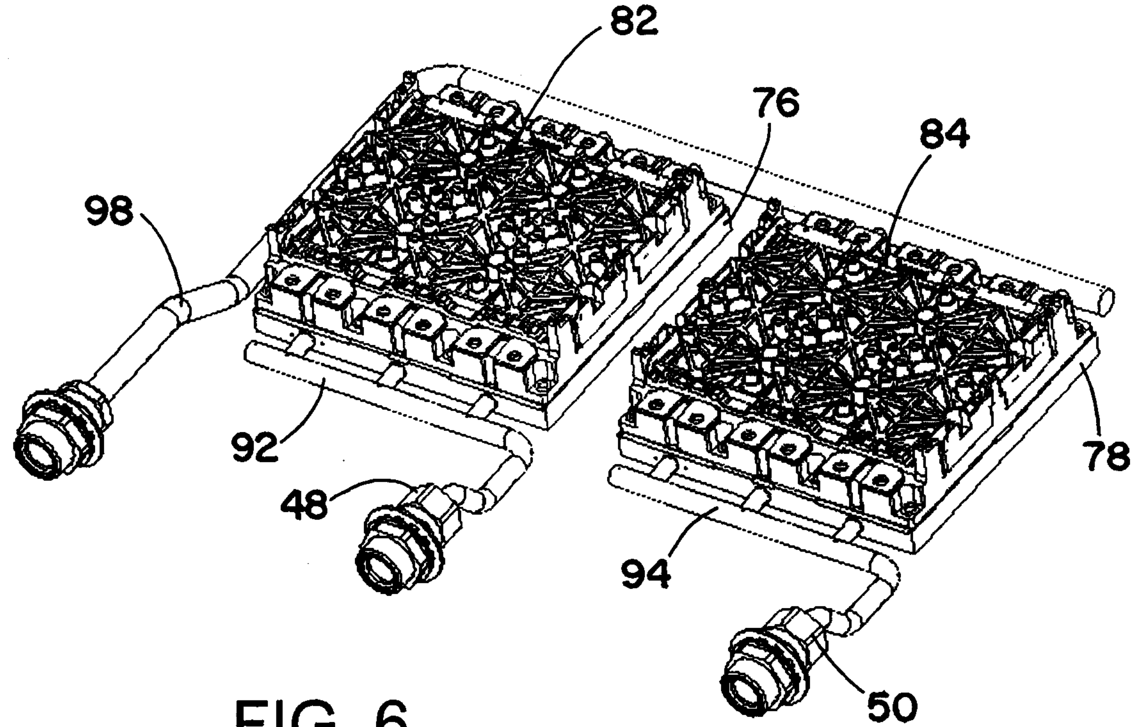

FIG. 6

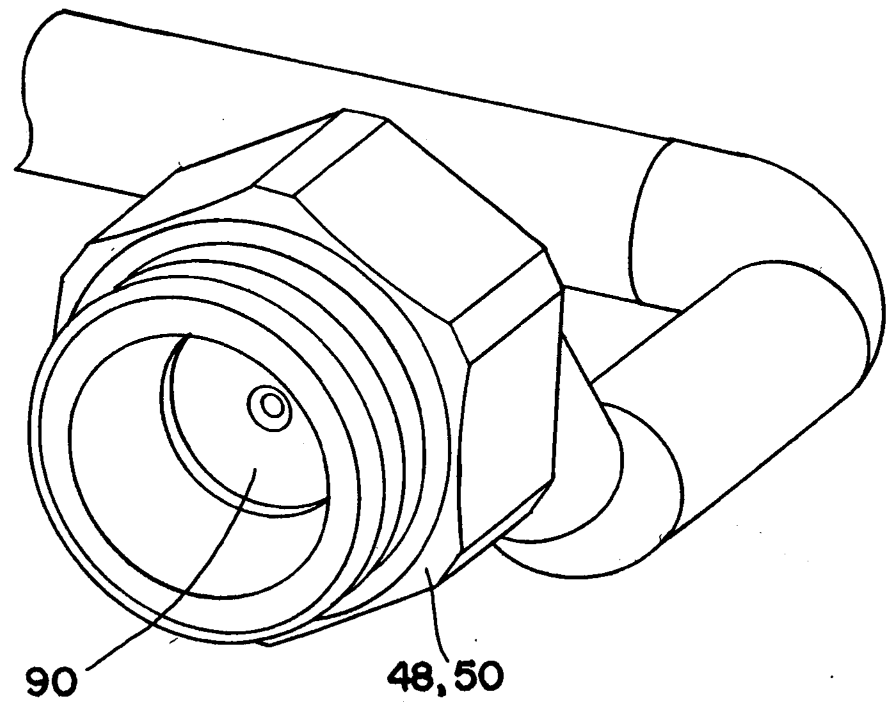

FIG. 7

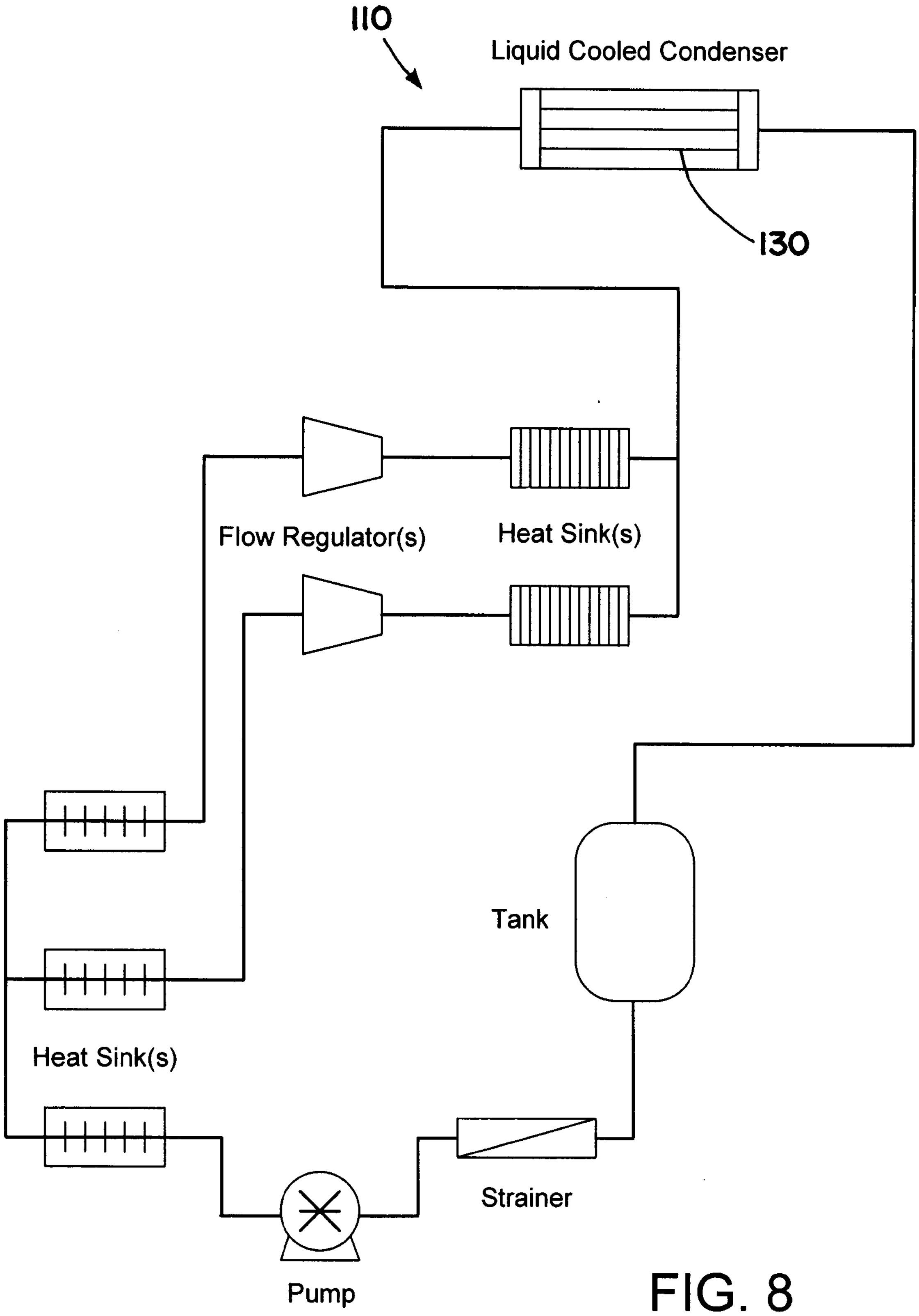
110
Liquid Cooled Condenser
130
Flow Regulator(s)
Heat Sink(s)
Tank
Heat Sink(s)
Strainer
Pump

FIG. 8

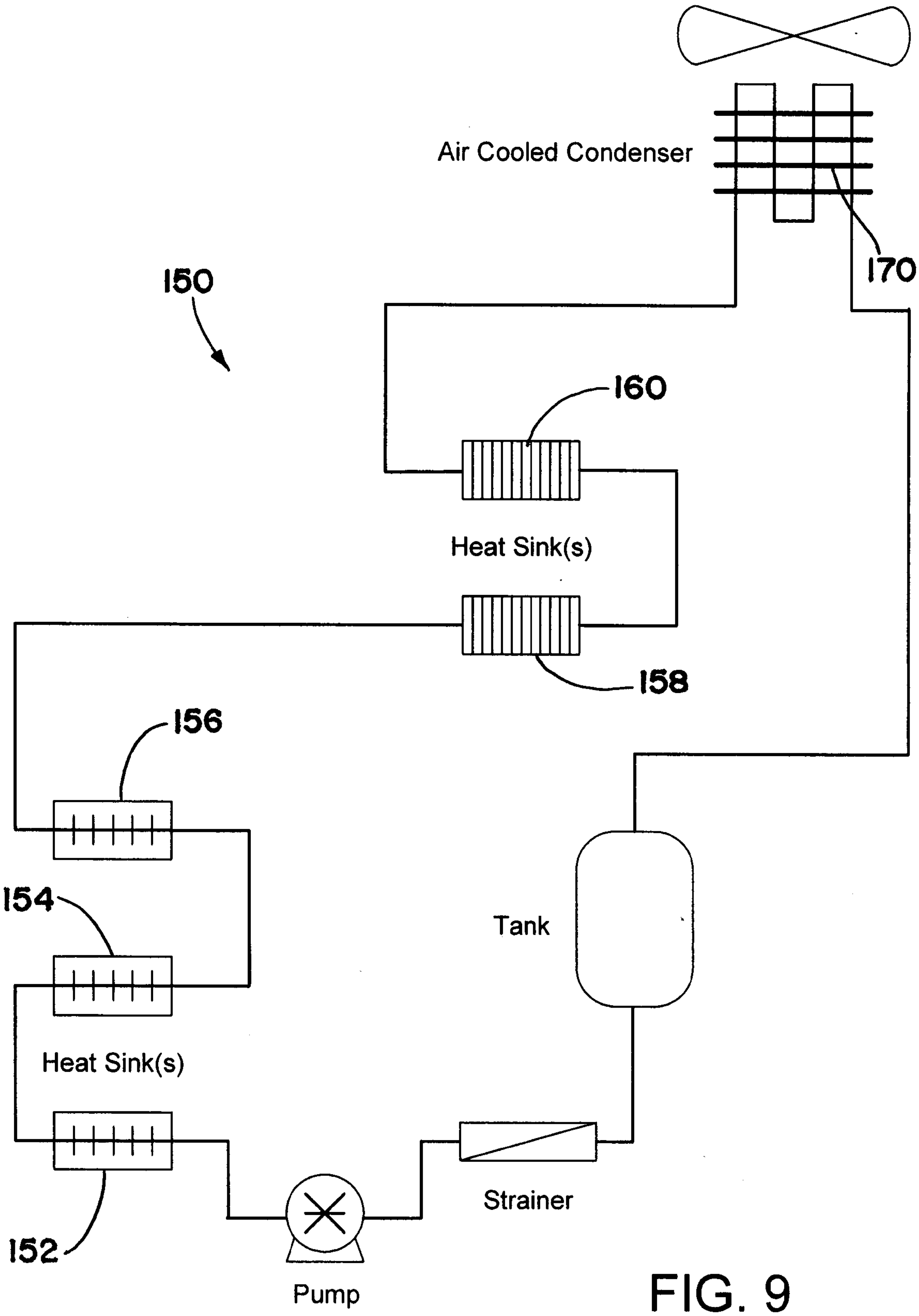
Air Cooled Condenser
170
150
160
Heat Sink(s)
158
156
154
Tank
Heat Sink(s)
Strainer
152
Pump

FIG. 9

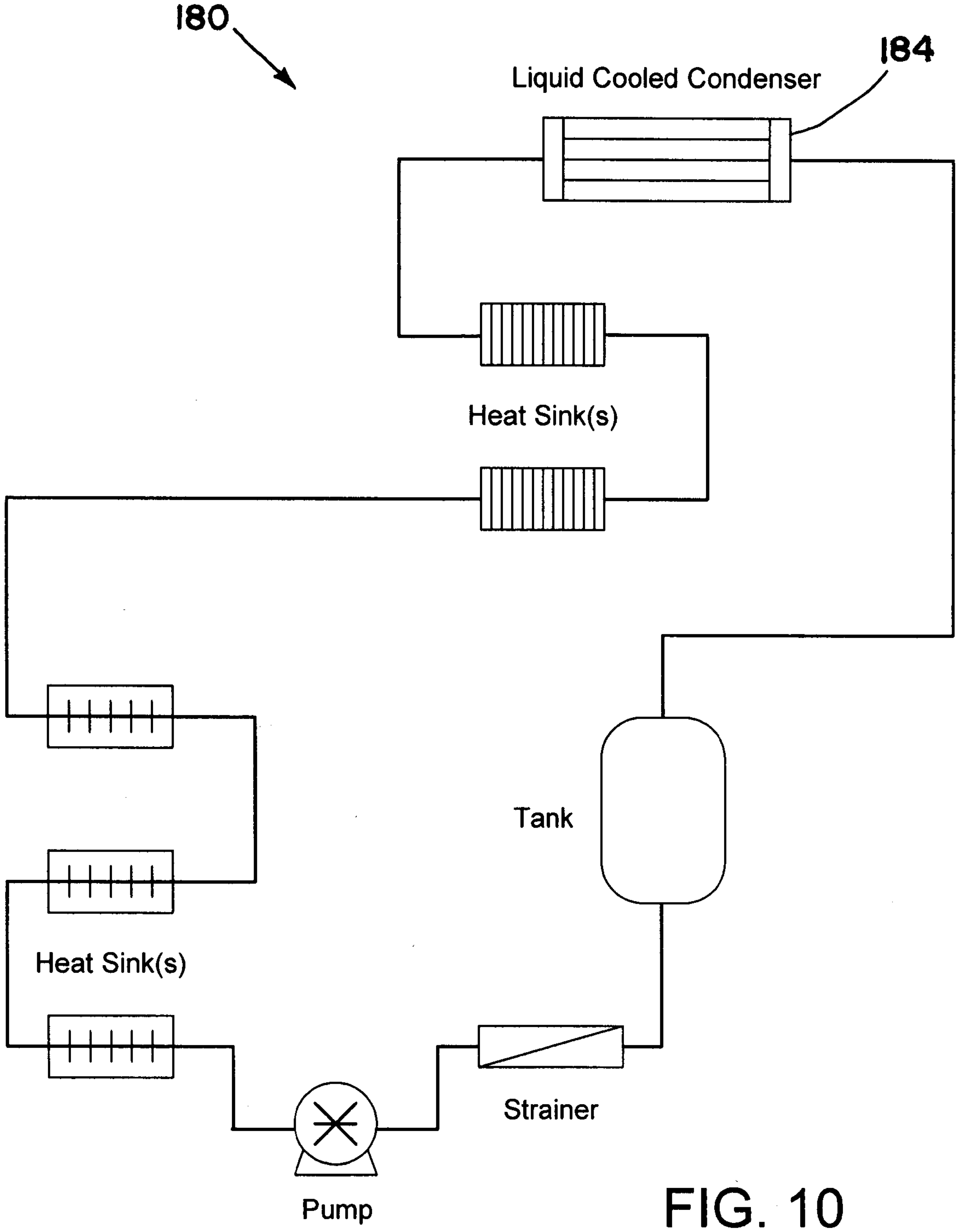
180
184
Liquid Cooled Condenser
Heat Sink(s)
Tank
Heat Sink(s)
Strainer
Pump

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/031833

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05K7/20 H01G2/08 H01M10/50 H01G11/18 F25B23/00
F25B25/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H05K H01G H01M F25B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2005/120737 A1 (BORROR STEVEN A [US] ET AL) 9 June 2005 (2005-06-09) paragraphs [0015], [0016], [0018], [0022], [0026]; figures 1-3 -----	1-16 17-19
X	US 2008/196867 A1 (SPEARING IAN [US]) 21 August 2008 (2008-08-21) paragraphs [0021] - [0024], [0028]; figures 2A-5 -----	1-16
X	WO 2011/017385 A1 (GILL SCOTT [US]; THOMPSON DALE [US]; O'SHAUGHNESSEY STEPHEN [US]; PARK) 10 February 2011 (2011-02-10) paragraphs [0014] - [0017]; figures 2,3 ----- -/--	1-16

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 February 2013	21/02/2013

Name and mailing address of the ISA/	Authorized officer
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