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(54) **APPARATUS FOR CONTROL OF FLUID TEMPERATURE**

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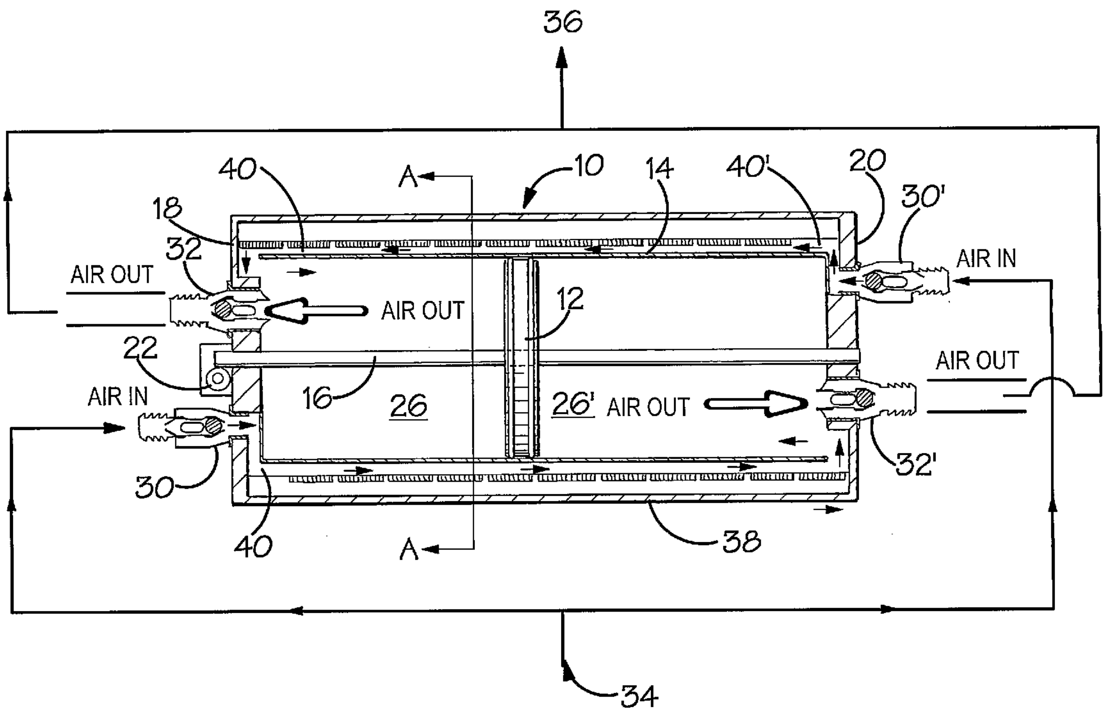
(57) **ABSTRACT**

The present invention relates to a device for controlling the temperature of a fluid by heating and/or cooling. It has a reciprocating, displacement type pumping arrangement which propels fluid from an outlet to an outlet via a conditioning chamber in which fluid temperature control is carried out by means of a thermoelectric heat pump which is preferably of Peltier type.



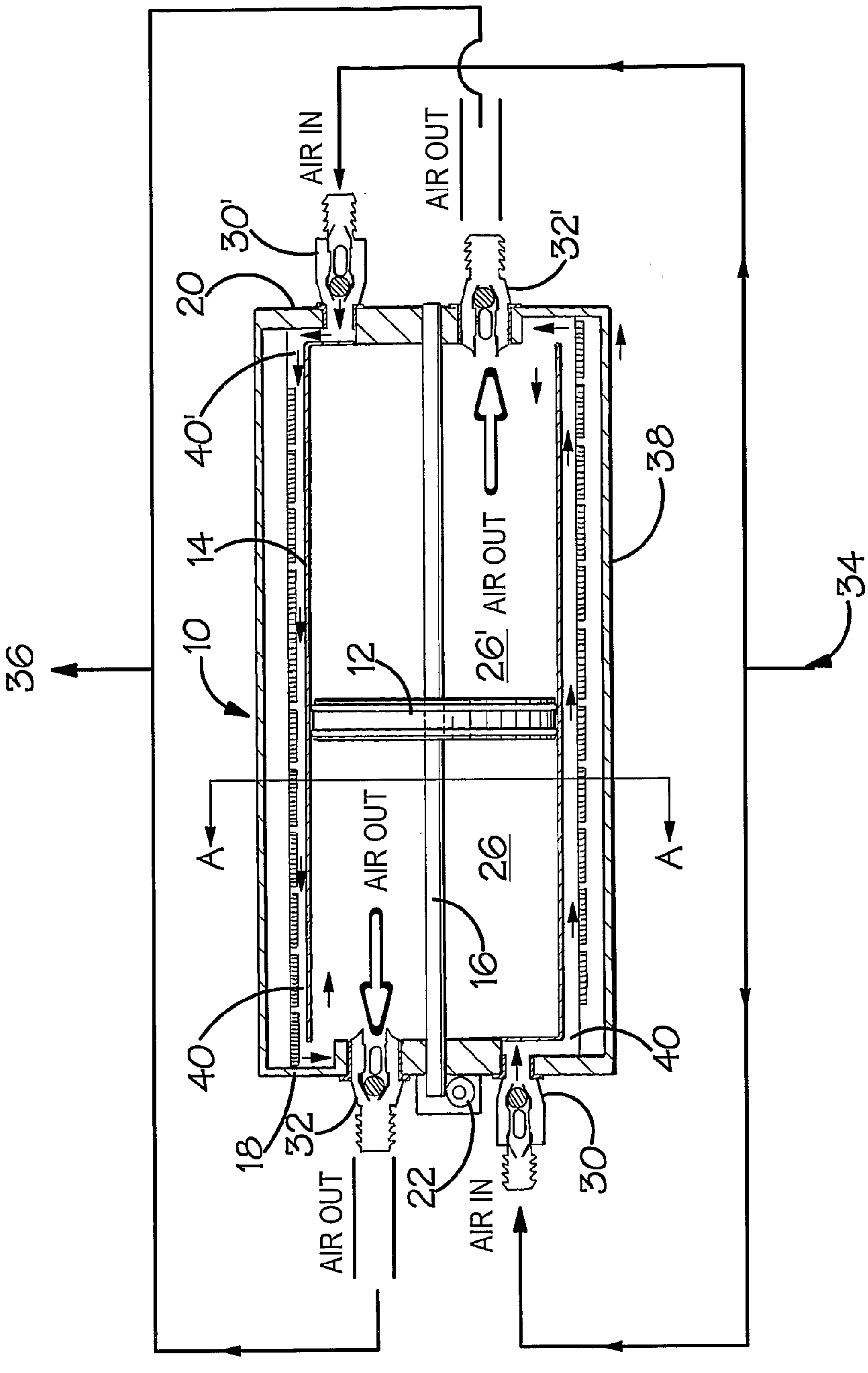

AIR IN
AIR OUT
30'
32'
20
40'
38
14
10
12
26'
AIR OUT
34
36
A
A
26
AIR OUT
16
40
40
18
32
22
30
AIR OUT
AIR IN

FIG.1.

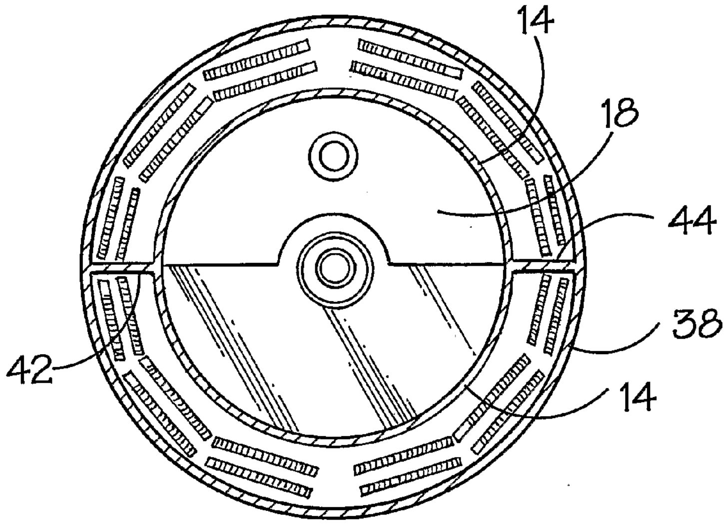
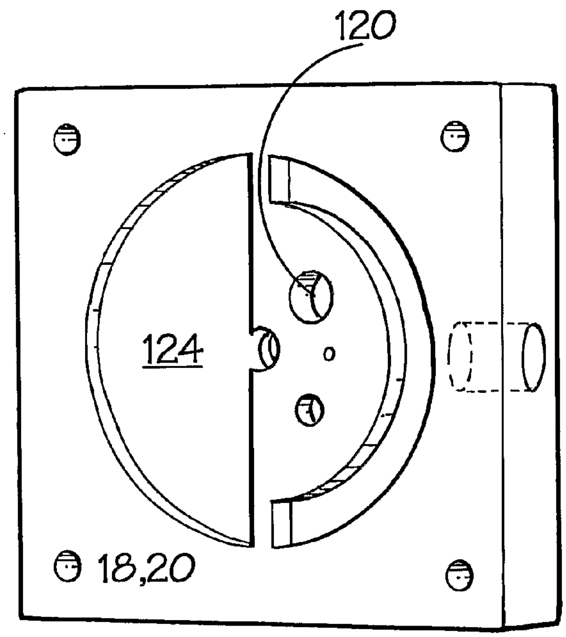


FIG.1a.

FIG.6.



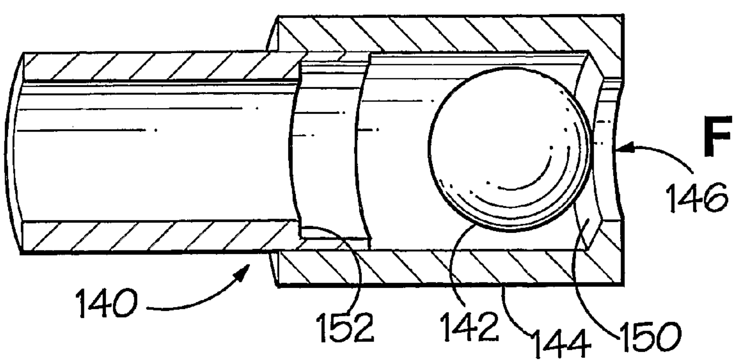


FIG.7.

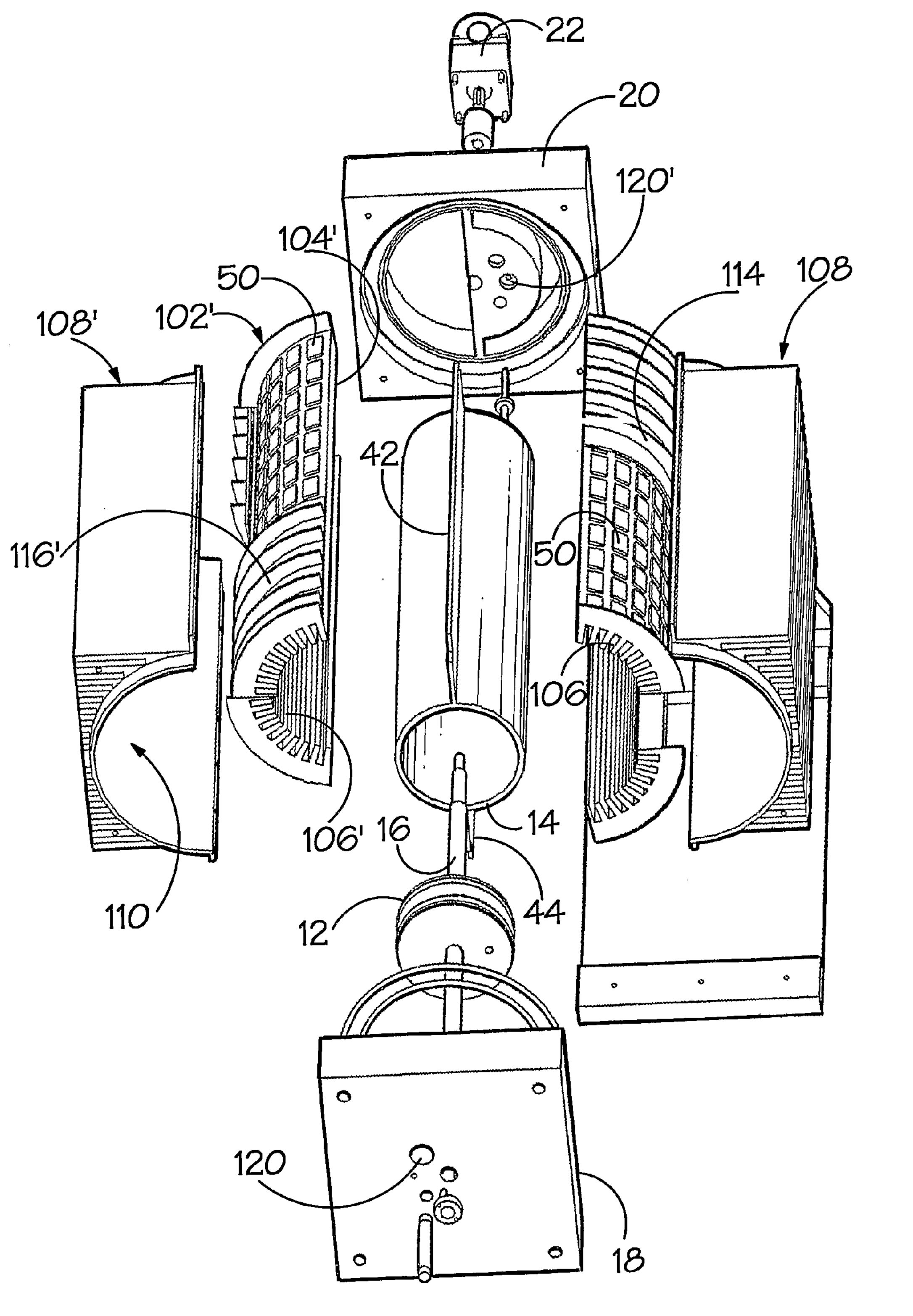

22
20
120'
104'
50
114
108
108'
102'
42
116'
50
106
106'
16
14
110
12
44
120
18

FIG.2.

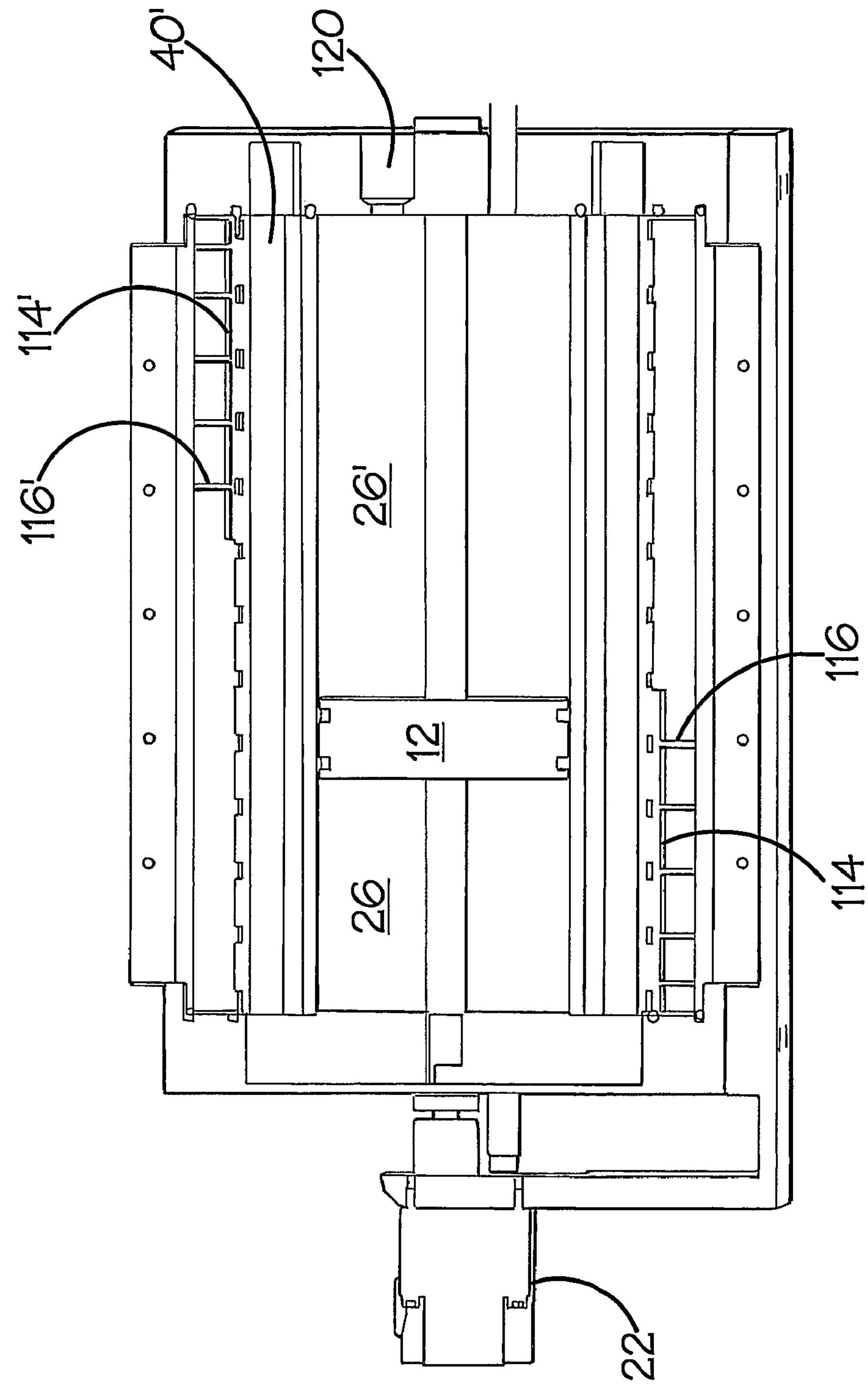


FIG.3.

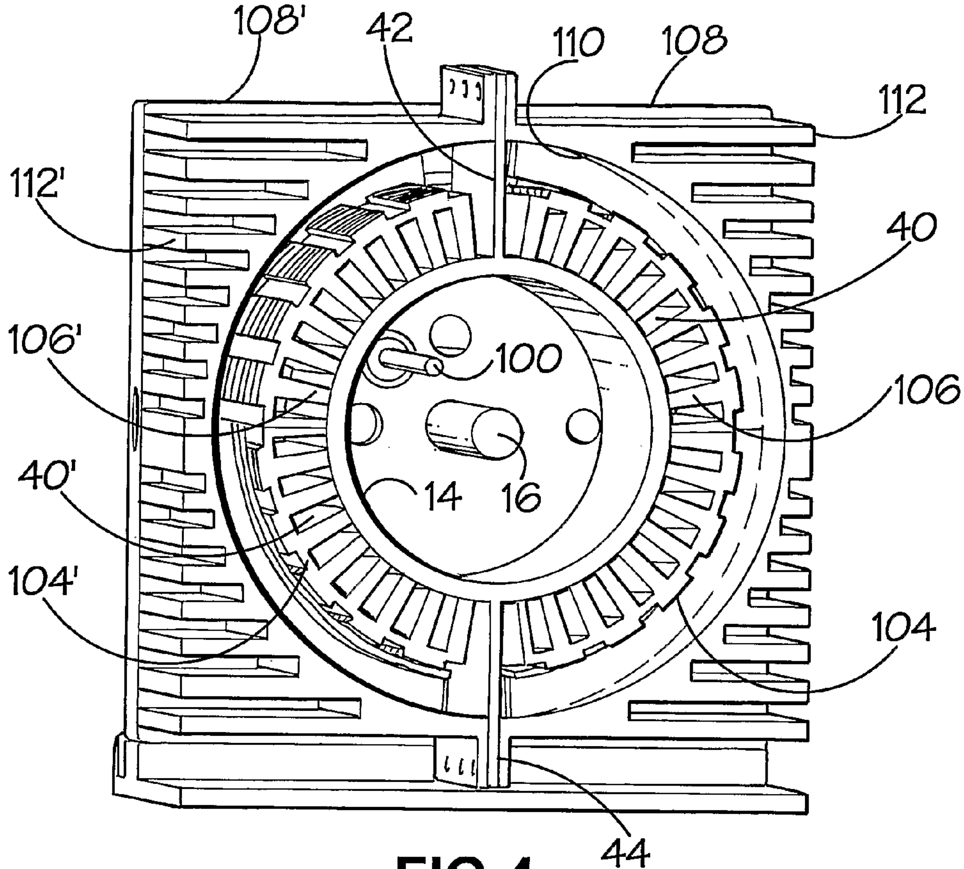

108'
42
110
108
112
112'
40
106'
100
106
40'
14
16
104'
104
44

FIG.4.

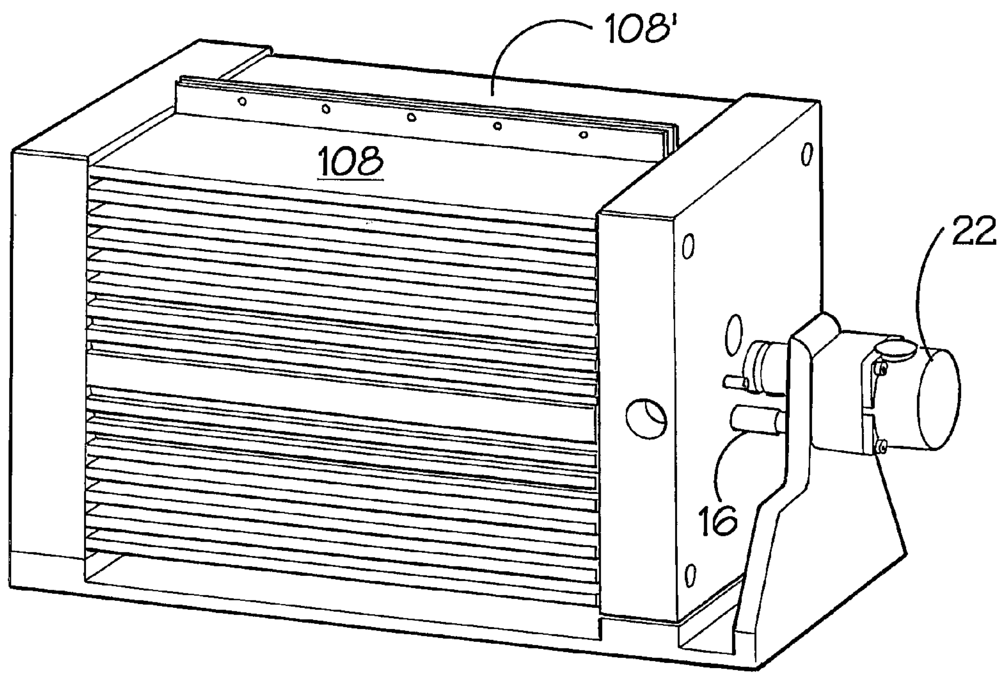

108'
108
22
16

FIG.5.

APPARATUS FOR CONTROL OF FLUID TEMPERATURE

[0001] The present invention relates to devices for controlling the temperature of a fluid by heating and/or cooling.

[0002] As used herein, the word "fluid" refers to both gases and liquids. There are very many devices in which fluid temperature needs to be raised and/or lowered. Examples include "white goods" such as freezers and washing machines; air-conditioners in buildings or vehicles; and any number of industrial processes.

[0003] Conventional cooling units—in air-conditioners, refrigerators and freezers, for example—rely upon compression followed by adiabatic expansion of a working fluid. Freon is a suitable working fluid. This conventional technology is of course enormously widely used and undeniably effective, but is subject to important problems. The working fluids conventionally chosen for their effectiveness in the compression/expansion cycle (often CFCs) are recognized as important greenhouse gases. To dispense with their use would be ecologically desirable. It would also be desirable to dispense with the pumping machinery required to pressurise the working fluid.

[0004] While the present invention has potential applications in many fields, a potentially important application relates to regulation of air temperature in air conditioners. As used herein the term "air conditioner" refers to a device which delivers a flow of air and has means for cooling and/or heating the air delivered. Conventional air conditioning units typically work by adiabatic expansion of a working fluid, with the cooled working fluid being supplied to a heat exchanger over which air is passed by a fan. Such conditioners are of course very widely used for conditioning the air in buildings, vehicles etc, typically under thermostatic control and with the additional facility for heating of the air when necessary.

[0005] However, conventional air conditioners are not ideally suited to certain applications. They require both a fan for circulation of air and a pump acting upon the working fluid. They can as a result create levels of noise and vibration which are unacceptable in some applications, particularly those requiring a relatively small throughput of air. In particular, there are applications in which it is desired to supply a small flow of air to the immediate vicinity of a person, as in the case of climate controlled bedding or seating. Such applications may involve circulation of temperature conditioned air within a closed system. U.S. Pat. No. 4,853,992 (YU) provides the example of a seat cushion which is cooled/heated by means of air circulated through an enclosed envelope forming the cushion itself. Alternatively the conditioned air may be released into the person's environment providing conditioned air in his/her immediate vicinity. In both cases the air-conditioning unit is typically mounted close to the user, making it important to keep noise and vibration to a minimum.

[0006] As an alternative to cooling devices reliant upon adiabatic fluid expansion, it is known to use solid state thermoelectric devices. The type of device of most relevance for present purposes is also referred to as a "Peltier" device, and functions as a heat pump. Widely available commercial examples of such devices are formed as a sandwich with two outer ceramic plates arranged around an array of small Bismuth Telluride elements. When a DC current is applied to an arrangement of these "heat pump pads", the device serves to pump heat from one plate to the other. By arranging for sinking of heat from the plate to which heat is pumped, such devices can be used to exert a cooling effect at the other plate. Solid state devices have important advantages. They are compact and have no moving parts to create noise or vibration. The direction in which heat is pumped between the devices' plates can be reversed simply by reversing the DC current applied to them, and so the same device can potentially be used in both heating and cooling.

[0007] French prior patent FR 2594668, (Chareire) discloses an air-conditioning system for use when sleeping which uses a "Peltier—effect fresh air generator" to supply air to an enclosure placed over the head of a sleeper. It appears to be reliant upon a fan for circulation of air. GB990668 (Malaker Laboratories Inc.) concerns a cryogenic system in which Peltier devices are used in a "cascade" to achieve very low temperatures. Gas being cooled is circulated between compression and expander cylinders, past the Peltier devices. JP4265482 (Kinoshita Masahiko et al) discloses provision of Peltier elements with radiating fins in an air passage to cool air entering a cylinder. EP0672831 (Isco) relates to an apparatus for supercritical fluid extraction which uses a thermo-electric element to cool a pumping arrangement. U.S. Pat. No. 5,242,403 discloses a metering pump for dispensing volatile anaesthetic liquid. The arrangement has a piston/cylinder arrangement which is cooled by a Peltier device, and also has a separate reservoir cooled by a further Peltier device.

[0008] There are examples in this prior art of devices which use reciprocating pumps to provide throughput of fluid. In these, the Peltier device cools the pump cylinder in order to cool the fluid being pumped. The interior wall of the cylinder is necessarily smooth and does not provide an ideal means for heat exchange with the fluid.

[0009] In accordance with a first aspect of the present invention there is a device for controlling fluid temperature, comprising a fluid inlet, a fluid outlet, and a reciprocating, displacement type pumping arrangement which is arranged to draw the fluid in through the inlet and to exhaust it through the outlet, wherein the pumping arrangement communicates with one of the inlet and the outlet via a conditioning chamber through which the fluid passes on its way from the inlet to the outlet and in which fluid temperature control is carried out, the device further comprising at least one solid state thermo-electric heat pump having a first side which is thermally coupled to fluid within the conditioning chamber and a second side which is arranged to transmit heat to a sink or to receive heat from a source, so that by means of the thermo-electric heat pump the temperature of the conditioning chamber wall, and of the fluid within the conditioning chamber, is controllable.

[0010] Using the pumping arrangement to propel fluid through a separate conditioning chamber makes it possible to form the interior of this chamber in a manner which promotes exchange of heat with the fluid. The interior of the conditioning chamber may be shaped to provide a high surface area for heat exchange.

[0011] A preferred embodiment comprises shaped heat exchange features within the conditioning chamber having surfaces exposed to fluid within the conditioning chamber to exchange heat with it the fluid, the heat exchange features also being thermally coupled to the conditioning chamber wall to exchange heat with that. The features in question promote heat exchange between the fluid and the thermo-electric heat pump. They may comprise fins. It is preferred that they are integrally formed with the conditioning chamber wall.

[0012] The pumping arrangement preferably has a cylinder and a reciprocating piston.

[0013] In a constructionally convenient embodiment, the cylinder is circular and the conditioning chamber is a substantially annular or semi-annular space around and concentric with the cylinder.

[0014] The conditioning chamber wall may be disposed around at least part of the cylinder, the conditioning chamber being defined between an outer surface of the cylinder and an inner surface of the conditioning chamber wall.

[0015] Where the device is to be used for cooling, it preferably comprises a heat sink arranged to receive heat from the second side of the thermo-electric heat pump. In one such embodiment the heat sink forms a shell surrounding the conditioning chamber wall.

[0016] In a particularly preferred embodiment of the present invention, the cylinder is divided by the piston into first and second working chambers so that piston motion in one direction causes fluid to be drawn into the first working chamber and to be exhausted from the second working chamber, and piston motion in the opposite direction causes fluid to be exhausted from the first working chamber and to be drawn into the second working chamber, the unit further comprising a valve arrangement which selectively connects whichever working chamber is at any moment exhausting fluid to the pump outlet, thereby providing mono-directional flow through the outlet.

[0017] Preferably each working chamber communicates with a respective one-way valve which is arranged to exhaust fluid from the chamber and is connected to the outlet. Still more preferably, each chamber additionally communicates with a respective one-way valve which is arranged to let fluid into the chamber.

[0018] In principle both working chambers could feed a single conditioning chamber. Preferably, however, the device comprises first and second conditioning chambers which are communicable respectively with the first and second working chambers within the cylinder.

[0019] Conveniently, the first and second conditioning chambers may together form an annulus surrounding the cylinder. This can be achieved through a construction in which the first and second conditioning chambers are both defined between the cylinder and the conditioning chamber wall.

[0020] A reciprocating pump might be expected to cause a high level of vibration, but in fact for applications in which fluid throughput requirements are relatively small, and given sufficient working volume within the pump, the velocity of the reciprocating components of the pump and the frequency of their motion can be small enough to create a low level of vibration and noise.

[0021] In accordance with a second aspect of the present invention there is a fluid cooling device comprising a reciprocating, displacement type pump which is arranged to circulate fluid mono-directionally from an inlet to an outlet via at least one cooling chamber, and at least one solid state thermo-electric heat pump associated with the cooling chamber to cool the fluid as it passes through the cooling chamber.

[0022] Specific embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

[0023] FIG. **1** is an axial, and somewhat schematic, section through a fluid temperature control device constructed in accordance with the present invention;

[0024] FIG. **1***a* is a radial, and again somewhat schematic, section through the device shown in FIG. **1**;

[0025] FIG. **2** is an exploded view of the major components of a further fluid temperature control device constructed in accordance with the present invention;

[0026] FIG. **3** shows a section through the device seen in FIG. **2**, taken in an axial plane;

[0027] FIG. **4** shows a section through the same device, taken in a radial plane;

[0028] FIG. **5** is a perspective view of the exterior of the same device;

[0029] FIG. **6** shows an end plate of the same device in plan; and

[0030] FIG. **7** shows a section through a ball valve used in the device, taken in an axial plane.

[0031] FIG. **1** is a somewhat simplified view of a device embodying the present invention which will serve to illustrate some of the relevant principles. The device **10** is self-contained, incorporating both a pump to circulate the fluid and heat exchange devices used to condition it.

[0032] The pump is of reciprocating displacement type, having a piston **12** which is received in a cylinder **14** with which it forms a sealed but sliding fit. The piston is reciprocally driven at low speed by means of a lead screw **16** which extends through the cylinder and is journalled at opposite ends of it in respective end caps **18**, **20**. An electric motor **22** drives the lead screw **16** through gearing. In the present embodiment the direction of movement of the piston **12** is reversed, when the piston reaches the end of its travel, by reversing the direction of rotation of the motor **22**. Suitable means for achieving this, eg by provision of a pair of micro switches arranged to be actuated by the piston when it reaches respective ends of its travel and connected to motor control electronics, will be apparent to the skilled person. The lead screw is received in an axial, through-going, threaded bore in the piston **12** by virtue of which its rotational motion is converted to linear piston motion. Of course the piston **12** must be prevented from rotating along with the lead screw but friction between the piston and cylinders is typically sufficient to ensure this. It will be apparent to the skilled person that other means of reciprocally driving the piston, e.g. using a crank or eccentric drive, could be adopted in other embodiments.

[0033] The pump is required to provide a flow of air which is mono-directional, despite reversal of the direction of piston movement. The piston divides its cylinder **14** into a pair of working chambers **26**, **26'**. Communicating with each working chamber is a pair of one-way valves **30**, **32** and **30' 32'**. The two valves communicating with a given working chamber are oppositely orientated. That is, one valve of the pair is arranged to let air into the relevant working chamber and the other is arranged to exhaust air from it. The two inlet valves **30**, **30'** are connected to a common air input of the air conditioning unit, schematically represented at **34**. The two exhaust valves **32**, **32'** are connected to a common air exhaust of the device, schematically indicated at **36**. Regardless of the direction of piston motion, there is always one working chamber **26** or **26'** exhausting air through the common exhaust **36** and its exhaust valve **32** or **32'** while the other chamber **26'** or **26** receives air through the common inlet **34** and its valve **30'**, **30**. In this way the valves ensure a mono-directional and (save for the brief times in its reciprocating motion when the piston is stationary) continuous throughput of fluid. However in other embodiments the two inlets and the two outlets need not be connected together. They could instead lead to different fluid sources and/or points of usage. Fluid recirculation from outlet to inlet could be provided, particularly to allow the fluid to go through multiple cooling phases to reach especially low temperatures.

[0034] Note that the cylinder **14** is contained within a cylindrical outer housing **38**, and that the path for inlet of fluid through the inlet valve **30** to the working chamber **26** is via a semi-annular chamber **40** defined between the cylinder **14** and the housing **38**. Likewise the path for inlet of fluid through the inlet valve **30'** to the working chamber **26'** is via a semi-annular chamber **40'**. The two semi-annular chambers **40**, **40'** extend along the cylinder's length and are separated by longitudinal dividing walls **42**, **44** which are seen in FIG. **2** to lie in a common plane containing the cylinder axis. As a result of this arrangement the inlet valve **30** which supplies working chamber **26** is at the far end of the cylinder from that chamber, and likewise inlet valve **30'** is at the far end of the cylinder from the working chamber **26'** which it supplies.

[0035] The semi-annular chambers **40**, **40'** may be referred to as "conditioning chambers" because it is within them that conditioning of the fluid by cooling and/or heating is carried out, by means of solid state thermoelectric devices **50**, **50'**. Within both of the chambers **40**, **40'** is a respective set of such devices, the devices within a given chamber being connected to a common electrical supply/control. The devices are arranged in semi-circular fashion within the conditioning chambers. Residence time of air in the vicinity of the thermoelectric devices is high due to the chambers' length and the relatively low air throughput. Thermostatic control, based for example on the temperature of output air, may be exercised over the thermoelectric devices' electrical supply. By reversing the DC supply applied to the devices, the unit can be caused to warm the air rather than cooling it. A thermistor in a pump working chamber or in its outlet may be used to sense output air temperature.

[0036] FIGS. **2** to **7** show a second physical embodiment of the present invention in greater constructional detail. Many of the major components of this embodiment have counterparts in the device of FIGS. **1** and **1***a*, and the same reference numerals are used for these components throughout. In the second embodiment piston **12** is once more driven through lead screw **16** by electric motor **22**. It is also prevented from rotating due to friction with the screw by a guide rod **100** which passes through the piston, forming a sealing fit with it. Cylinder **14** carries dividing walls **42**, **44**, which lie on opposite sides of the piston and in a common axial plane. In the present embodiment the conditioning chambers **40**, **40'** are formed by means of a pair of semi-annular shells **102**, **102'** positioned around the cylinder. These shells are formed of thermally conductive material, metal being favoured. They each have a conditioning chamber wall portion **104**, **104'** carrying on its radially outer face a respective bank of solid state thermoelectric heat pump devices **50**, **50'** of Peltier type. Radially inner faces of each wall portion **104**, **104'** are provided with features serving to promote exchange of heat with the fluid in the respective conditioning chamber. Such features serve to increase the surface area available for heat exchange, as compared with the case of a smooth cylindrical face. In the present embodiment they take the form of fins **106**,**106'** which are integrally formed with the chamber walls **104**, **104'** and which extend along the axial direction. the effect is to create, within each conditioning chamber, a set of narrow passages for throughput of fluid, within which heat exchange is promoted.

[0037] Where the device is used for cooling, heat passes from the fluid to the conditioning chamber walls **104**, **104'**, whence it is pumped by the heat pump devices **50**, **50'**, which are mounted upon, and thermally coupled to, the chamber walls. To dissipate this heat, the device's outer casing is formed as a heat sink. This casing is constructed in two casing halves **108**, **108'** and assembled around the semi-annular shells **102**, **102'** forming the conditioning chamber. Its innermost face **110** is cylindrical and its outer surface is formed by a set of fins **112**, **112'** which provide surface area for exchange of heat with the atmosphere. If necessary a fin may be used to provide air flow over the fins.

[0038] A route is required for conduction of heat from the outermost pads of the heat pump devices **50**, **50'** to the external heat sink, and this is provided in the present embodiment by means of semi-annular conduction shells **114**, **114'** whose radially inner faces are thermally coupled to the outermost faces of the heat pump devices. The conduction shells carry on their radially outer faces integral conduction vanes **116**, **116'**, formed in the present embodiment as circumferentially extending rings, which serve to conduct heat to the casing halves **108**, **108'** forming the heat sink.

[0039] The flow of air into, out of, and between chambers of the device is provided for by means of recesses in end plates **18**, **20**, one of which is shown on its own in FIG. **6**. Throughgoing, axially directed bores **120**, **120'** provide for inlet of fluid to the respective cylinder working chambers (see FIG. **3**) and receive one-way valves (which are omitted from FIG. **3**, but will be described below. A conduit connecting each working chamber **26**, **26'** in the cylinder to its associated conditioning chamber is needed, and this is provided by virtue of a semi-circular recess **124** formed in the end plate and positioned to communicate with the respective chambers. Fluid outlet from the conditioning chambers is through "C" shaped recess **130** which is positioned to communicate only with the relevant conditioning chamber, and a radial bore **132** leading from it, which threadedly receives a one-way outlet valve (not shown in FIG. **6** but seen in FIG. **7**). The end plates **18**, **20** are formed from thermally insulating material, specifically plastics, to minimise heat transfer from the outer heat sink **108**, **108'** to the inner components.

[0040] For the sake of completeness, FIG. **7** shows a suitable one-way valve although its construction is conventional and of course the skilled person is aware of numerous other suitable valving arrangements. The valve **140** has a ball **142** captively housed in a hollow circular valve housing **144** providing a valve inlet **146** and outlet **148**. The ball is able to move back and forth between a valve seat **150**, against which it forms a seal when necessary to prevent back-flow of fluid, and a stop shoulder **152**, against which the ball can rest without preventing forward fluid flow.

[0041] The illustrated device is well suited to serving as an air conditioning unit, in which case the conditional air it emits may be supplied to a climate controlled bed or seat. The input air may come from the general environment or alternatively air may be recirculated from the bed or seat. The invention is also applicable to the field of refrigeration. The cooled air output from the conditioning unit described above may be fed to a cabinet of a refrigerator, freezer, cooler, and chiller cabinet etc. to provide the necessary cooling effect. Alternatively the same general construction described above and depicted herein could be used for a device used in cooling a liquid or gaseous working fluid to be supplied to the heat exchanger of a refrigerated cabinet. The device's inlet and outlet would be connected to the heat exchanger and circulate working fluid through it.

[0042] In fact devices embodying the present invention have a wide range of possible applications. Water cooling is one such. A filter maybe placed in the fluid flow path to remove foreign bodies such as water contaminants. Electrolysis could be carried out upon the fluid within the device, at controlled temperature. In re-processing of Uranium there is a requirement for fluid temperature regulation and the device is potentially applicable in this context.

1. A device for controlling fluid temperature, comprising a fluid inlet, a fluid outlet, and a reciprocating, displacement type pumping arrangement comprising a piston and cylinder which is arranged to draw the fluid in through the inlet and to exhaust it through the outlet, wherein the pumping arrangement communicates with one of the inlet and the outlet via a conditioning chamber through which the fluid passes on its way from the inlet to the outlet and in which fluid temperature control is carried out, the device further comprising at least one solid state thermo-electric heat pump having a first side which is thermally coupled to fluid within the conditioning chamber and a second side which is arranged to transmit heat to a sink or to receive heat from a source, so that by means of the thermo-electric heat pump the temperature of the conditioning chamber wall, and of the fluid within the conditioning chamber, is controllable wherein the cylinder is divided by the piston into first and second working chambers so that piston motion in one direction causes fluid to be drawn into the first working chamber and to be exhausted from the second working chamber, and piston motion in the opposite direction causes fluid to be exhausted from the first working chamber and to be drawn into the second working chamber, the unit further comprising a valve arrangement, which selectively connects whichever working chamber is at any moment exhausting fluid to the pump outlet, thereby providing monodirectional flow through the outlet.

2. A device as claimed in claim **1**, comprising shaped heat exchange features within the conditioning chamber having surfaces exposed to fluid within the conditioning chamber to exchange heat with the fluid, the heat exchange features also being thermally coupled to the thermoelectric heat pump to exchange heat with that.

3. A device as claimed in claim **1** wherein the conditioning chamber has a thermally conductive wall whose interior is exposed to the fluid, the thermoelectric heat pump being mounted to and thermally coupled to the exterior of said conditioning chamber wall.

4. A device as claimed in claim **2** wherein the heat exchange features comprise fins.

5. A device as claimed in claim **4** wherein the heat exchange features are integrally formed with the conditioning chamber wall.

6. A device as claimed in claim **4** wherein the fins extend along a fluid flow direction within the conditioning chamber.

7. A device as claimed in claim **4** wherein the pump comprises a piston and a cylinder.

8. A device as claimed in claim **7** wherein the cylinder is circular and the conditioning chamber is a substantially annular or semi-annular cavity around and concentric with the cylinder.

9. A device as claimed in claim **7** wherein the aforementioned thermally conductive conditioning chamber wall is disposed around at least part of the cylinder, the conditioning chamber being defined between an outer surface of the cylinder and an inner surface of the conditioning chamber wall.

10. A device as claimed in any preceding claim, further comprising a heat sink arranged to receive heat from the second side of the thermo-electric heat pump.

11. A device as claimed in claim **7** further comprising a heat sink which is arranged to receive heat from the second side of the thermo-electric pump and which forms a shell surrounding the conditioning chamber wall.

12. A device as claimed in claim **1** comprising two end plates wherein each endplate provides for inlet of fluid into the respective cylinder working chambers and comprises a conduit connecting each working chamber to it's associated conditioning chamber.

13. A device as claimed in claim **12**, wherein each working chamber communicates with a respective one-way valve which is arranged to exhaust fluid from the chamber and is connected to the outlet.

14. A device as claimed in claim **13** wherein each chamber additionally communicates with a respective one-way valve which is arranged to let fluid into the chamber.

15. A device as claimed in claim **12**, comprising first and second conditioning chambers which are communicable respectively with the first and second working chambers within the cylinder.

16. A device as claimed in claim **15** wherein the first and second conditioning chambers together form an annulus surrounding the cylinder.

17. A device as claimed in claim **16** wherein the first and second conditioning chambers are both defined between the cylinder and the conditioning chamber wall.

18. A device as claimed in claim **17** wherein the first and second conditioning chambers are separated from each other by a dividing wall in a plane containing the cylinder axis.

19. A device as claimed in claim **17**, wherein the pumping arrangement comprises a lead screw which threadedly engages with the piston in order to reciprocally drive it.

20. A device as claimed in claim **17** which is an air conditioning device.

21. A bed or a seat comprising an air conditioning device as claimed in claim **20**.

22. A refrigeration unit provided with a device according to claim **20**.

23. A method for controlling fluid temperature in a device comprising a cylinder divided by a piston into first and second working chambers which working chambers communicate with one or more conditioning chambers which have at least one solid state thermo electric device associated therewith, wherein:

i. the piston motion in one direction causes fluid to be drawn into the first working chamber and to be exhausted from the second working chamber; and
ii. the piston motion in the opposite direction causes fluid to be exhausted from the first working chamber and to be drawn into the second working chamber; and in which
iii. a valve arrangement selectively circulates fluid mono directionally from a fluid inlet to a fluid outlet via the conditioning chamber.

24. A method as claimed in claim **23** wherein the fluid goes through multiple cooling or heating phases by fluid recirculation.

25. A method as claimed in claim **23** wherein the residence time of the fluid is increased by increasing the fluid path length within the conditioning chamber.

* * * * *