



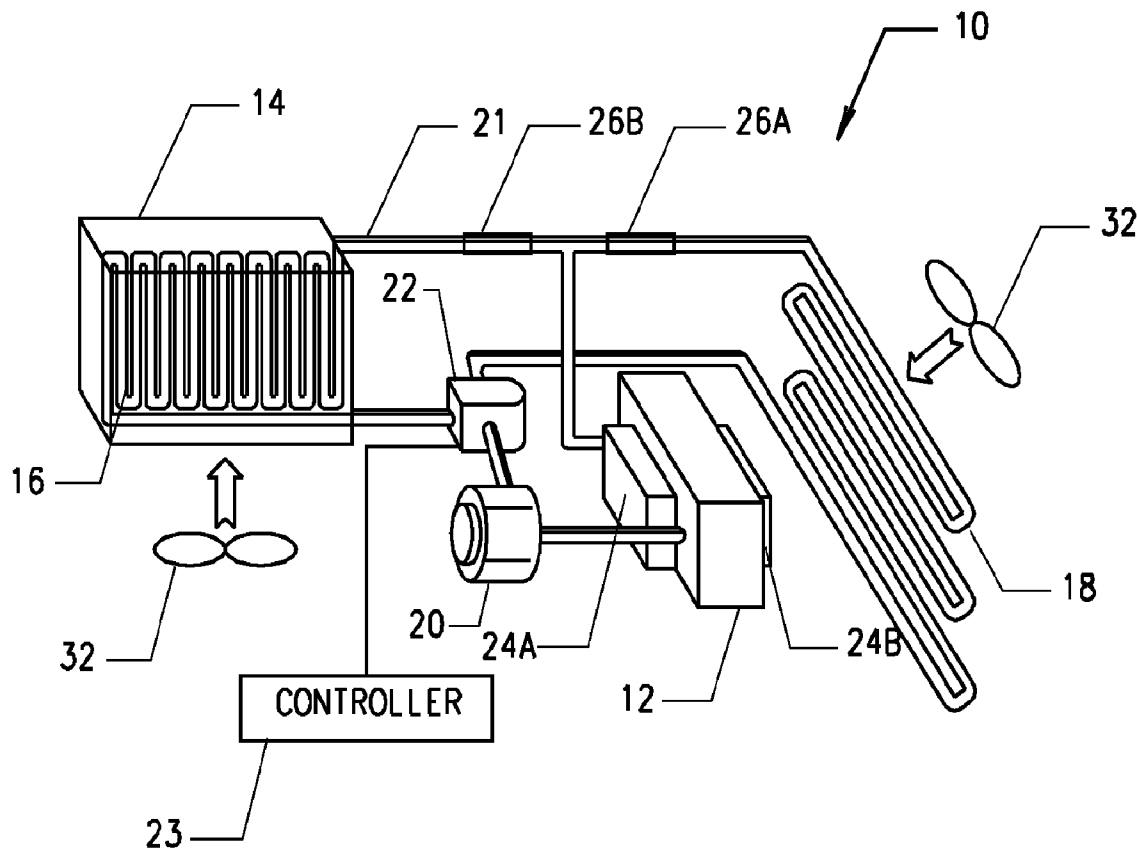
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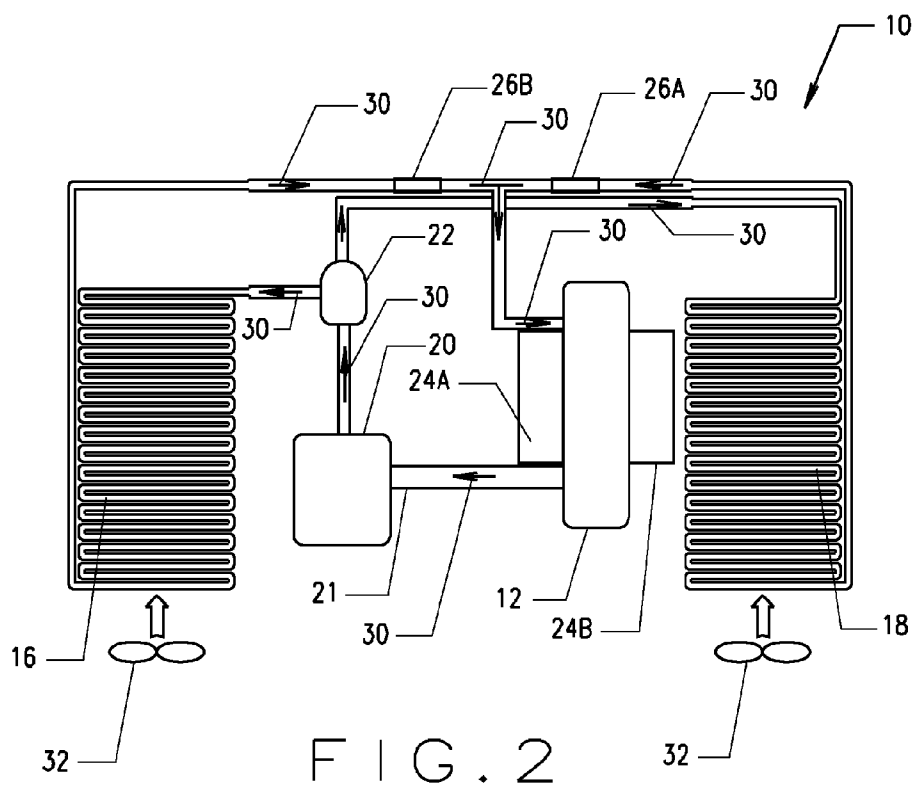
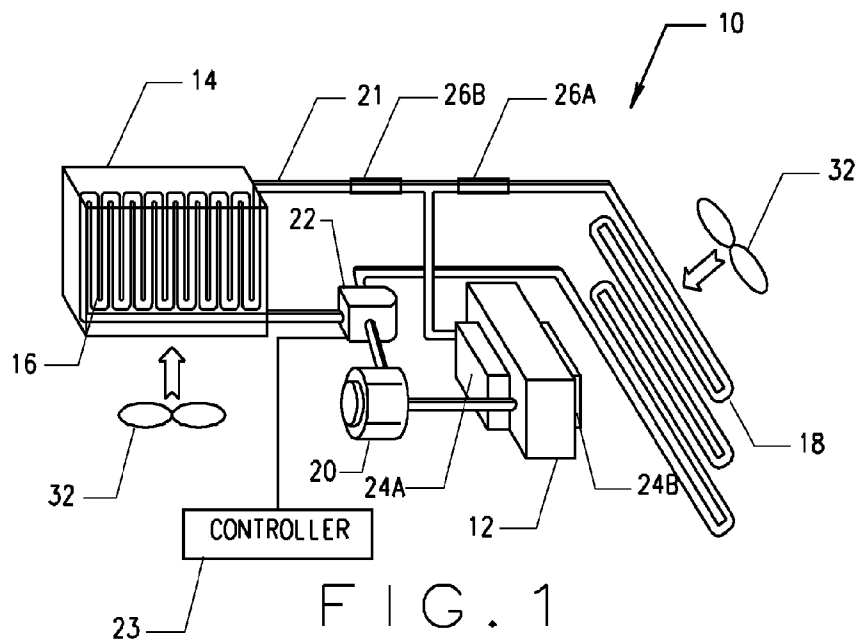
(19) **United States**(12) **Patent Application Publication**
Celik et al.(10) **Pub. No.: US 2012/0222428 A1**(43) **Pub. Date: Sep. 6, 2012**(54) **COMBINED-LOOP MAGNETIC
REFRIGERATION SYSTEM****Publication Classification**(51) **Int. Cl.**
F25B 21/00 (2006.01)(52) **U.S. Cl.** 62/3.1(57) **ABSTRACT**

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 exchanger in which the magnetocaloric material is demagnetized for further cooling of the cooled transfer fluid.

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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**

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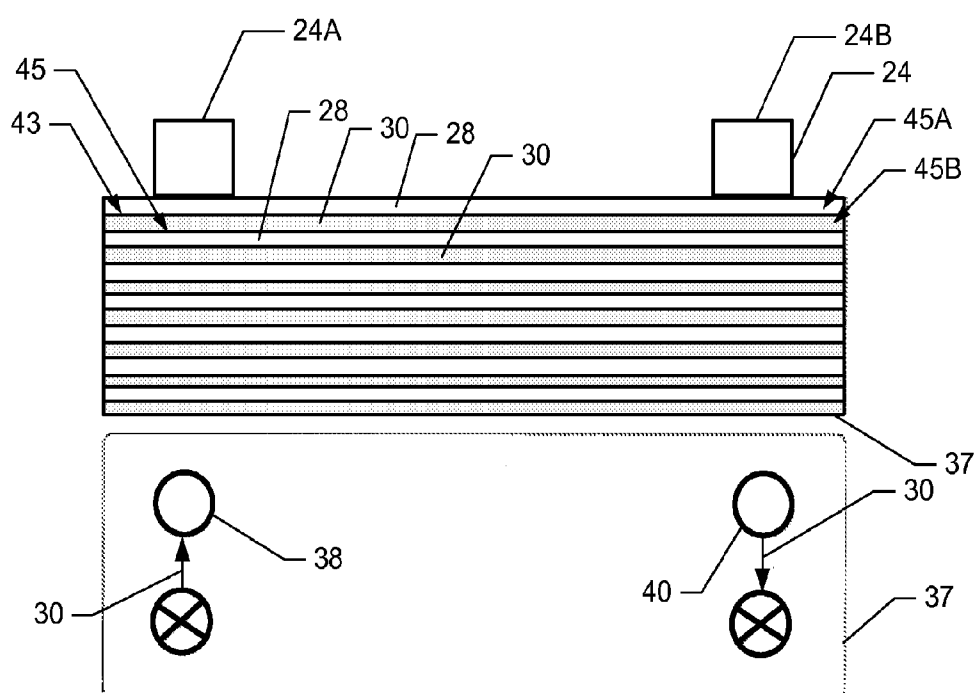


FIG. 3

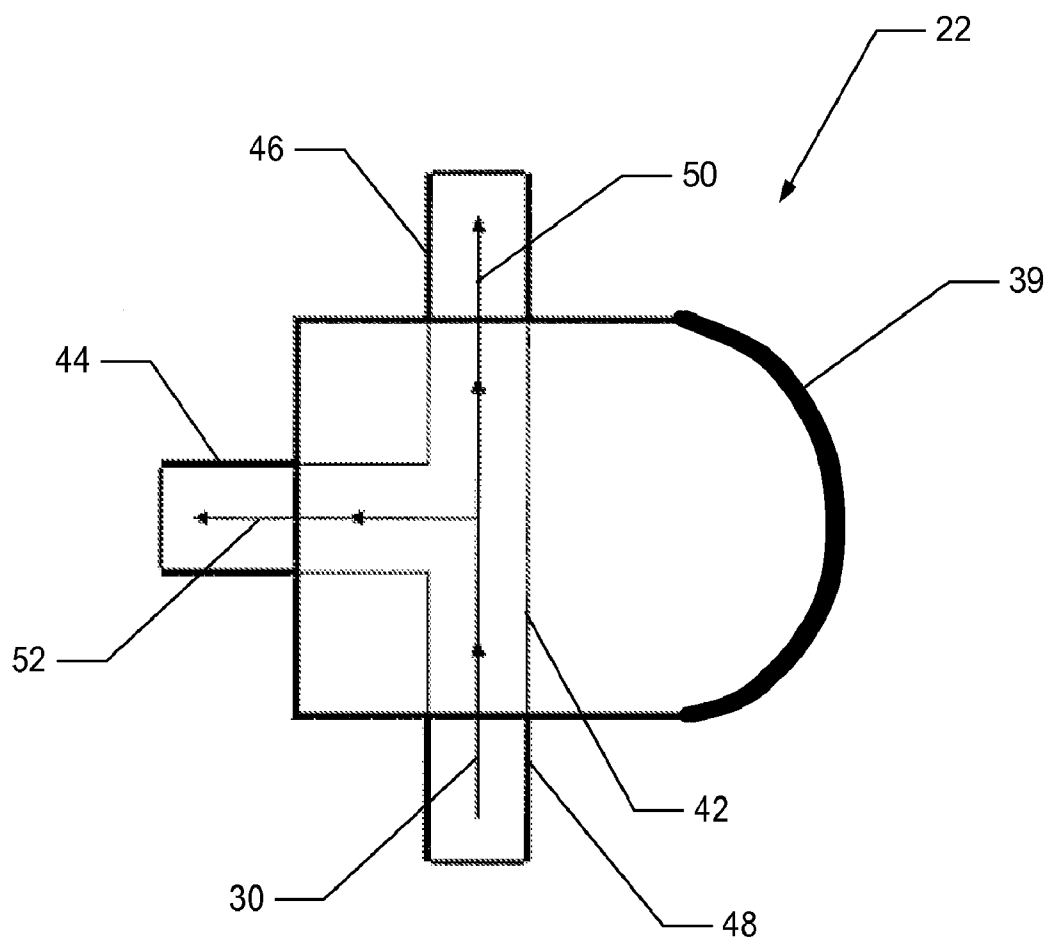


FIG. 4

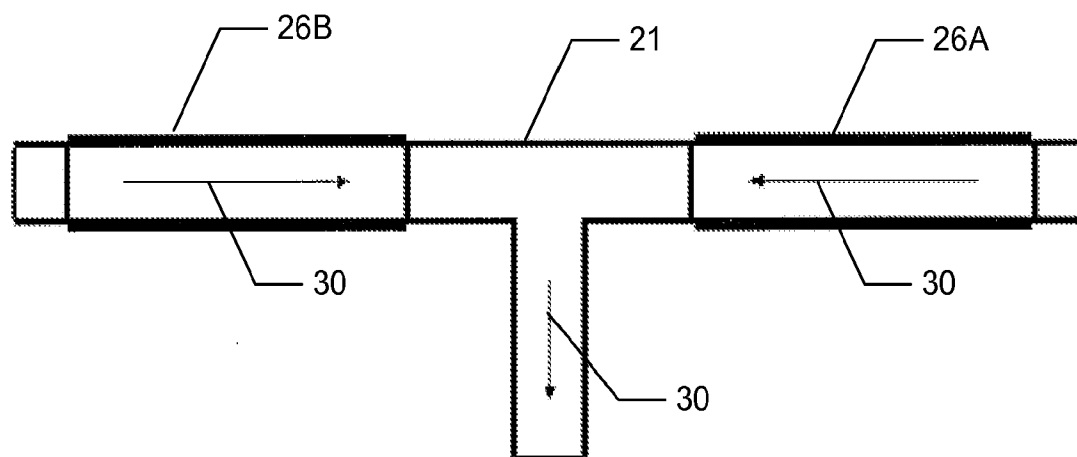


FIG. 5

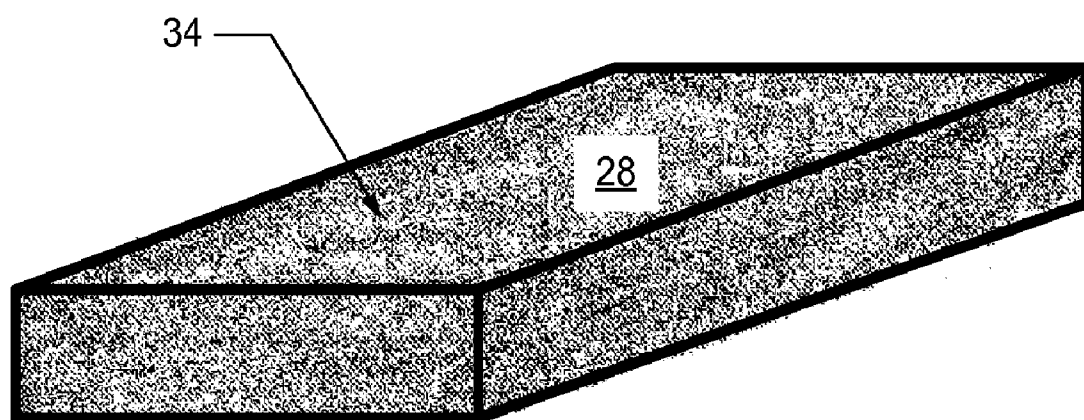
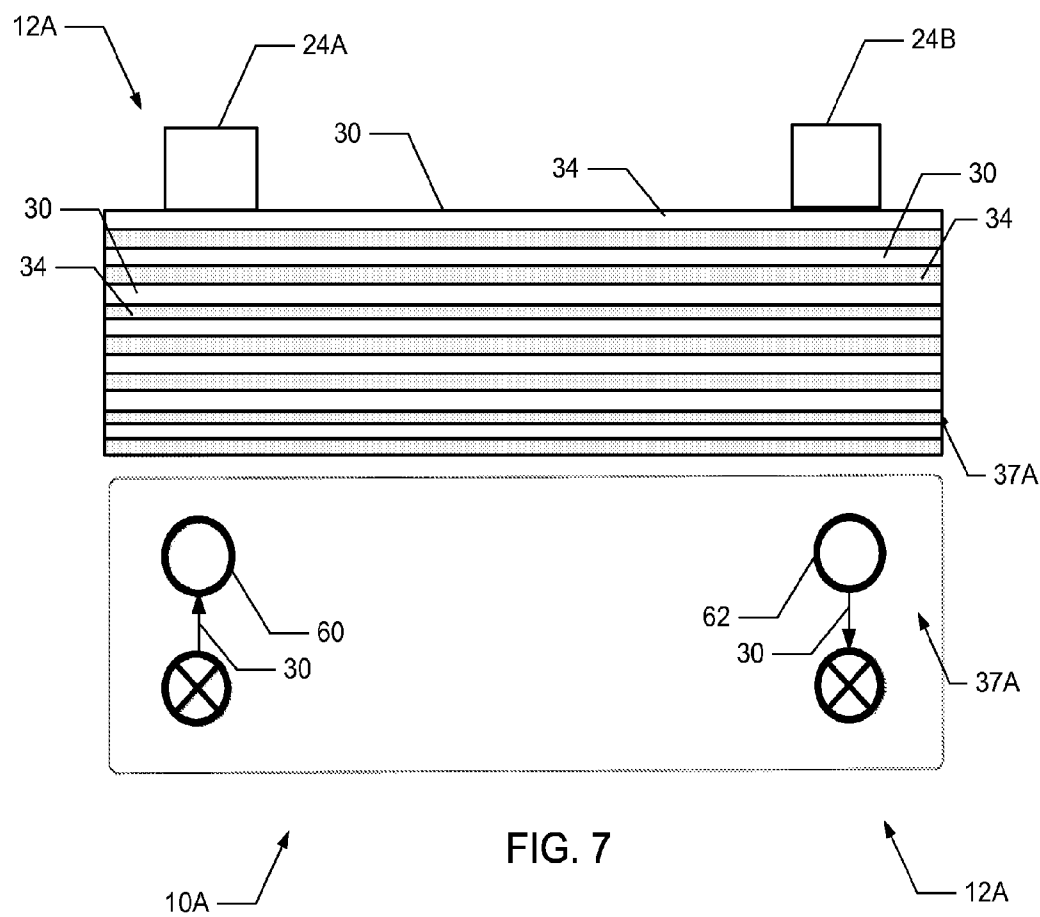


FIG. 6



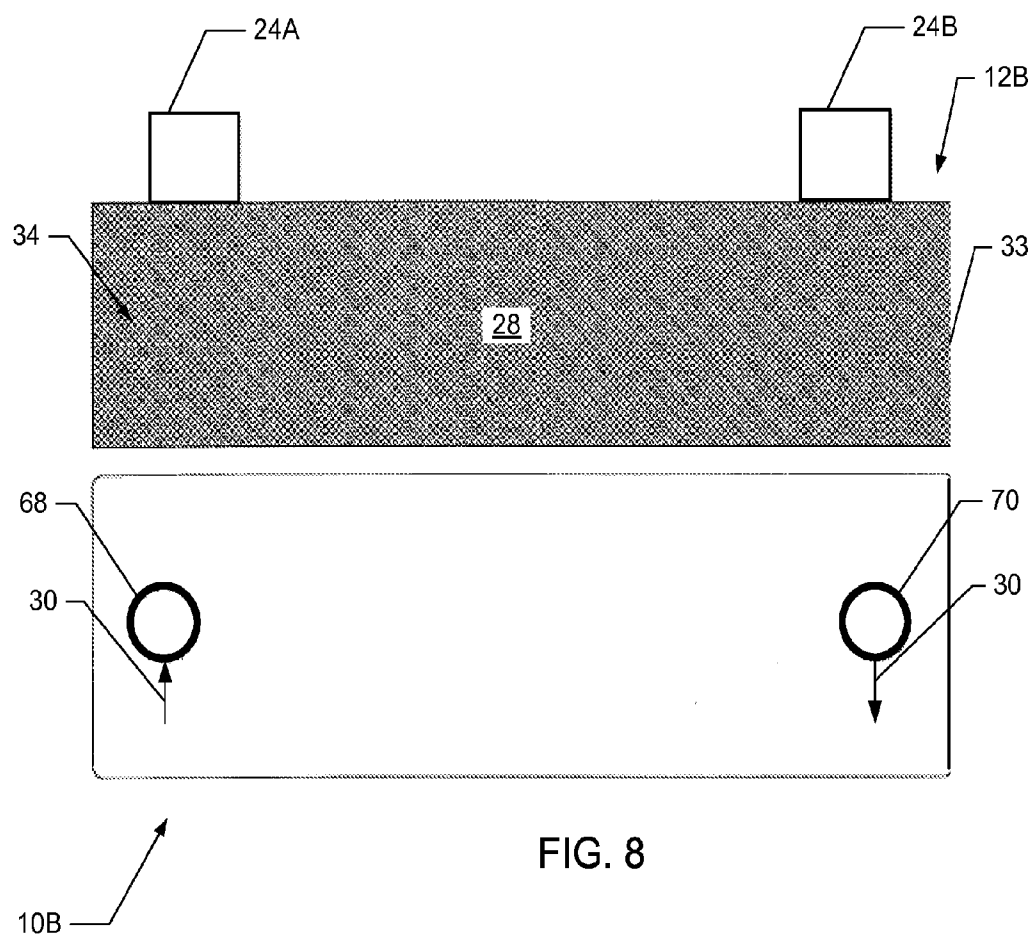


FIG. 8

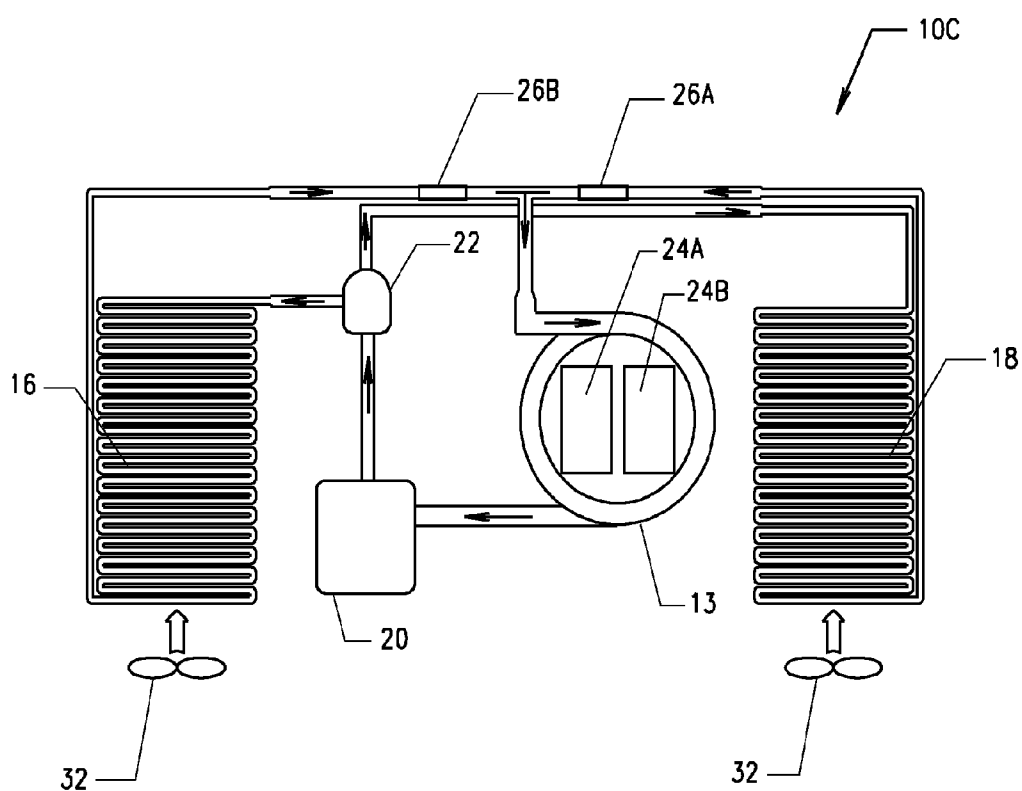


FIG. 9

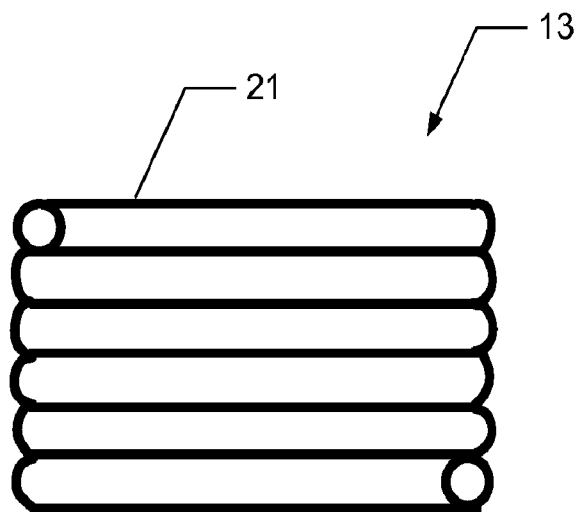


FIG. 10

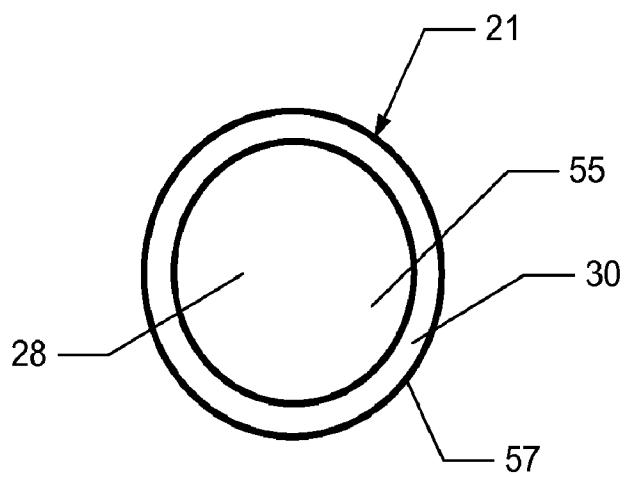


FIG. 10A

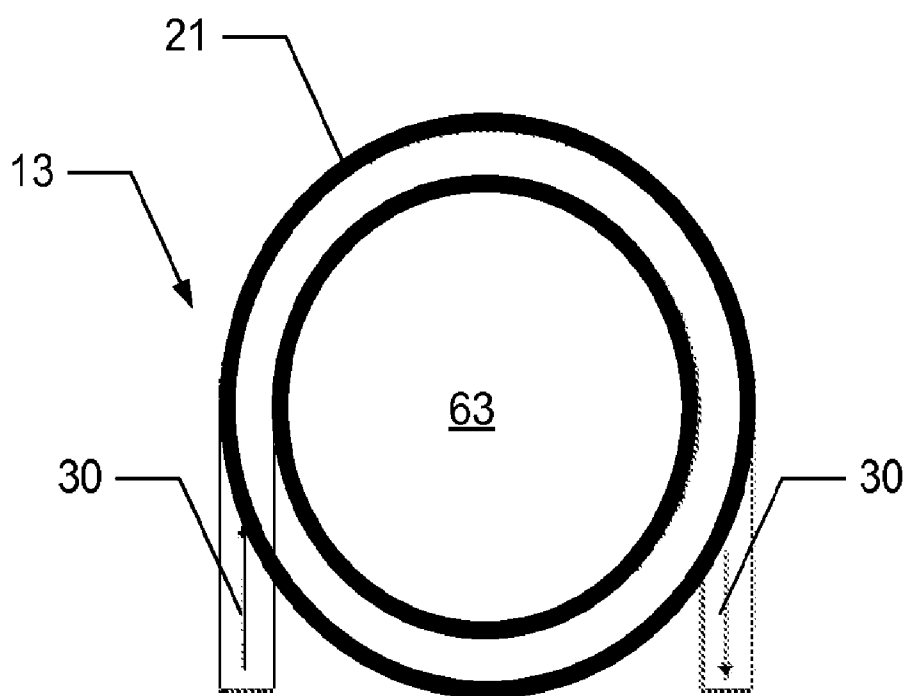
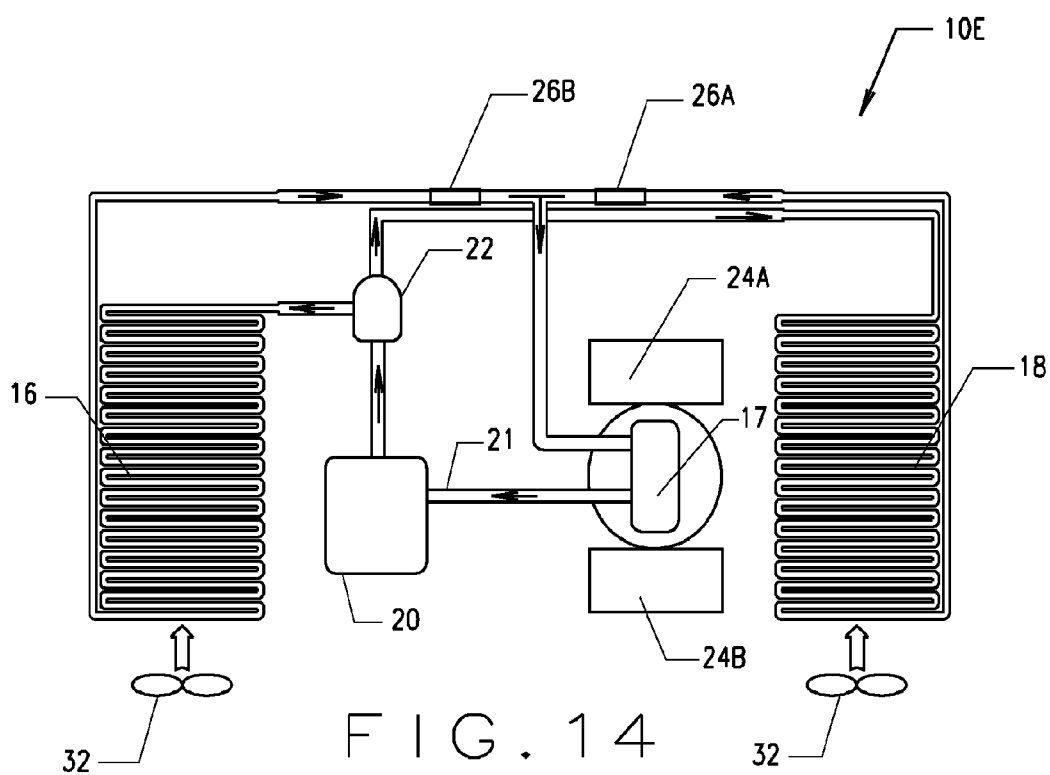
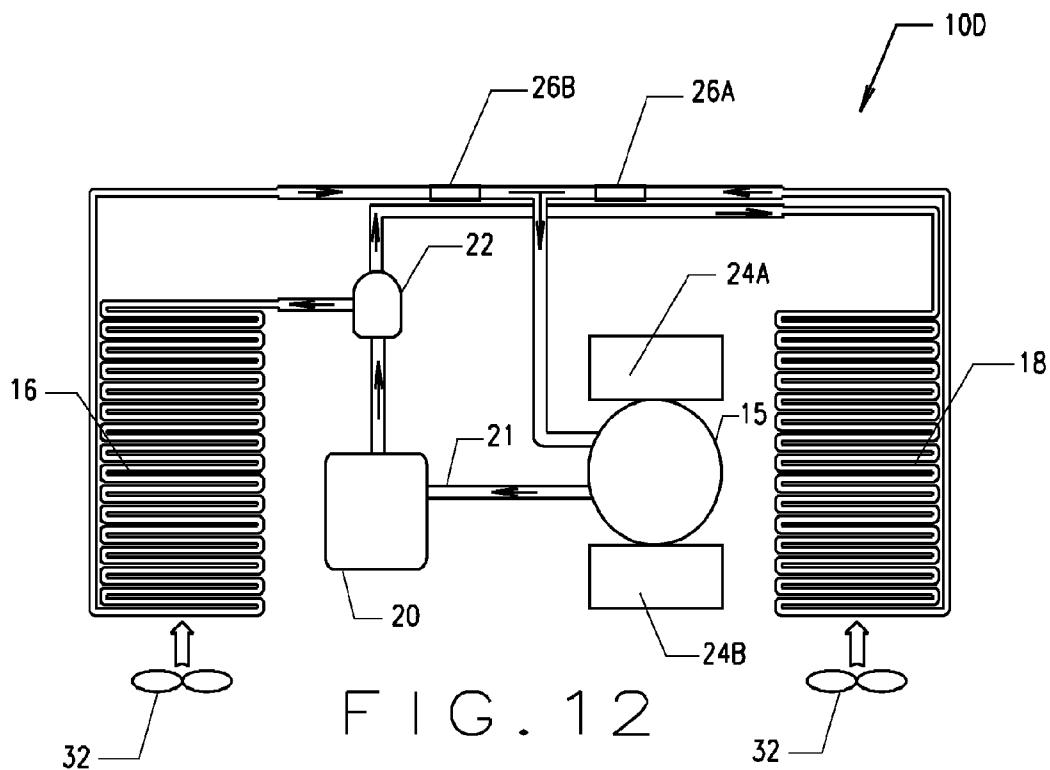


FIG. 11



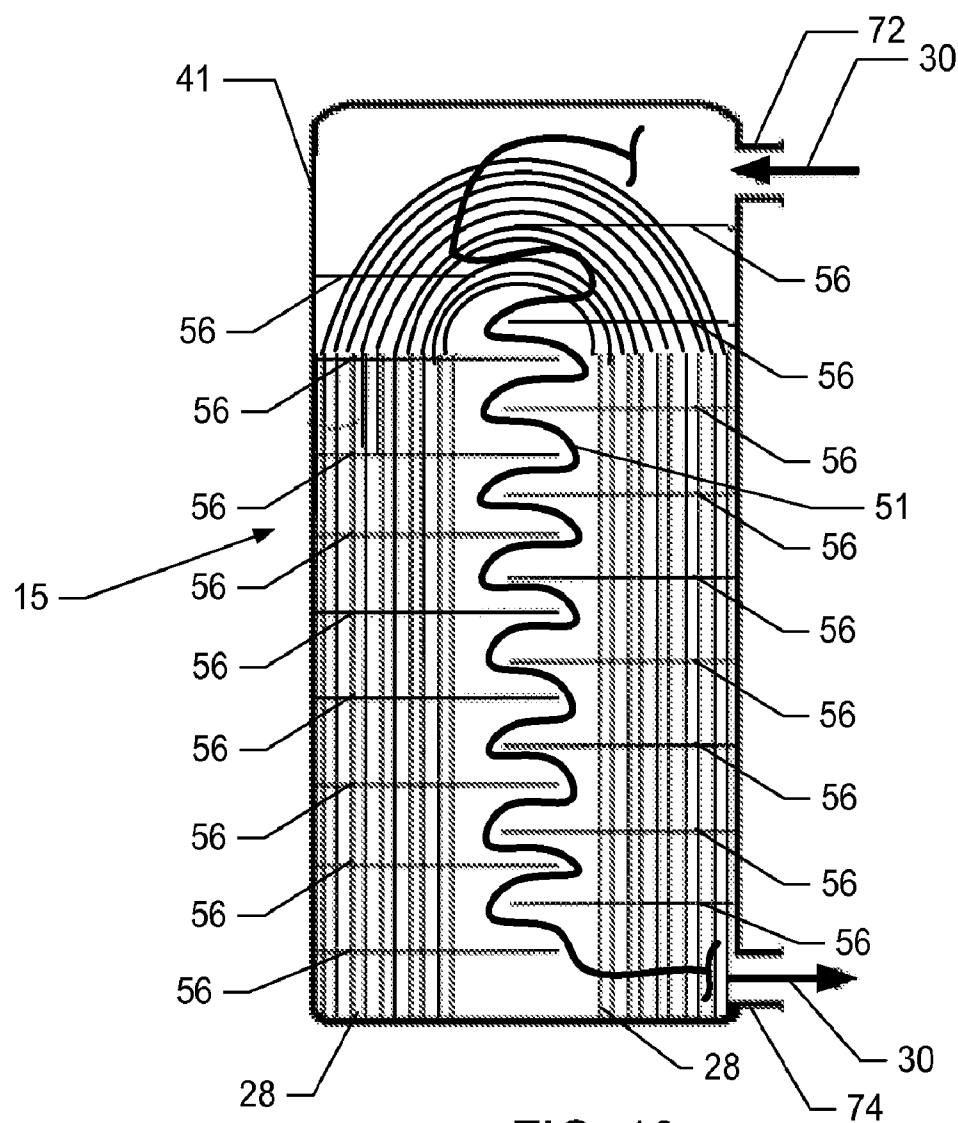


FIG. 13

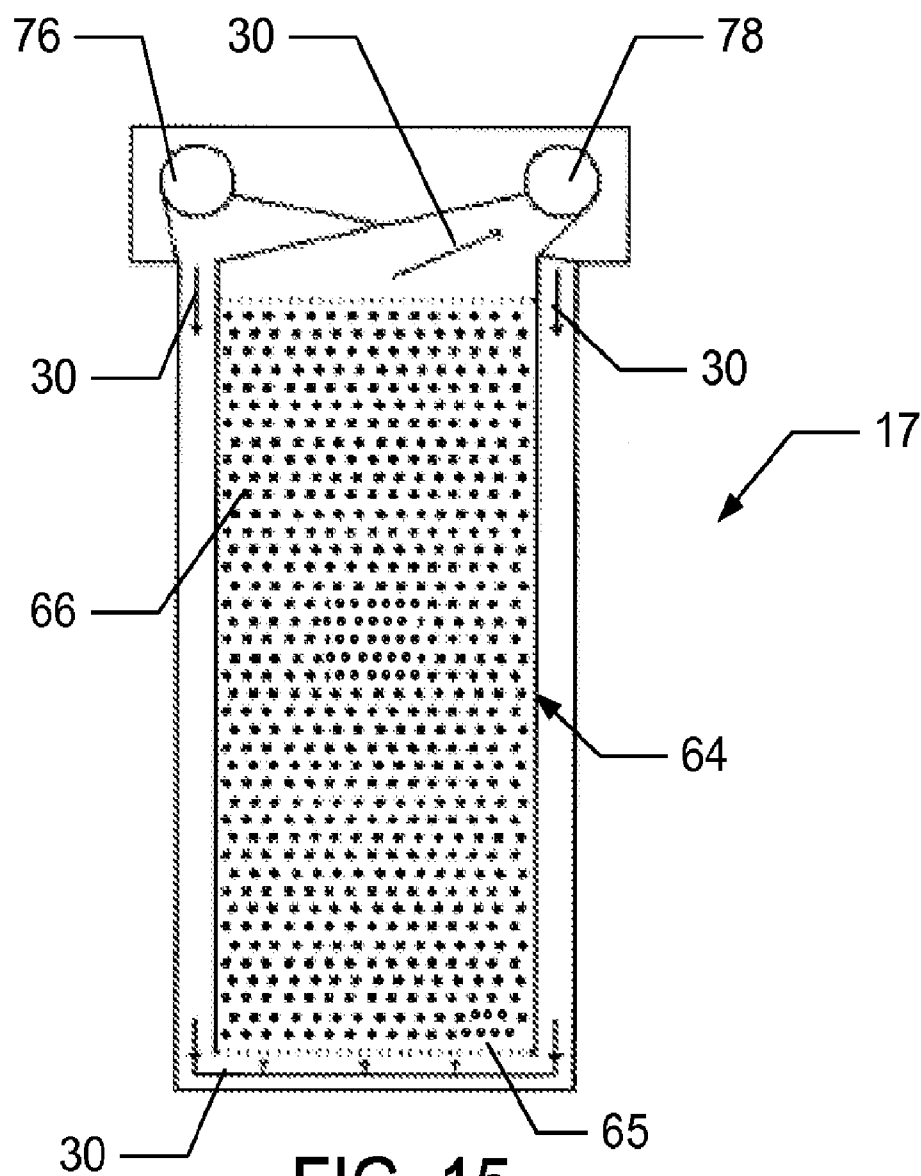


FIG. 15

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 45A and 45B throughout the brazed heat exchanger 12. As shown in FIG. 3, alternate channels 45A each include a magnetocaloric material 28 and respective alternating channels 45B are adapted for flow of the transfer fluid 30 through each channel 45B 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 electro-

magnets, 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 24A and 24B 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 24A and 24B are activated and deactivated by the magnetic refrigeration system 10. The magnetocaloric material 28 contained in each channel 45A of the brazed heat exchanger 12 is heated up to a predetermined temperature when the pair of electromagnets 24A and 24B 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 45A radiates and is transferred to the transfer fluid 30 flowing inside adjacent alternating channels 45B 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 26A 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 26B 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 12 during the second pass with the electromagnets 24A and 24B 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 26B 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 10A, is illustrated. Magnetic refrigeration system 10A is substantially similar to the first embodiment of the magnetic refrigeration system 10; however, magnetic refrigeration system 10A includes a brazed heat exchanger 12A 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 12A 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 12A includes a body 37A 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 12A communicates with an inlet 60 and an outlet 62 for the ingress and egress of transfer fluid 30 through the heat exchanger 12A. A pair of electromagnets 24A and 24B is positioned on opposite sides of the body 37A 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 10B, is illustrated. Magnetic refrigeration system 10B is substantially similar to the first embodiment of the magnetic refrigeration system 10 with the exception that a brazed heat exchanger 12B 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 12B may include one or more fluid inlets 68 for the ingress of transfer fluid 30 into the brazed heat exchanger 12B and one or more fluid outlets 70 for the egress of transfer fluid 30 from the brazed heat exchanger 12B. 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 24A and 24B 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 10C, is illustrated. Magnetic refrigeration system 10C 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 24A and 24B 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 10D, is illustrated. Magnetic refrigeration system 10D 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 10E, is illustrated. Magnetic refrigeration system 10E 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 cold 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 con-

tained 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 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.

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