US 20120222428A1

(19) United States
(12) Patent Application Publication
Celik et al.
(10) Pub. No.: US 2012/0222428 A1
(43) Pub. Date: Sep. 6, 2012

(54) COMBINED-LOOP MAGNETIC REFRIGERATION SYSTEM

(76) Inventors: **Serdar Celik**, Edwardsville, IL (US); **Chris Euler**, Edwardsville, IL (US); **Mehmet Hamdi Kural**, Edwardsville, IL (US)

(21) Appl. No.: **13/509,371**

(22) PCT Filed: **Aug. 2, 2010**

(86) PCT No.: **PCT/US10/44079**

§ 371 (c)(1), (2), (4) Date: **May 11, 2012**

(30) **Foreign Application Priority Data**

Nov. 11, 2009 (US) 61260138

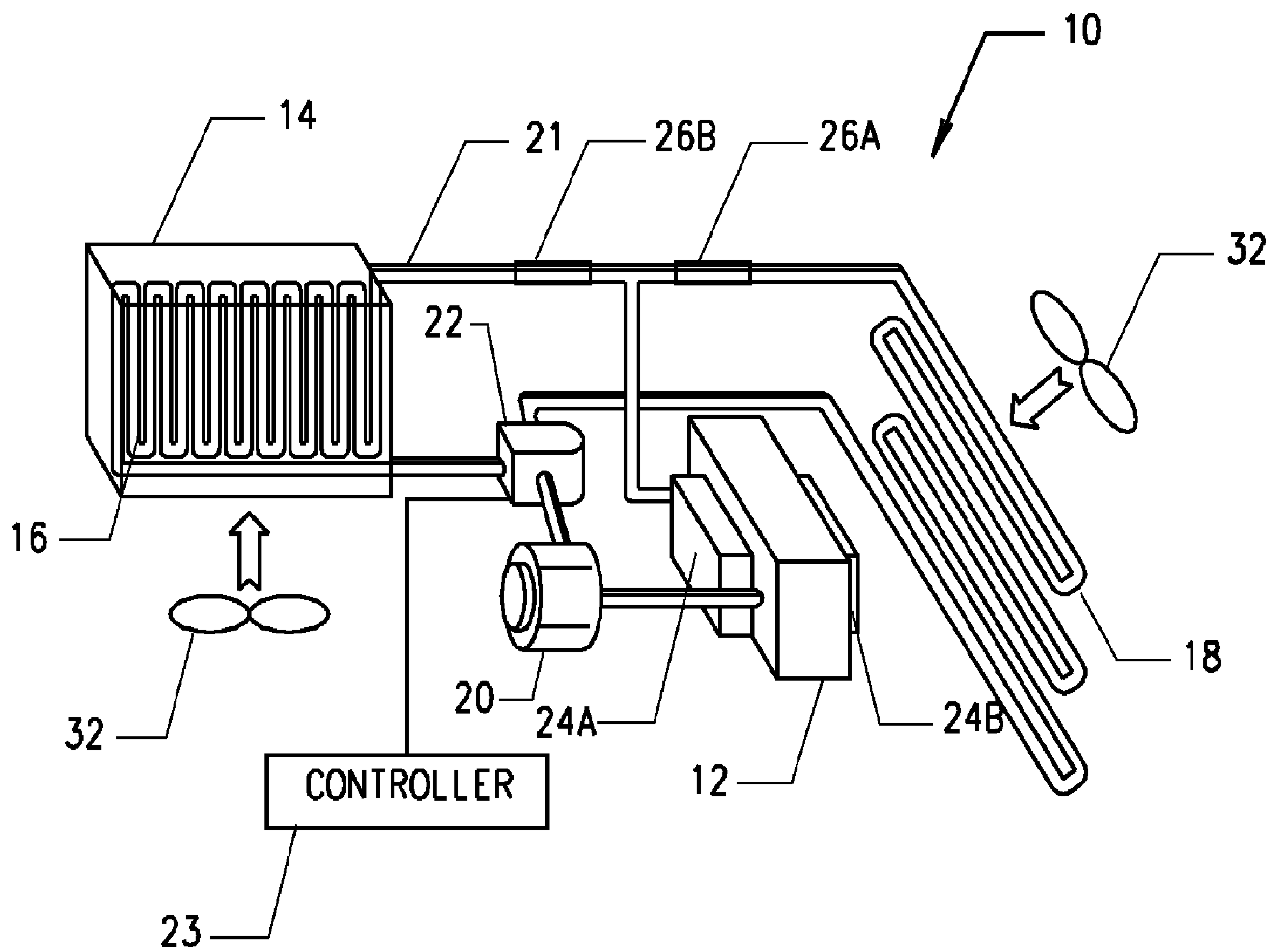
Publication Classification

(51) **Int. Cl.**
F25B 21/00 (2006.01)

(52) **U.S. Cl.** **62/3.1**

(57) **ABSTRACT**

A magnetic refrigeration system having a magnetocaloric material for adjusting the temperature of a transfer fluid is disclosed. The magnetic refrigeration system includes tubing filled with the transfer fluid that flows in a first pass through a heat exchanger having a magnetocaloric material that is magnetized by one or more electromagnets and heats the transfer fluid. The magnetocaloric material is magnetized and demagnetized by one or more electromagnets controlled by a timer/controller device. A three-way solenoid valve controls the flow of heated transfer fluid from the heat exchanger and directs the heated transfer fluid to a warm heat exchanger for cooling of the transfer fluid. The cooled transfer fluid is then passed a second time through the heat ex changer in which the magnetocaloric material is demagnetized for further cooling of the cooled transfer fluid.



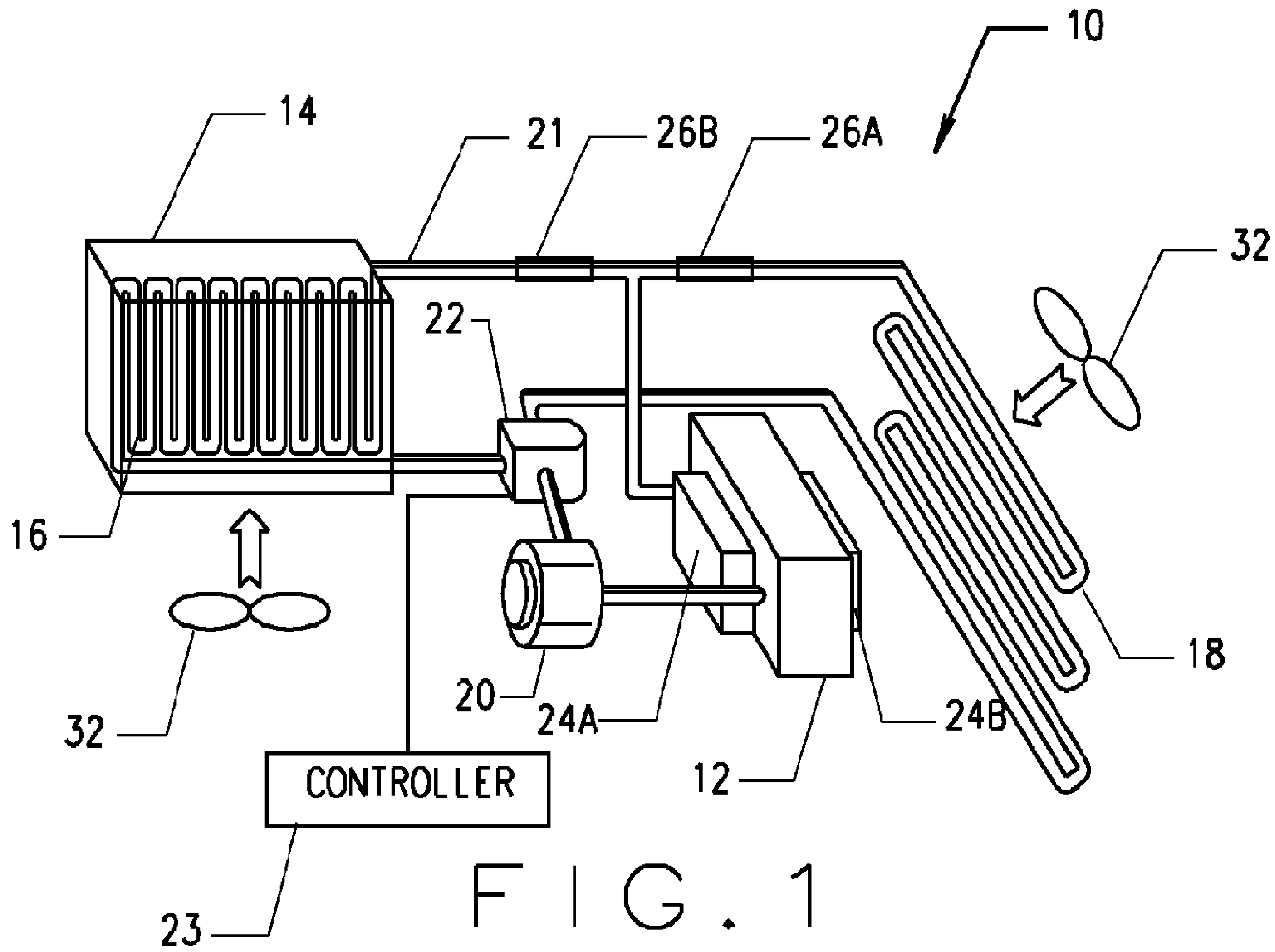

10
14
21
26B
26A
32
22
16
18
20
24A
24B
32
12
CONTROLLER
23

FIG. 1

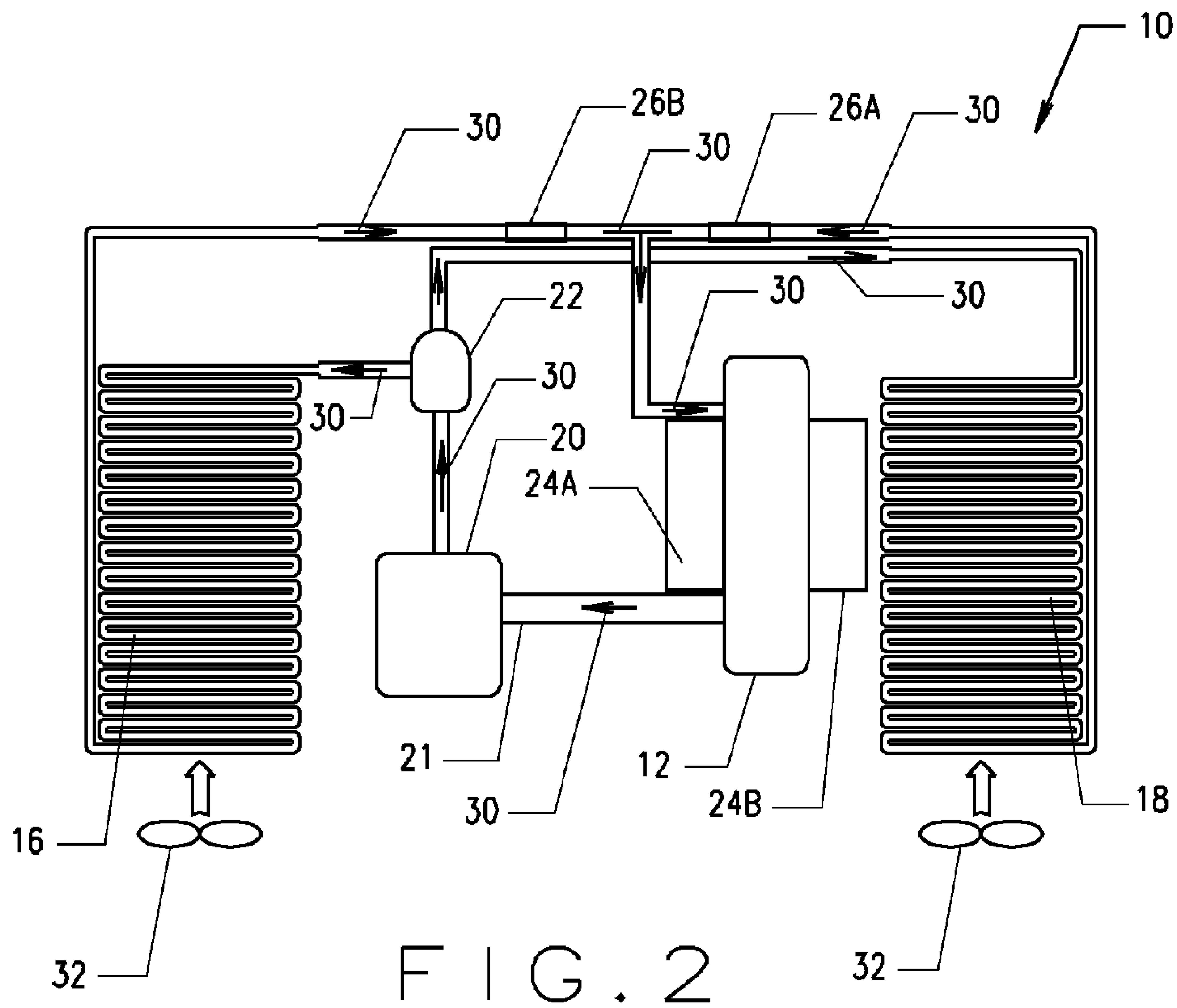

10
30
26B
30
26A
30
22
30
30
30
20
24A
21
12
24B
30
16
18
32
32

FIG. 2

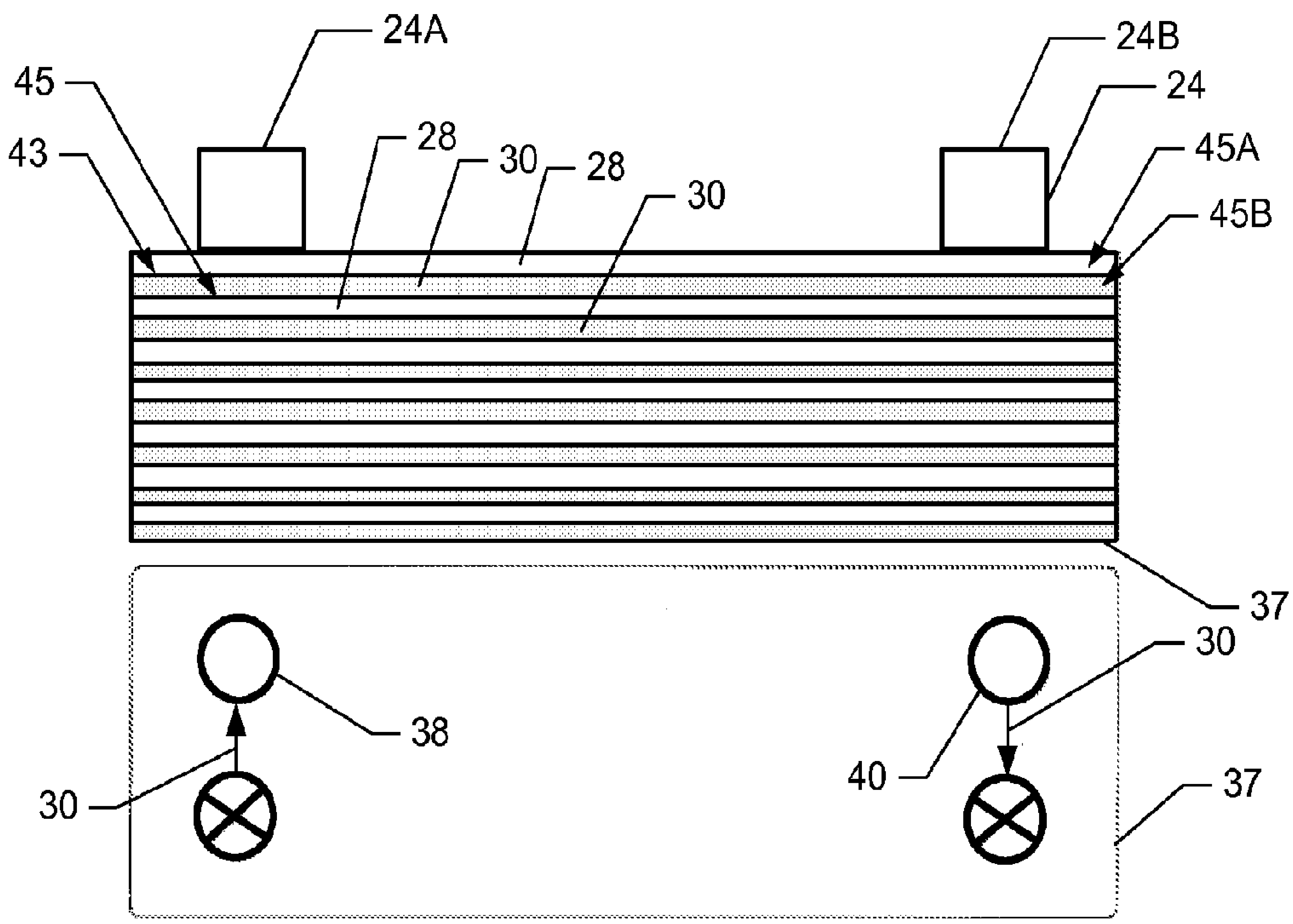


FIG. 3

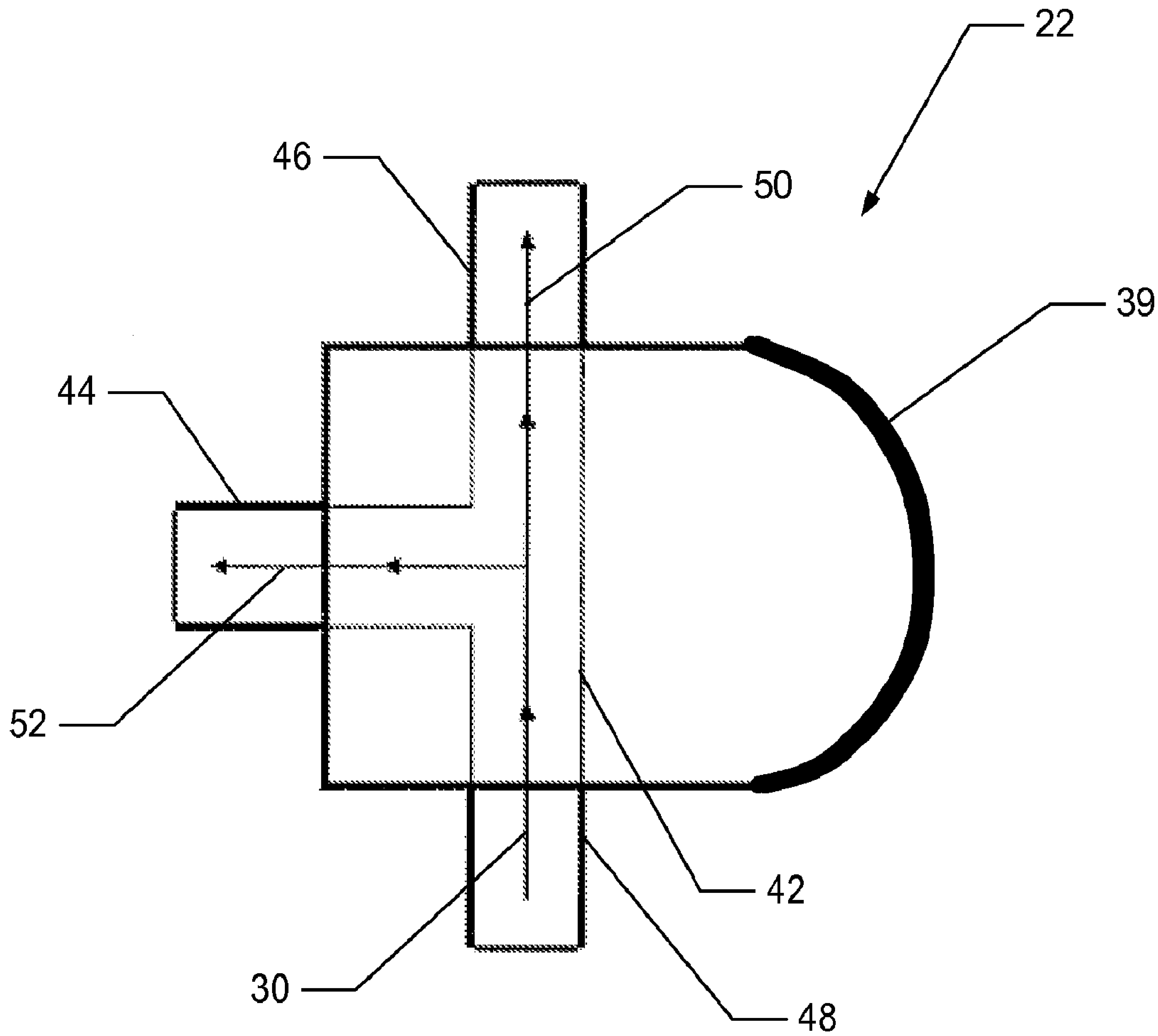


FIG. 4

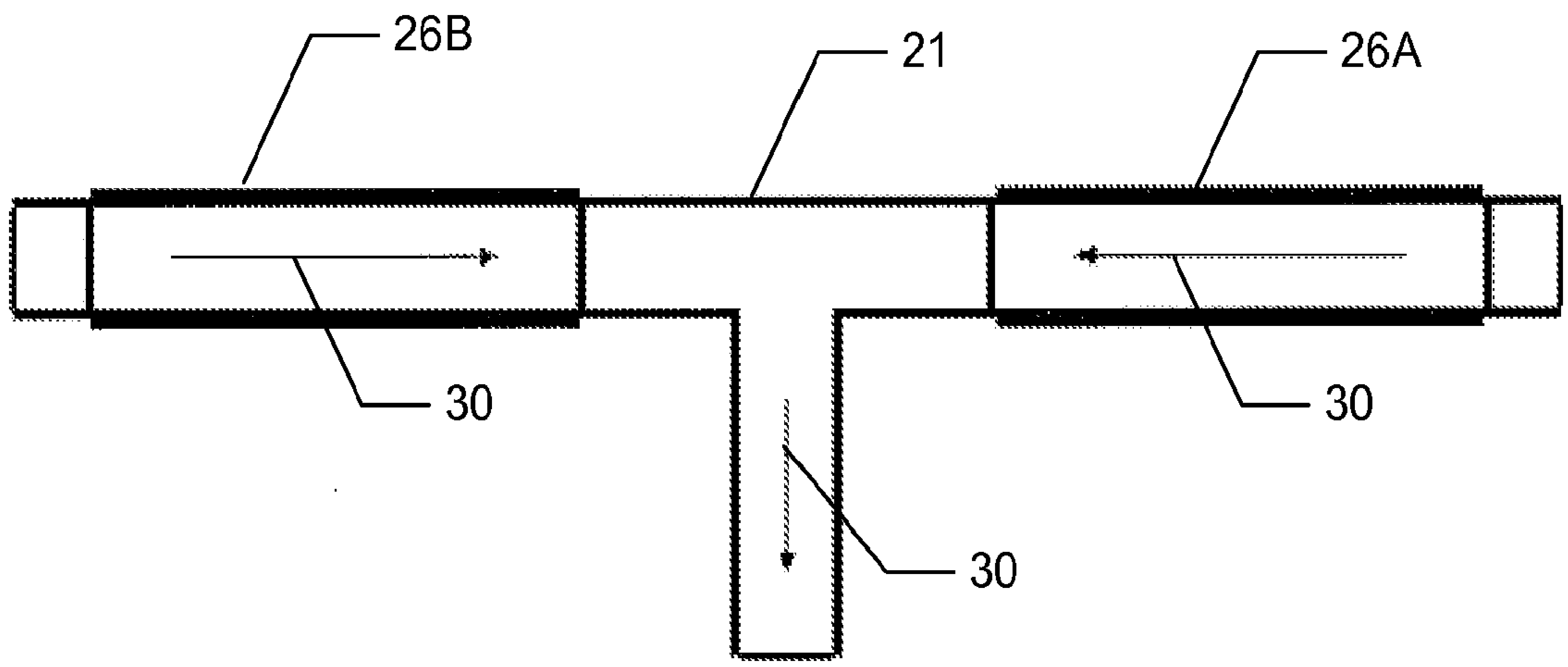


FIG. 5

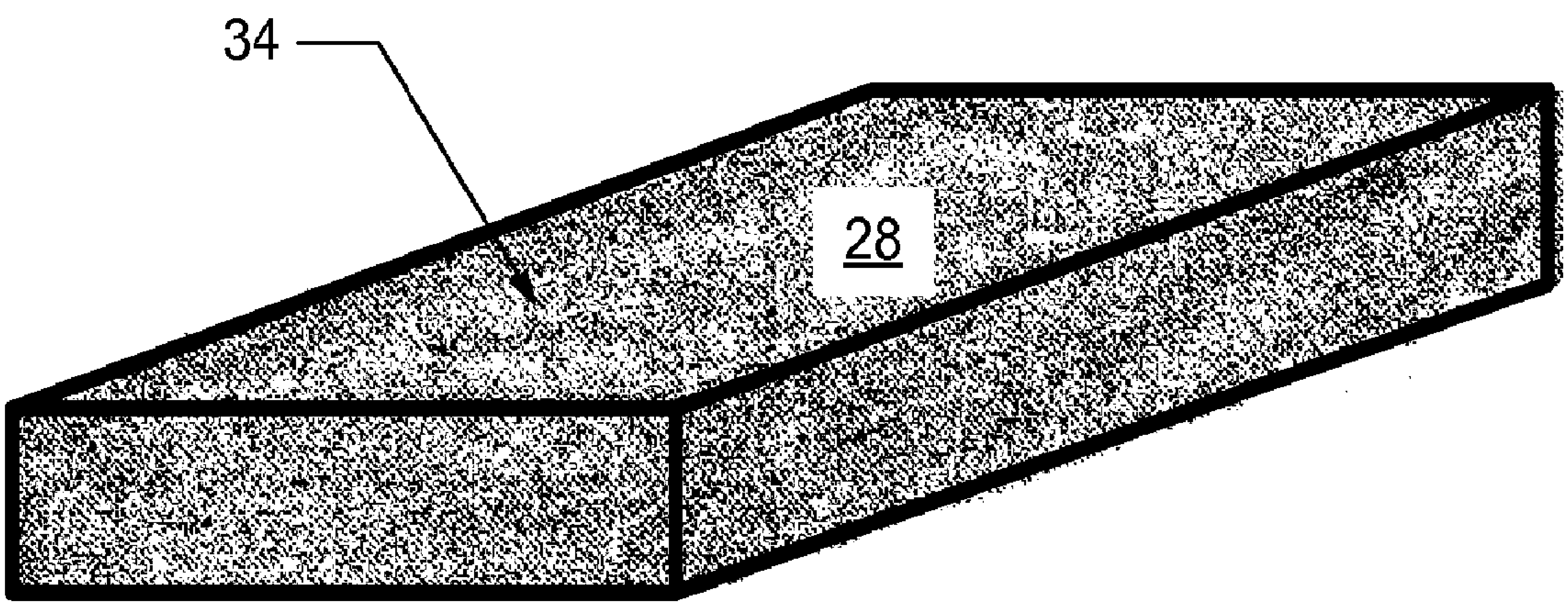


FIG. 6

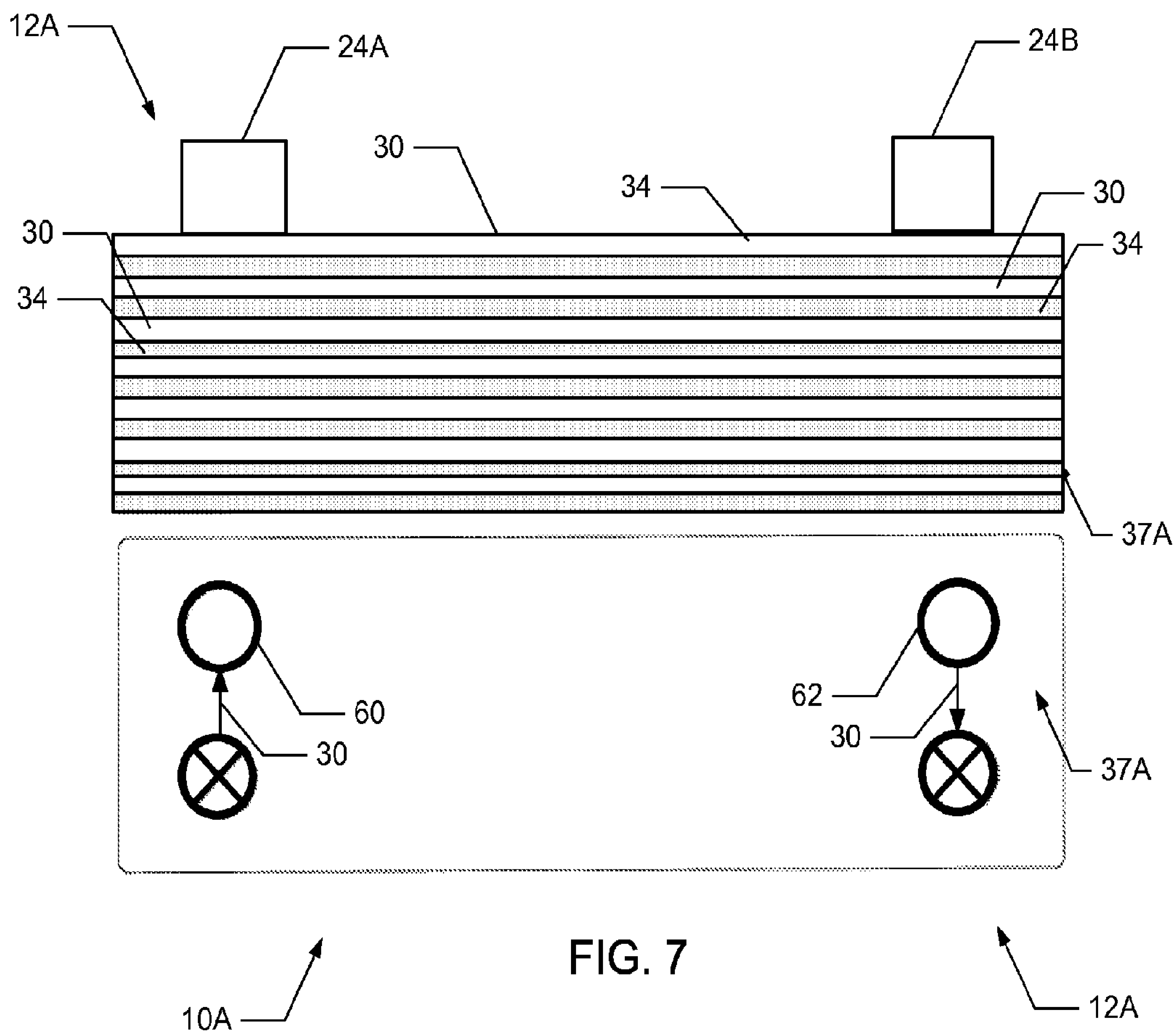


FIG. 7

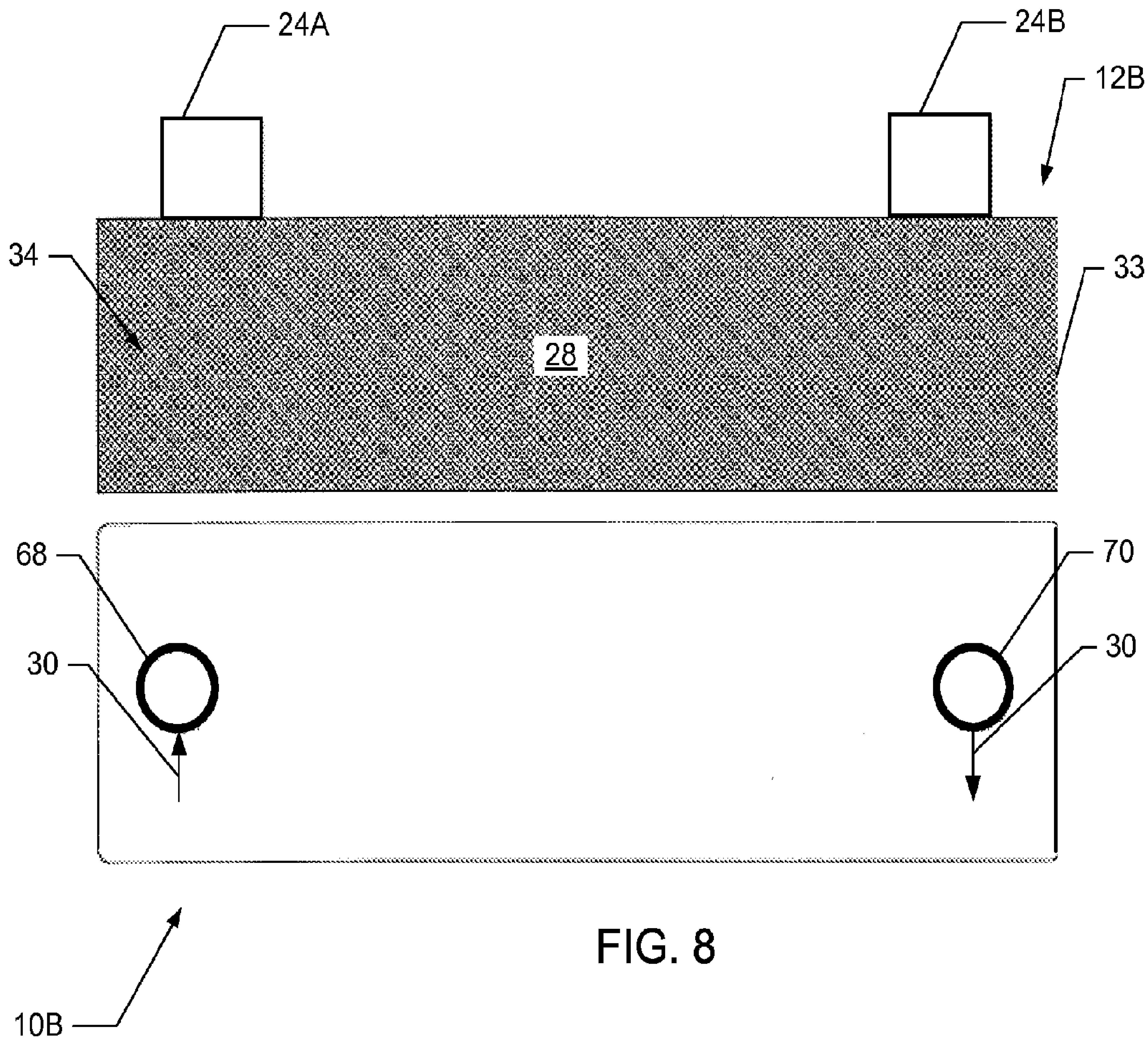
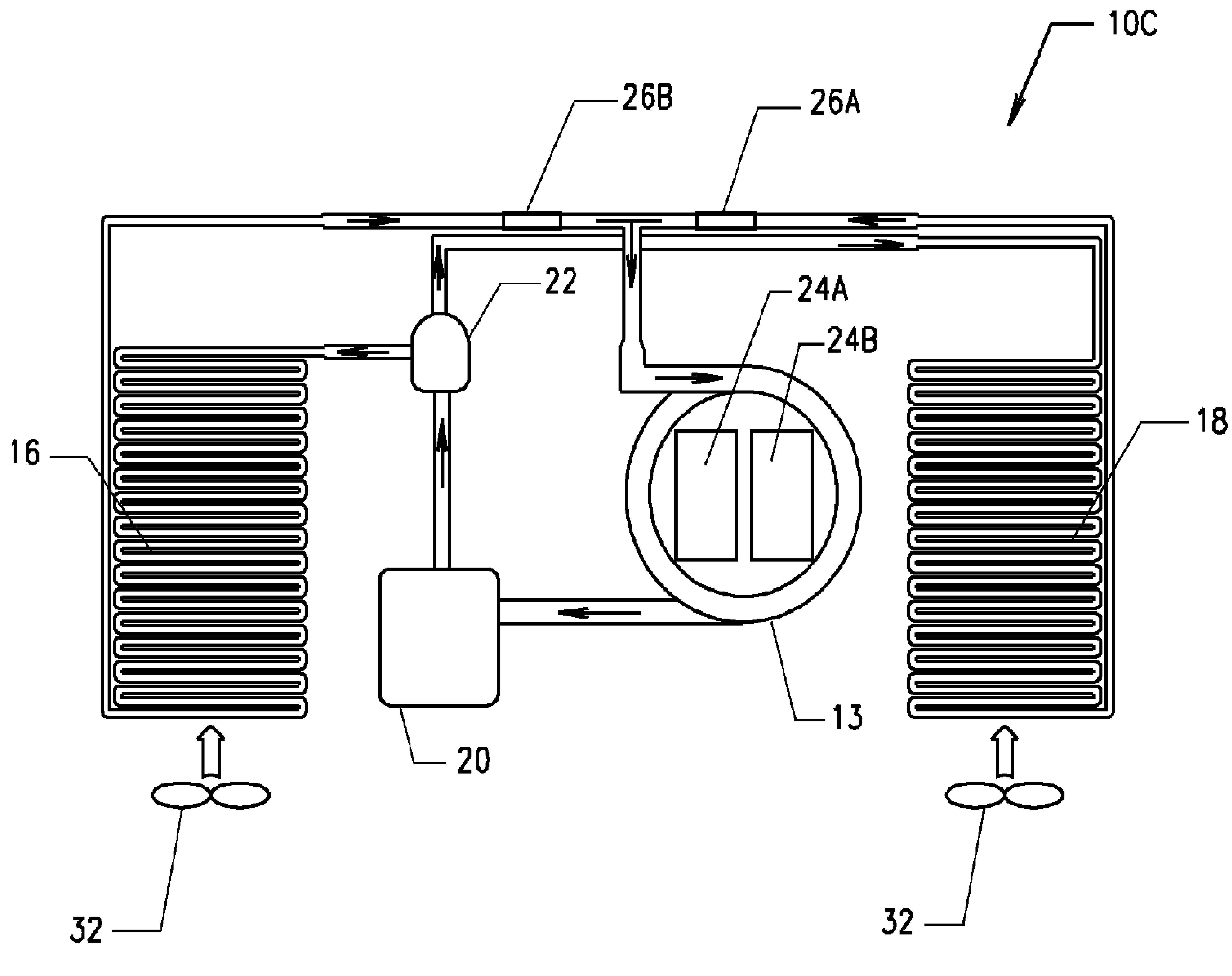


FIG. 8



F I G . 9

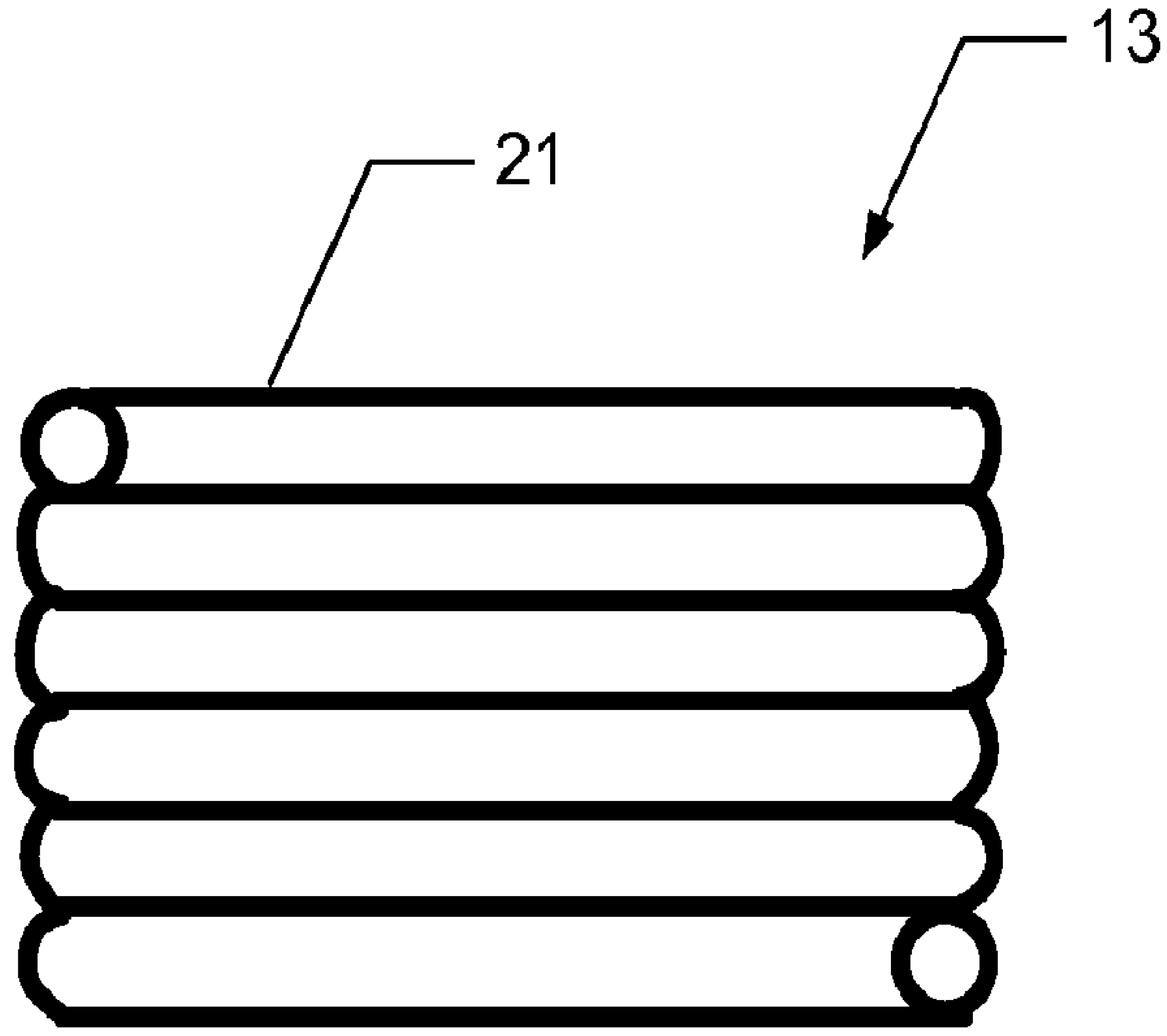


FIG. 10

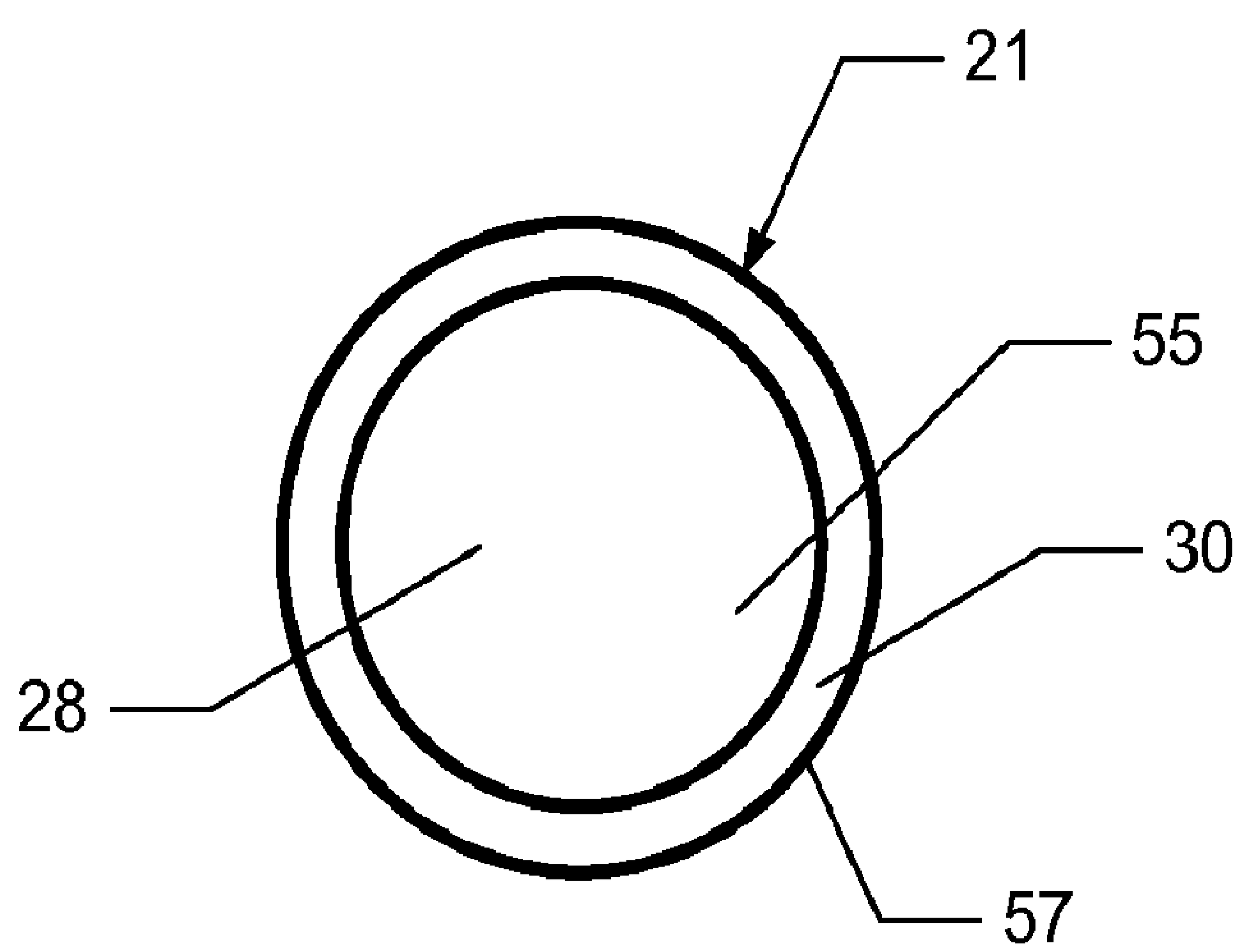


FIG. 10A

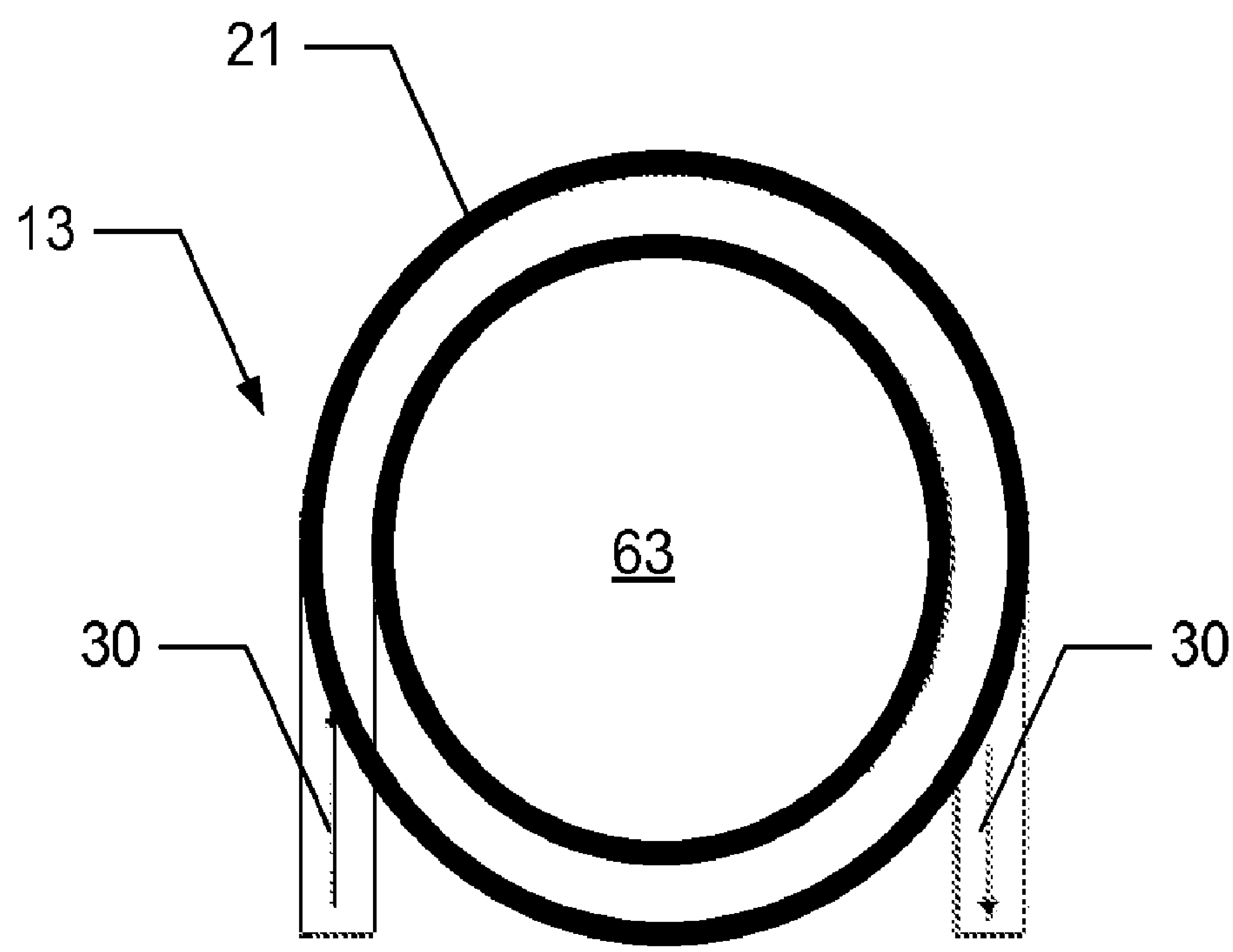


FIG. 11

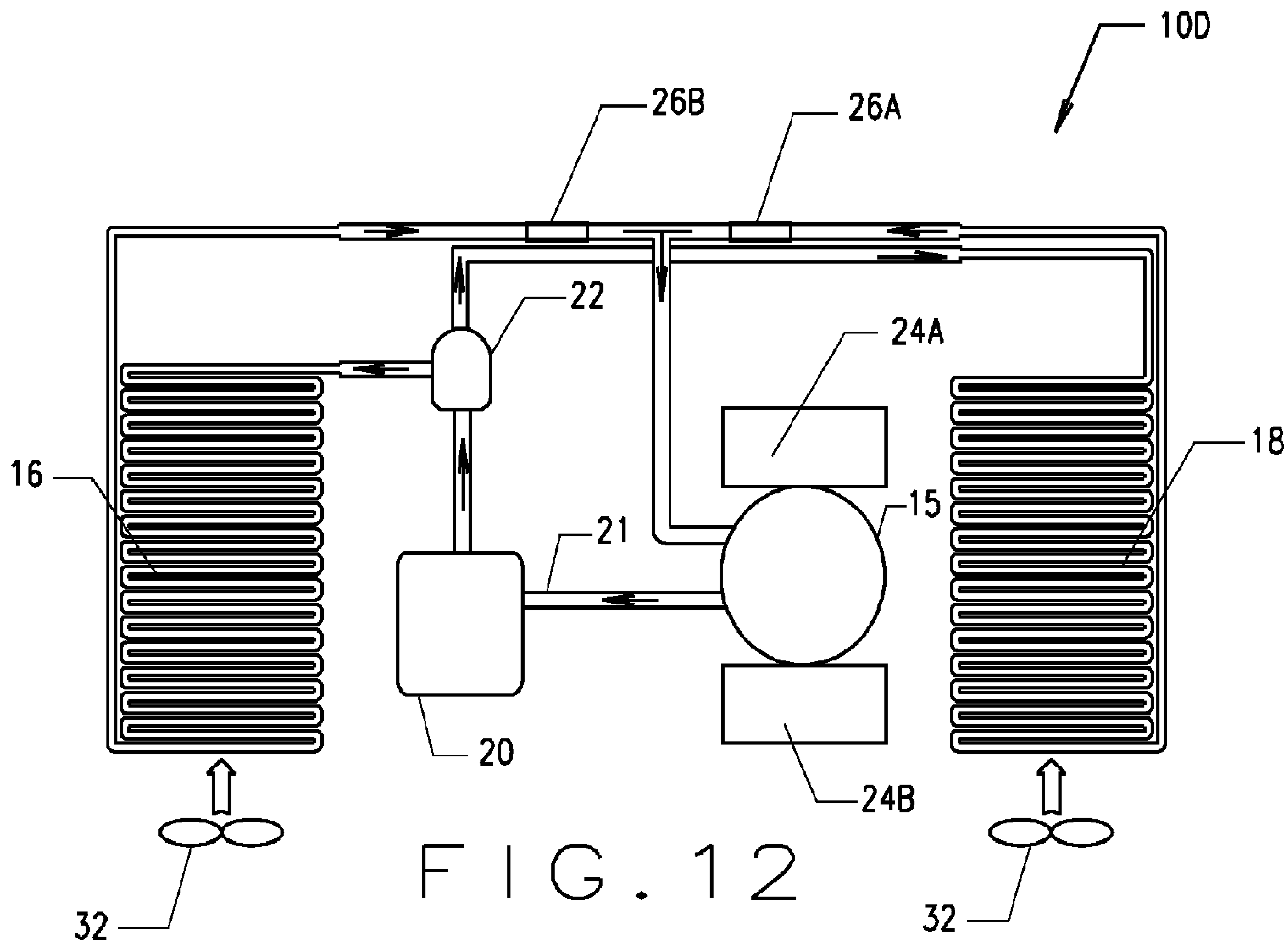

10D
26B
26A
22
24A
18
16
15
21
20
24B
32
32

FIG. 12

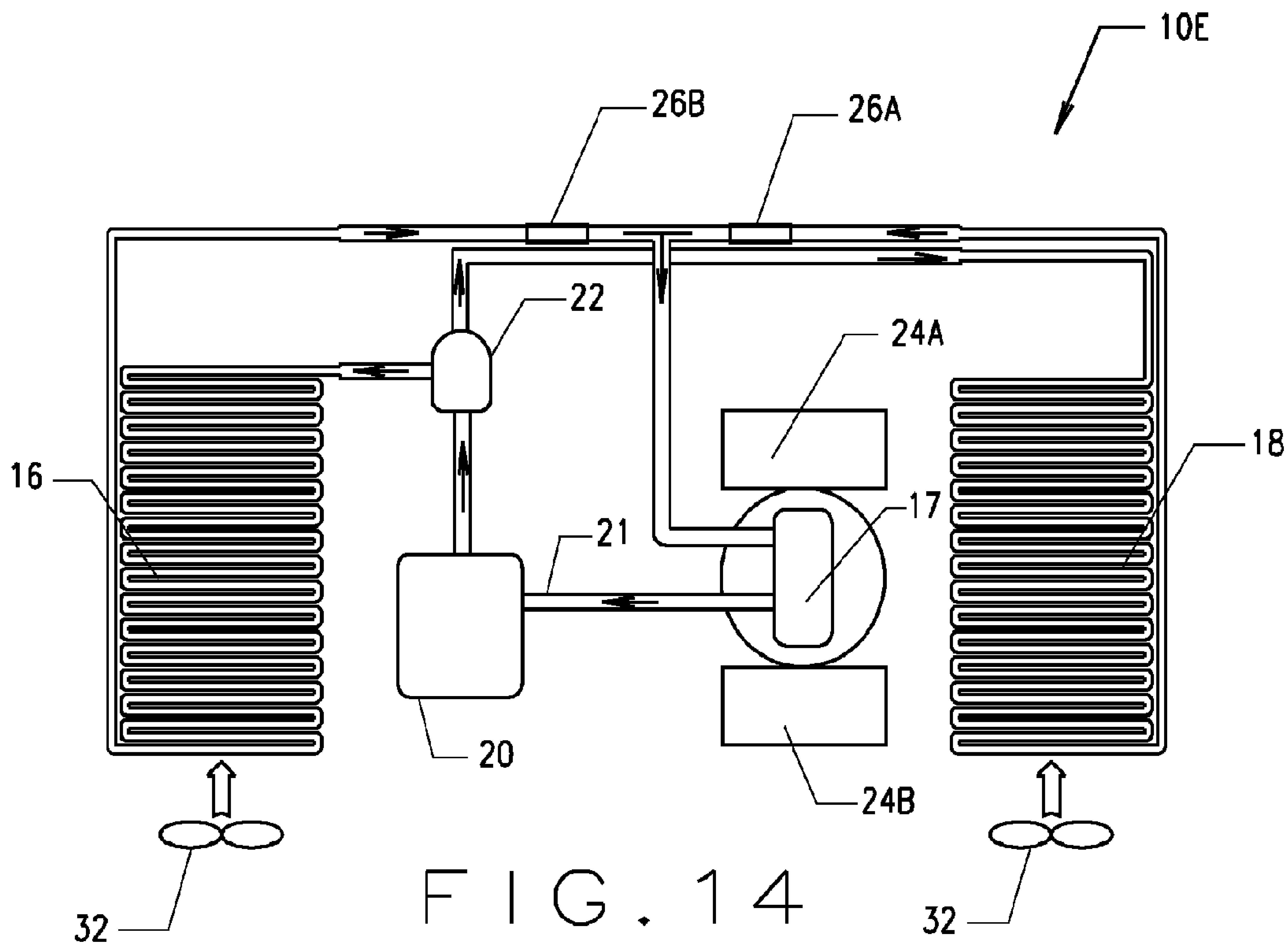

10E
26B
26A
22
24A
18
16
17
21
20
24B
32
32

FIG. 14

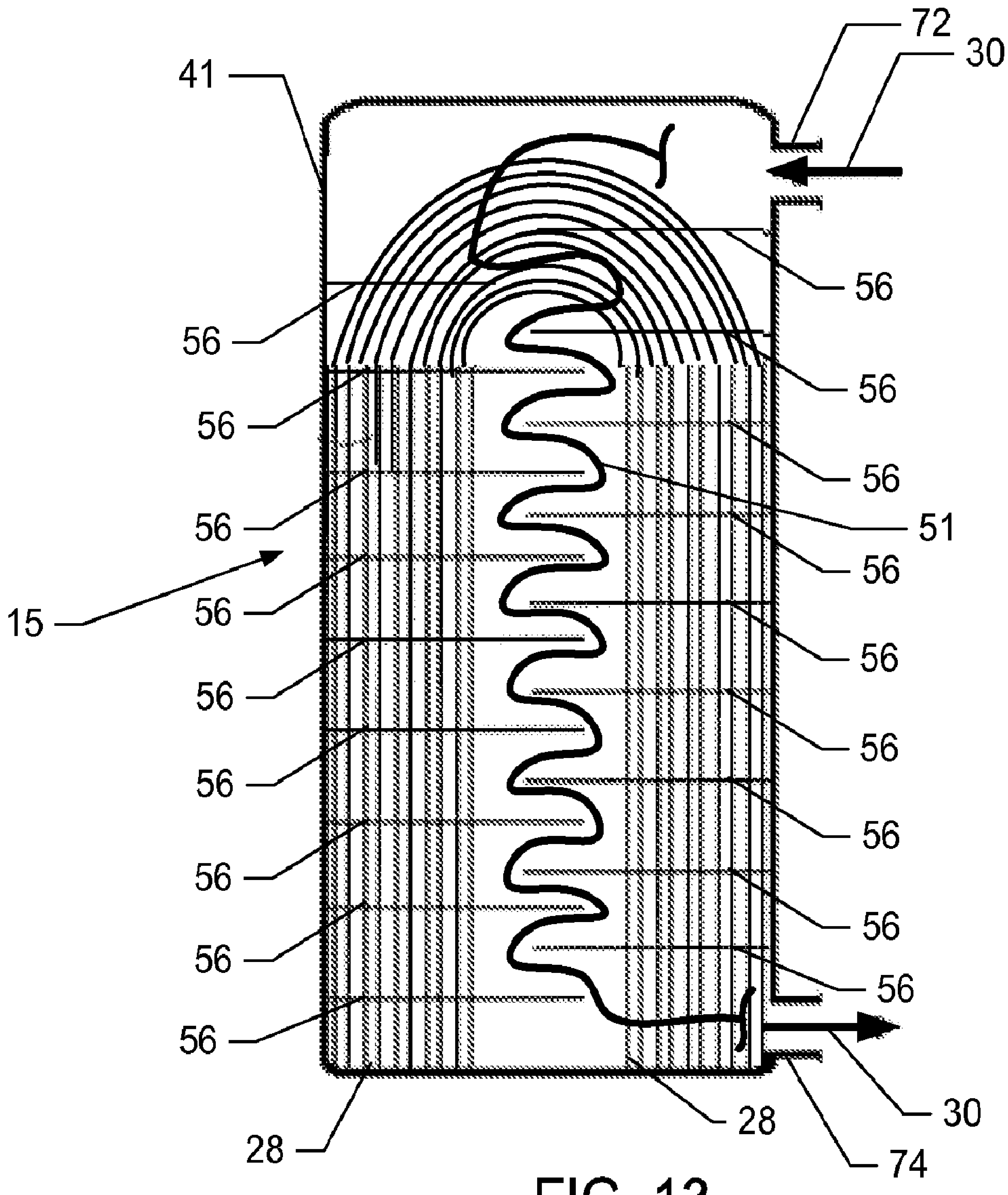

72
30
41
56
56
56
56
56
56
51
15
56
56
56
56
56
56
56
56
56
56
56
56
56
56
56
56
28
28
30
74

FIG. 13

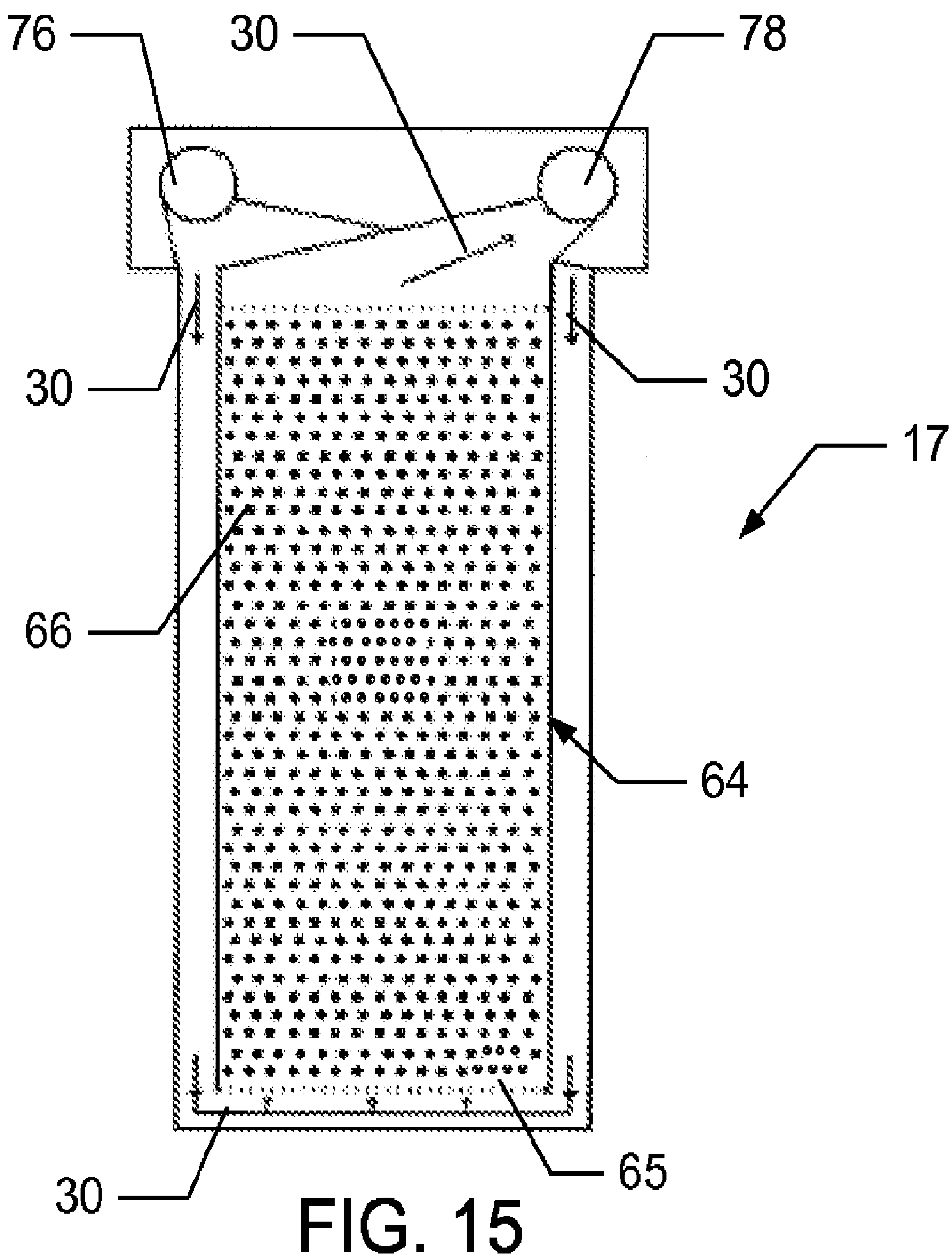


FIG. 15

COMBINED-LOOP MAGNETIC REFRIGERATION SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims benefit of U.S. Provisional Application No. 61/260,138 filed on Nov. 11, 2009.

FIELD

[0002] This document relates to a magnetic refrigeration system, and more particularly to a magnetic refrigeration system for generating a magnetocaloric effect that changes the temperature of a transfer fluid for cooling a magnetic refrigerator.

BACKGROUND

[0003] It is well known in refrigeration technology to employ a gas compression and expansion cycle arrangement to generate the necessary cooling effect inside a refrigerator in a room temperature environment. However, refrigeration technology that relies on a gas compression and expansion cycle arrangement raises issues related to environmental destruction caused by the use of particular Freon gases as well as CFC substitutes that can be discharged into the environment.

[0004] In recent years magnetic refrigeration technology has shown great promise because of its environmental-friendliness and high efficiency relative to the conventional gas compression and expansion cycle arrangement of prior refrigeration technology. In particular, magnetic refrigeration technology relies on a magnetocaloric effect. The magnetocaloric effect is a phenomenon in which the temperature of a magnetocaloric material changes in accordance with a changing external magnetic field being applied by a magnet to magnetize or demagnetize the magnetocaloric material. In the late twentieth century, a magnetic refrigeration system called an Active Magnetic Refrigeration System that uses a magnetocaloric material for cooling a refrigerator in a room temperature environment was developed. Magnetic refrigeration based on this type of magnetocaloric system required that a magnetic field generated by a magnet be applied to a magnetocaloric material that is heated when magnetized such that thermal energy is transferred to the adjacent area by a transfer fluid that flows through adjacent tubing. Although the prior art magnetic refrigeration systems have been successful, there is still a need in the art for further improvements and advances that promote greater efficiencies in magnetic refrigeration technology.

SUMMARY

[0005] In an embodiment, a magnetic refrigeration system may include a transfer fluid that flows through tubing in communication with a brazed heat exchanger. The brazed heat exchanger has alternating layers of tubing and magnetocaloric material. One or more electromagnets are operative for magnetizing and demagnetizing the magnetocaloric material. A controller controls the operation of one or more electromagnets such that the transfer fluid is heated in a first pass through the brazed heat exchanger when the magnetocaloric material is magnetized by one or more electromagnets and then the transfer fluid is cooled in a second pass through the brazed heat exchanger when the magnetocaloric material is demagnetized. A circulation pump is provided for circulating fluid flow of the transfer fluid through the tubing. In addition, a warm heat exchanger is in selective fluid flow communication with the brazed heat exchanger for transferring heat from the transfer fluid after the first pass of the transfer fluid through the brazed heat exchanger. A cold heat exchanger cools a refrigerator cabinet when the transfer fluid flowing through the cold heat exchanger provides a cooling effect to the interior of the refrigerator cabinet after the second pass through the brazed heat exchanger. A three-way valve is provided for directing the flow of transfer fluid from the brazed heat exchanger to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration system is completed.

[0006] In another embodiment, a magnetic refrigeration system may include a transfer fluid that flows through tubing in communication with a brazed heat exchanger. The brazed heat exchanger has alternating layers of tubing and a magnetocaloric foam containing a magnetocaloric material. One or more electromagnets are operative for magnetizing and demagnetizing the magnetocaloric material contained in the magnetocaloric foam. A controller device controls the operation of one or more electromagnets such that the transfer fluid is heated in a first pass through the brazed heat exchanger when the magnetocaloric material contained in the magnetocaloric foam is magnetized by one or more electromagnets and then the transfer fluid is cooled in a second pass through the brazed heat exchanger when the magnetocaloric material in the magnetocaloric foam is demagnetized. A circulation pump is provided for circulating fluid flow of the transfer fluid through the tubing. In addition, a warm heat exchanger is in selective fluid flow communication with the brazed heat exchanger for transferring heat from the transfer fluid after the first pass of the transfer fluid through the brazed heat exchanger. A cold heat exchanger cools a refrigerator cabinet when the transfer fluid flowing through the cold heat exchanger provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the brazed heat exchanger. A three-way valve is provided for directing the flow of transfer fluid from the brazed heat exchanger to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration system is completed.

[0007] In yet another embodiment, a magnetic refrigeration system may include a transfer fluid that flows through tubing in communication with a brazed heat exchanger. The brazed heat exchanger includes an enclosure filled with magnetocaloric foam containing a magnetocaloric material in communication with the tubing in which the transfer fluid flows through. One or more electromagnets are operative for magnetizing and demagnetizing the magnetocaloric material contained in the magnetocaloric foam. A controller device controls the operation of one or more electromagnets such that the transfer fluid is heated during a first pass through the brazed heat exchanger when the magnetocaloric material in the magnetocaloric foam is magnetized and cooled in a second pass through the brazed heat exchanger when the magnetocaloric material contained in the magnetocaloric foam is demagnetized. A circulation pump is provided for circulating fluid flow of the transfer fluid through the tubing. In addition, a warm heat exchanger is in selective fluid flow communication with the brazed heat exchanger for transferring heat from the transfer fluid after the first pass of the transfer fluid through the brazed heat exchanger. A cold heat exchanger cools a refrigerator cabinet when the transfer fluid flowing through the cold heat exchanger provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the brazed heat exchanger. A three-way valve is provided for directing the flow of transfer fluid from the brazed heat exchanger to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration system is completed.

[0008] In a further embodiment, a magnetic refrigeration system may include a transfer fluid that flows through tubing being in communication with a coaxial heat exchanger. The coaxial heat exchanger includes tubing having an inner tube surrounded by an outer tube, wherein the outer tube is filled with a transfer fluid and the inner tube has a magnetocaloric material. One or more electromagnets are operative for magnetizing and demagnetizing the magnetocaloric material. A controller device controls the operation of one or more electromagnets such that the transfer fluid is heated during a first pass through the coaxial heat exchanger when the magnetocaloric material is magnetized and cooled during a second pass through the coaxial heat exchanger when the magnetocaloric material is demagnetized. A circulation pump is provided for circulating fluid flow of the transfer fluid through the tubing. In addition, a warm heat exchanger is in selective fluid flow communication with the coaxial heat exchanger for transferring heat from the transfer fluid after the first pass through the coaxial heat exchanger. A cold heat exchanger cools a refrigerator cabinet when the transfer fluid flowing through the cold heat exchanger provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the coaxial heat exchanger. A three-way valve is provided for directing the flow of transfer fluid from the coaxial heat exchanger to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid after one cycle of the magnetic refrigeration system is completed.

[0009] In another embodiment, a magnetic refrigeration system may include a transfer fluid that flows through tubing in communication with a U-tube heat exchanger. The U-tube heat exchanger includes an enclosure that encases U-shaped tubing having a magnetocaloric material with a plurality of baffles spaced within the interior of the enclosure to guide the flow of transfer fluid through the enclosure of the U-tube heat exchanger. One or more electromagnets are in operative for magnetizing and demagnetizing the magnetocaloric material. A controller device controls the operation of one or more electromagnets such that the transfer fluid is heated in a first pass through the U-tube heat exchanger when the magnetocaloric material is magnetized by one or more electromagnets and then cooled in a second pass through the U-tube heat exchanger when the magnetocaloric material is demagnetized. A circulation pump is provided for circulating fluid flow of the transfer fluid through the tubing. In addition, a warm heat exchanger is in selective fluid flow communication with the U-tube heat exchanger for transferring heat from the transfer fluid after the first pass of the transfer fluid through the U-tube heat exchanger. A cold heat exchanger cools a refrigerator cabinet when the transfer fluid flowing through the cold heat exchanger provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the coaxial heat exchanger. A three-way valve is provided for directing the flow of transfer fluid from the U-tube heat exchanger to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration system is completed.

[0010] In one other embodiment, a magnetic refrigeration system may include a transfer fluid that flows through tubing in communication with a fluidized bed. The fluidized bed includes a packed bed in fluid flow communication with the tubing. The packed bed includes one or more membranes and a magnetocaloric material for mixing with the transfer fluid as the transfer fluid flows through the pack bed. One or more electromagnets are operative for magnetizing and demagnetizing the magnetocaloric material. A controller controls the operation of one or more electromagnets such that the transfer fluid is heated in a first pass of the transfer fluid through the fluidized bed when the magnetocaloric material is magnetized and cooled in a second pass of the transfer fluid through the fluidized bed when the magnetocaloric material is demagnetized. A circulation pump is provided for circulating fluid flow of the transfer fluid through the tubing. In addition, a warm heat exchanger is in selective fluid flow communication with the fluidized bed for transferring heat from the transfer fluid after the first pass of the transfer fluid through the fluidized bed. A cold heat exchanger cools a refrigerator cabinet when the transfer fluid provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the fluidized bed. A three-way valve is provided for directing the flow of transfer fluid from the fluidized bed to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration system is completed.

[0011] Additional objectives, advantages and novel features will be set forth in the description which follows or will become apparent to those skilled in the art upon examination of the drawings and detailed description which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** is a perspective view of a first embodiment for the magnetic refrigeration system;

[0013] FIG. **2** is a simplified illustration of the first embodiment for the magnetic refrigeration system showing the fluid pathway of the transfer fluid within the system;

[0014] FIG. **3** is a simplified illustration of a brazed heat exchanger for the first embodiment of the magnetic refrigeration system;

[0015] FIG. **4** is a simplified illustration of the three-way solenoid valve for the magnetic refrigeration system;

[0016] FIG. **5** is a simplified illustration of the check valve arrangement for magnetic refrigeration system;

[0017] FIG. **6** is a perspective view of magnetocaloric foam containing a magnetocaloric material used in a second embodiment of the magnetic refrigeration system;

[0018] FIG. **7** is a simplified illustration of a brazed heat exchanger including the magnetocaloric foam in alternating layers for the second embodiment of the magnetic refrigeration system;

[0019] FIG. **8** is a simplified illustration of a brazed heat exchanger having an enclosure filled with the magnetocaloric foam for a third embodiment of the magnetic refrigeration system;

[0020] FIG. 9 is a simplified illustration of a coaxial heat exchanger used with a fourth embodiment of the magnetic refrigeration system;

[0021] FIG. 10 is a side view of the coaxial heat exchanger;

[0022] FIG. 10A is an enlarged end view of the coaxial heat exchanger shown in FIG. 10;

[0023] FIG. 11 is a top view of the coaxial heat exchanger;

[0024] FIG. 12 is simplified illustration of a U-tube heat exchanger used with a fifth embodiment of the magnetic refrigeration system;

[0025] FIG. 13 is a simplified illustration of the U-Tube heat exchanger;

[0026] FIG. 14 is a simplified illustration of a fluidized bed used with a sixth embodiment of the magnetic refrigeration system; and

[0027] FIG. 15 is a simplified illustration of the fluidized bed.

[0028] Corresponding reference characters indicate corresponding elements among the view of the drawings. The headings used in the figures should not be interpreted to limit the scope of the claims.

DETAILED DESCRIPTION

[0029] Referring to the drawings, one embodiment of the magnetic refrigeration system is illustrated and generally indicated as **10** in FIGS. **1-3**. A first embodiment of the magnetic refrigeration system **10** includes a brazed heat exchanger **12** that heats a transfer fluid **30** from ambient temperature, for example **25** degrees Celsius, to a predetermined temperature range of between 25.1-26.0 degrees Celsius in a first pass of the transfer fluid **30** through the brazed heat exchanger **12** and then cools the transfer fluid **30** to another predetermined temperature range of between 24.0-24.9 degrees Celsius in a second pass of the transfer fluid **30** through the brazed heat exchanger **12**. The brazed heat exchanger **12** includes an exchanger body **37** having a plurality of plates **43** therein, which are vacuum brazed together to form alternate layers of plates **43** that define alternating channels **45**A and **45**B throughout the brazed heat exchanger **12**. As shown in FIG. **3**, alternate channels **45**A each include a magnetocaloric material **28** and respective alternating channels **45**B are adapted for flow of the transfer fluid **30** through each channel **45**B to transfer thermal energy between the magnetocaloric material **28** and transfer fluid **30** as shall be discussed in greater detail below. As used herein, the term "magnetocaloric material" shall mean any material that provides a magnetocaloric effect such that a magneto-thermodynamic phenomenon is generated in which a reversible change in temperature of a suitable material is caused by exposing the material to a changing magnetic field.

[0030] The brazed heat exchanger **12** includes a fluid inlet **38** for permitting the ingress of transfer fluid **30** into the exchanger body **37** and a fluid outlet **40** for the egress of transfer fluid **30** from the exchanger body **37**. Hollow tubing **21** communicates with the fluid inlet **38** and fluid outlet **40** of the brazed heat exchanger **12** for transporting the transfer fluid **30** between various components throughout the magnetic refrigeration system **10** as illustrated in FIG. **2**. In one embodiment, the transfer fluid **30** used within the magnetic refrigeration system **10** may be water. In other embodiments, the transfer fluid **30** may be a water-ethylene glycol mixture, air, or helium.

[0031] Magnetic refrigeration system **10** also includes one or more electromagnets **26**, such as superconducting electromagnets, that could yield a magnetic field in the range of between 0.5-10 Tesla. In the first embodiment, the magnetic refrigeration system **10** includes a pair of electromagnets **24**A and **24**B that are oriented on opposite sides of exchanger body **37** for magnetizing and demagnetizing the magnetocaloric material **28** inside the brazed heat exchanger **12** when the electromagnets **24**A and **24**B are activated and deactivated by the magnetic refrigeration system **10**. The magnetocaloric material **28** contained in each channel **45**A of the brazed heat exchanger **12** is heated up to a predetermined temperature when the pair of electromagnets **24**A and **24**B are activated as the transfer fluid **30** makes the first pass through the brazed heat exchanger **12**. The heat generated by the magnetized magnetocaloric material **28** inside channels **45**A radiates and is transferred to the transfer fluid **30** flowing inside adjacent alternating channels **45**B as the transfer fluid **30** flows from the fluid inlet **38** and then exits the fluid outlet **40** of the brazed heat exchanger **12**.

[0032] Referring back to FIG. **2**, after the heated transfer fluid **30** exits the fluid outlet **40** of the brazed heat exchanger **12** a circulation pump **20** may continuously circulate the flow of transfer fluid **30** to a solenoid valve **22** that guides the transfer fluid **30** to a warm heat exchanger **18** or cold heat exchanger **16**. In one embodiment, the solenoid valve **22** is a three-way solenoid valve **22** that permits the transfer fluid **30** to flow to either the warm heat exchanger **18** after the transfer fluid **30** has been heated up by the brazed heat exchanger **12** during the first pass by the transfer fluid **30**, or the cold heat exchanger **16** once the transfer fluid **30** has been cooled down after making the second pass through the brazed heat exchanger **12**.

[0033] Referring to FIG. **4**, the solenoid valve **22** includes a solenoid valve body **39** that defines a fluidic channel arrangement **42** with gates (not shown) that channel transfer fluid **30** to either the warm heat exchanger **18** during the first pass or the cold heat exchanger **16** during the second pass of the transfer fluid through the brazed heat exchanger **12** as one cycle of the magnetic refrigeration system **10** has been completed. For example, the solenoid valve **22** may be similar to those valves used in heat pumps and air conditioners. In particular, the fluidic channel **42** defines a cold fluidic outlet **44** for transport of the transfer fluid **30** to the cold heat exchanger **16** and a warm fluidic outlet **46** for transport of the transfer fluid **30** to the warm heat exchanger **18**. The solenoid valve **22** is controlled by a timer/controller device **23** that operates the gates to control the flow of transfer fluid **30** through either the cold fluidic outlet **44** or warm fluidic outlet **46**. As shown, warm fluid pathway **50** designates the flow of transfer fluid **30** from the solenoid valve **20** to the warm heat exchanger **18**, while the cold fluid pathway **52** designates the flow of transfer fluid **30** from the solenoid valve **20** to the cold heat exchanger **16** as shall be discussed in greater detail below.

[0034] Once the transfer fluid **30** has been heated up during the first pass through the brazed heat exchanger **12** and is circulated by the circulation pump **20**, the heated transfer fluid **30** enters the solenoid valve **22**. As the transfer fluid **30** enters the solenoid valve **22**, the timer/controller device **23** controls the gates of the valve **22** such that the transfer fluid **30** that enters the fluid inlet **48** is made to exit through the warm fluid outlet **46** for transport to the warm heat exchanger **18**. The heated transfer fluid **30** entering the warm heat exchanger **18** is then cooled as the heat contained in the transfer fluid **30** is transferred through the tubing **21** of the warm heat exchanger **18**. In one embodiment of the warm heat exchanger **18**, tubing **21** may have a U-tube configuration that allows the heat contained in the transfer fluid **30** to be readily and efficiently transferred through the tubing **21**. The warm heat exchanger **18** may include a circulation fan **32** to assist in dissipating the radiated heat transferred from the heated transfer fluid **30**.

[0035] Referring to FIGS. **2** and **5**, after exiting the warm heat exchanger **18**, the cooled transfer fluid **30** is directed back for a second pass through the brazed heat exchanger **12** via a one-way check valve **26**A that permits one-way fluid flow through tubing **21** and into the fluid inlet **38** of the brazed heat exchanger **12** as illustrated by the arrows that indicate fluid flow of transfer fluid **30**. Another one-way check valve **26**B permits fluid flow only from the cool heat exchanger **16** and prevents any transfer fluid **30** from flowing from the warm heat exchanger **18** to the cold heat exchanger **16**. The cooled transfer fluid **30** reenters the brazed heat exchanger **30** during the second pass with the electromagnets **24**A and **24**B turned off by the timer/controller **23**, thereby placing the magnetocaloric material **28** in a demagnetized state. In the demagnetized state, the magnetocaloric material **28** is cooled down and is maintained at a temperature that is lower than the temperature of the cooled transfer fluid **30** reentering the brazed heat exchanger **12** from the warm heat exchanger **18**. In one embodiment, the temperature range of the cooled transfer fluid **30** that returns from the brazed heat exchanger **12** may be in a range of between 24.5 to 25.5 degrees Celsius. As the cooled transfer fluid **30** travels through the brazed heat exchanger **12** the relatively cooler temperature of the magnetocaloric material **28** surrounding the flow of the cooled transfer fluid **30** transfers thermal energy between the magnetocaloric material **28** and the transfer fluid **30**, thereby further reducing the temperature of the cooled transfer fluid **30** as heat from the transfer fluid **30** is transferred to the magnetocaloric material **28**. At the outlet of the brazed heat exchanger **12**, the temperature of the transfer fluid **30** may be in the range of between 24.0-24.9 degrees Celsius for the first cycle.

[0036] Once the cooled transfer fluid **30** is further cooled down in the brazed heat exchanger **12** during the second pass, the further cooled transfer fluid **30** re-enters the solenoid valve **22** and the timer/controller **23** switches the gates of the valve **22** such that the transfer fluid **30** exits only through the cold fluid outlet **44** and enters the cold heat exchanger **16**. The cold heat exchanger **16** cools the interior of a refrigeration cabinet **14** that is exposed to the surrounding ambient temperature. For example, the refrigerator cabinet **14** may be cooled down to a temperature range of between 19.0-23.0 degrees Celsius when the ambient temperature surrounding the refrigerator cabinet **14** is about 25 degrees Celsius. In one embodiment, the tubing **21** of the cold heat exchanger **16** has a U-tube configuration such that the further cooled transfer fluid **30** flowing through tubing **21** provides a cooling effect by reducing the temperature of the refrigeration cabinet **14** to a desired cool temperature. After the further cooled transfer fluid **30** is circulated through the cold heat exchanger **16**, the transfer fluid **30** exits through the one-way check valve **26**B and enters the brazed heat exchanger **12** to begin the next cycle of the magnetic refrigeration system **10**.

[0037] In one embodiment of the magnetic refrigeration system **10**, the coefficient of performance using water as the transfer fluid **30** is 0.4 wherein the coefficient of performance for prior art magnetic refrigeration system is in the range of between 0.05-0.5. In addition, at an ambient temperature of 25 degrees Celsius, the magnetic refrigeration system **10** can achieve a temperature within the transfer fluid **30** of 21 degrees Celsius in the cold heat exchanger and a temperature within the transfer fluid **30** of 27 degrees Celsius in the warm heat exchanger. As such, the temperature of the transfer fluid **30** is reduced by 0.7 degrees Celsius from the first pass to the second pass through the magnetic refrigeration system **10**.

[0038] Referring to FIGS. **6** and **7**, a second embodiment of the magnetic refrigeration system, designated **10**A, is illustrated. Magnetic refrigeration system **10**A is substantially similar to the first embodiment of the magnetic refrigeration system **10**; however, magnetic refrigeration system **10**A includes a brazed heat exchanger **12**A that replaces the magnetocaloric material **28** in a solid state with a magnetocaloric foam material **34** that contains a magnetocaloric material **28**. The magnetocaloric foam **34** completely fills a space to form alternating layers within the brazed heat exchanger **12**A that increases the heat transfer area of the magnetocaloric material **28**, thereby producing a higher rate of heat transfer between the magnetocaloric material **28** and the transfer fluid **30** flowing through tubing **21**. The timer/controller device **23** also controls the magnetization and demagnetization of the magnetocaloric material **28** in the magnetocaloric foam **34** in order to adjust the temperature of the transfer fluid **30** through the magnetic refrigeration system **10**.

[0039] As shown in FIG. **7**, the second embodiment of the brazed heat exchanger **12**A includes a body **37**A that encases alternating U-shaped layers of magnetocaloric foam **34** and U-shaped tubing **21** in which the transfer fluid **30** flows through. The U-shaped tubing **21** inside the brazed heat exchanger **12**A communicates with an inlet **60** and an outlet **62** for the ingress and egress of transfer fluid **30** through the heat exchanger **12**A. A pair of electromagnets **24**A and **24**B is positioned on opposite sides of the body **37**A for magnetizing and demagnetizing the magnetocaloric material **28** in the magnetocaloric foam **34** when actuated by the timer/controller device **23**.

[0040] Referring to FIG. **8**, a third embodiment of the magnetic refrigeration system, designated **10**B, is illustrated. Magnetic refrigeration system **10**B is substantially similar to the first embodiment of the magnetic refrigeration system **10** with the exception that a brazed heat exchanger **12**B includes an enclosure **33** completely filled with the magnetocaloric foam **34** in which the transfer fluid **30** flows through. The enclosure **33** of the brazed heat exchanger **12**B may include one or more fluid inlets **68** for the ingress of transfer fluid **30** into the brazed heat exchanger **12**B and one or more fluid outlets **70** for the egress of transfer fluid **30** from the brazed heat exchanger **12**B. As noted with the other embodiments, the timer/controller device **23** controls the magnetization and demagnetization of the magnetocaloric material **128** contained in the magnetocaloric foam **34** inside the enclosure **33** by the electromagnets **24**A and **24**B such that the temperature of as the transfer fluid **30** is adjusted as fluid flows through the foam **34** that fills the inside of enclosure **33**.

[0041] Referring to FIGS. **9-11**, a fourth embodiment of the magnetic refrigeration system, designated **10**C, is illustrated. Magnetic refrigeration system **10**C replaces the brazed heat exchanger **12** of the other embodiments with a coaxial heat exchanger **13** having tubing **21** that defines an inner tube **55** filled with the magnetocaloric material **28** surrounded by an outer tube **57** wherein the transfer fluid **30** flows. Alternatively, the magnetocaloric material **28** may fill the inner tube **55**, while the transfer fluid **30** may flow through the outer tube

57. Electromagnets **24**A and **24**B may be positioned in the axial space **63** defined by the coaxial heat exchanger **13** or a plurality of electromagnets **24** may be positioned around the tubing **21** surrounding the magnetocaloric material **28** in order to adjust the temperature of the transfer fluid **30**.

[0042] As shown in FIGS. **12** and **13**, a fifth embodiment of the magnetic refrigeration system, designated **10**D, is illustrated. Magnetic refrigeration system **10**D includes a U-tube heat exchanger **15** having an enclosure **41** that encases U-shaped tubing **21** filled with the magnetocaloric material **28**. A plurality of baffles **56** may be spaced between the fluid inlet **72** and fluid outlet **74** of the enclosure **41**. This arrangement of baffles **56** guides the flow of transfer fluid **30** entering the fluid inlet **72** over a greater area of the U-shaped tubing **21** within the enclosure **41** as illustrated by fluid flow **51**, thereby providing a greater transfer rate of thermal energy between the magnetocaloric material **28** and the transfer fluid **30**.

[0043] Referring to FIGS. **14** and **15**, a sixth embodiment of the magnetic refrigeration system, designated **10**E, is illustrated. Magnetic refrigeration system **10**E replaces the brazed heat exchanger **12** of the other embodiment with a fluidized bed **17**, which allows direct contact between the magnetocaloric material **28** and the transfer fluid **30**. The fluidized bed **17**, which is formed to enable a solid-fluid mixture for improved heat transfer, includes a packed bed **64** that defines an opening **65** for inflow of transfer fluid **30** through the packed bed **64** from a fluid inlet **76** to a fluid outlet **78**. As the transfer fluid **30** enters the packed bed **64**, the magnetocaloric material **28** is mixed with the transfer fluid **30**. Membranes **66** contained inside the packed bed **64** prevents mixing of the magnetocaloric material **28** with the transfer fluid **30** so that the magnetocaloric material **28** does not become entrained with the transfer fluid **30** as the fluid **30** exits the fluidized bed **17**. The membranes **66** may be elastic or rigid bodies, such as strainers used in conventional refrigeration or plumbing system.

[0044] It should be understood from the foregoing that, while particular embodiments have been illustrated and described, various modifications can be made thereto without departing from the spirit and scope of the invention as will be apparent to those skilled in the art. Such changes and modifications are within the scope and teachings of this invention as defined in the claims appended hereto.

What is claimed is:

1. A magnetic refrigeration system comprising:

a transfer fluid that flows through a tubing in communication with a brazed heat exchanger, the brazed heat exchanger including alternating layers consisting of the tubing and a magnetocaloric material;

one or more electromagnets being operative for magnetizing and demagnetizing the magnetocaloric material, a controller device controls the operation of the one or more electromagnets such that the transfer fluid is heated in a first pass through the brazed heat exchanger when the magnetocaloric material is magnetized by the one or more electromagnets and cooled in a second pass through the brazed heat exchanger when the magnetocaloric material is demagnetized;

a warm heat exchanger in selective fluid flow communication with the brazed heat exchanger for transferring heat from the transfer fluid after the first pass of the transfer fluid through the brazed heat exchanger;

a cold heat exchanger cools a refrigerator cabinet when the transfer fluid flowing through the cold heat exchanger provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the brazed heat exchanger; and

a three-way valve for directing the flow of transfer fluid from the brazed heat exchanger to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration system is completed.

2. The magnetic refrigeration system of claim **1**, wherein the transfer fluid is water, a water-ethylene glycol mixture, or a helium gas.

3. The magnetic refrigeration system of claim **1**, further comprising:

a circulation pump for circulating fluid flow of the transfer fluid through the tubing;

4. The magnetic refrigeration system of claim **1**, wherein the magnetocaloric material generates a magnetocaloric effect when the one or more electromagnets magnetizes and demagnetizes the magnetocaloric material.

5. The magnetic refrigeration system of claim **1**, wherein the one or more electromagnets generate a magnetic field in the range of between 0.5-10 Tesla.

6. The magnetic refrigeration system of claim **1**, wherein the three-way valve is a solenoid valve.

7. The magnetic refrigeration system of claim **1**, wherein the three-way valve includes a cold fluidic outlet in selective fluid flow communication with the cold heat exchanger.

8. The magnetic refrigeration system of claim **1**, wherein the three-way valve includes a warm fluidic outlet in selective fluid flow communication with the warm heat exchanger.

9. The magnetic refrigeration system of claim **1**, further comprising at least one one-way valve for preventing flow of the transfer fluid directly from the warm heat exchanger to the cool heat exchanger

10. The magnetic refrigeration system of claim **1**, wherein the refrigeration cabinet is exposed to an outside ambient temperature.

11. The magnetic refrigeration system of claim **10**, wherein the ambient temperature is about 25 degrees Celsius.

12. The magnetic refrigeration system of claim **1**, wherein the transfer fluid is heated during the first pass to a temperature range of between 25.1-26.0 degrees Celsius.

13. The magnetic refrigeration system of claim **1**, wherein the transfer fluid is cooled during a second pass to a temperature range of between 24.0-24.9 degrees Celsius.

14. The magnetic refrigeration system of claim **1**, wherein the refrigeration cabinet is cooled down to a temperature range of between 19.0 to 23.0 degrees Celsius.

15. The magnetic refrigeration system of claim **1**, further comprising:

A timer/controller component for controlling the operation of the three-way valve such that either the warm fluidic outlet is in fluid flow communication with the warm heat exchanger or the cold fluidic outlet is in fluid flow communication with the warm heat exchanger.

16. A magnetic refrigeration system comprising:

a transfer fluid that flows through a tubing in communication with a brazed heat exchanger, the brazed heat exchanger including alternating layers of the tubing and a magnetocaloric foam, the magnetocaloric foam containing a magnetocaloric material;

one or more electromagnets being operative for magnetizing and demagnetizing the magnetocaloric material contained in the magnetocaloric foam, a controller device controls the operation of the one or more electromagnets such that the transfer fluid is heated in a first pass through the brazed heat exchanger when the magnetocaloric material in the magnetocaloric foam is magnetized by the one or more electromagnets and cooled in a second pass through the brazed heat exchanger when the magnetocaloric material in the magnetocaloric foam is demagnetized;

a circulation pump for circulating fluid flow of the transfer fluid through the tubing;

a warm heat exchanger in selective fluid flow communication with the brazed heat exchanger for transferring heat from the transfer fluid after the first pass of the transfer fluid through the brazed heat exchanger;

a cold heat exchanger cools a refrigerator cabinet when the transfer fluid flowing through the cold heat exchanger provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the brazed heat exchanger; and

a three-way valve for directing the flow of transfer fluid from the brazed heat exchanger to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration system is completed.

17. A magnetic refrigeration system comprising:

a transfer fluid that flows through a tubing in communication with a brazed heat exchanger, the brazed heat exchanger including an enclosure in communication with the tubing, the enclosure being filled with a magnetocaloric foam in which the transfer fluid flows through, the magnetocaloric foam containing a magnetocaloric material;

one or more electromagnets being operative for magnetizing and demagnetizing the magnetocaloric material contained in the magnetocaloric foam, a controller device controls the operation of the one or more electromagnets such that the transfer fluid is heated in a first pass through the brazed heat exchanger when the magnetocaloric material in the magnetocaloric foam is magnetized and cooled in a second pass through the brazed heat exchanger when the magnetocaloric material contained in the magnetocaloric foam is demagnetized;

a circulation pump for circulating fluid flow of the transfer fluid through the tubing;

a warm heat exchanger in selective fluid flow communication with the brazed heat exchanger for transferring heat from the transfer fluid after the first pass of the transfer fluid through the brazed heat exchanger;

a cold heat exchanger cools a refrigerator cabinet when transfer fluid flowing through the cold heat exchanger for provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the brazed heat exchanger; and

a three-way valve for directing the flow of transfer fluid from the brazed heat exchanger to either the warm heat exchanger during the first pass of transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration system is completed.

18. A magnetic refrigeration system comprising:

a transfer fluid that flows through a tubing in communication with a coaxial heat exchanger, the coaxial heat exchanger including tubing defining an inner tube surrounded by an outer tube, wherein the outer tube is filled with a transfer fluid and the inner tube is filled with a magnetocaloric material;

one or more electromagnets being operative for magnetizing and demagnetizing the magnetocaloric material, a controller device controls the operation of the one or more electromagnets such that the transfer fluid is heated in a first pass through the coaxial heat exchanger when the magnetocaloric material is magnetized by the one or more electromagnets and cooled in a second pass through the coaxial heat exchanger when the magnetocaloric material is demagnetized;

a circulation pump for circulating fluid flow of the transfer fluid through the tubing;

a warm heat exchanger in selective fluid flow communication with the coaxial heat exchanger for transferring heat from the transfer fluid after the first pass of the transfer fluid through the coaxial heat exchanger;

a cold heat exchanger cools a refrigerator cabinet when the transfer fluid flowing through the cold heat exchanger provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the coaxial heat exchanger; and

a three-way valve for directing the flow of transfer fluid from the coaxial heat exchanger to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration is completed.

19. A magnetic refrigeration system comprising:

a transfer fluid that flows through a tubing in communication with a U-tube heat exchanger, the U-tube heat exchanger including an enclosure that encases U-shaped tubing filled with a magnetocaloric material, a plurality of baffles being spaced within the enclosure to guide the flow of transfer fluid through the U-tube heat exchanger;

one or more electromagnets being operative for magnetizing and demagnetizing the magnetocaloric material, a controller controls the operation of the one or more electromagnets such that the transfer fluid is heated in a first pass through the U-tube heat exchanger when the magnetocaloric material is magnetized by the one or more electromagnets and cooled in a second pass through the U-tube heat exchanger when the magnetocaloric material is demagnetized;

a circulation pump for circulating fluid flow of the transfer fluid through the tubing;

a warm heat exchanger in selective fluid flow communication with the U-tube heat exchanger for transferring heat from the transfer fluid after the first pass of the transfer fluid through the U-tube heat exchanger;

a cold heat exchanger cools a refrigerator cabinet when the transfer fluid flowing through the cold heat exchanger provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the U-tube heat exchangers; and

a three-way valve for directing the flow of transfer fluid from the U-tube heat exchanger to either the warm heat exchanger during the first pass of the transfer fluid or the cold heat exchanger during the second pass of the transfer fluid as one cycle of the magnetic refrigeration system is completed.

20. A magnetic refrigeration system comprising:

a transfer fluid, that flows through a tubing in communication with a fluidized bed, the fluidized bed including a packed bed in communication with the tubing, the packed bed including membranes and a magnetocaloric material for mixing with the transfer fluid as the transfer fluid flows through the pack bed;

one or more electromagnets being operative for magnetizing and demagnetizing the magnetocaloric material; controls the operation of the one or more electromagnets such that the transfer fluid is heated in a first pass through the fluidized bed when the magnetocaloric material is magnetized by the one or more electromagnets and cooled in a second pass through the fluidized bed when the magnetocaloric material is demagnetized;

a circulation pump for circulating fluid flow of the transfer fluid through the tubing;

a warm heat exchanger in selective fluid flow communication with the fluidized bed for transferring heat from the transfer fluid after the first pass of the transfer fluid through the fluidized bed;

a cold heat exchanger cools with a refrigerator cabinet when the transfer flowing through the fluidized bed provides a cooling effect to the interior of the refrigerator cabinet after the second pass of the transfer fluid through the fluidized bed; and

a three-way valve for directing the flow of transfer fluid from the fluidized bed to either the warm heat exchanger or the cold heat exchanger after the second pass of the transfer fluid as one cycle of the magnetic refrigeration is completed.

* * * * *