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(54) REFRIGERATION APPARATUS AND METHOD

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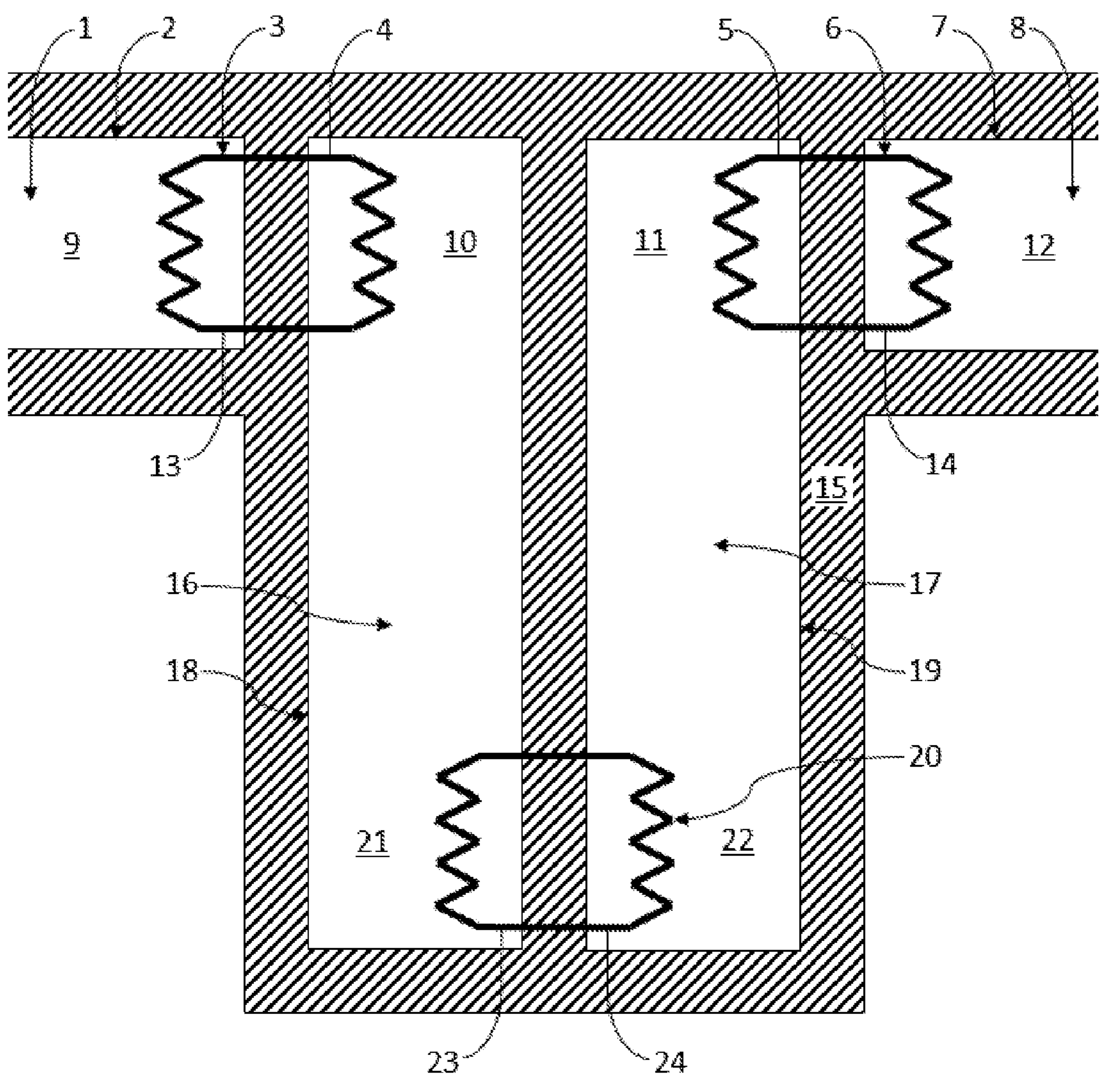
CPC *F24H 7/04* (2013.01); *F24V 50/00* (2018.05)

(57) **ABSTRACT**

A heat exchange system includes a first reservoir having a first and second point and a first thermal material contained in the first reservoir. A first thermal contact is thermally coupled with the second point. Application of a force to the first thermal material can result in a temperature difference between the first and second points.



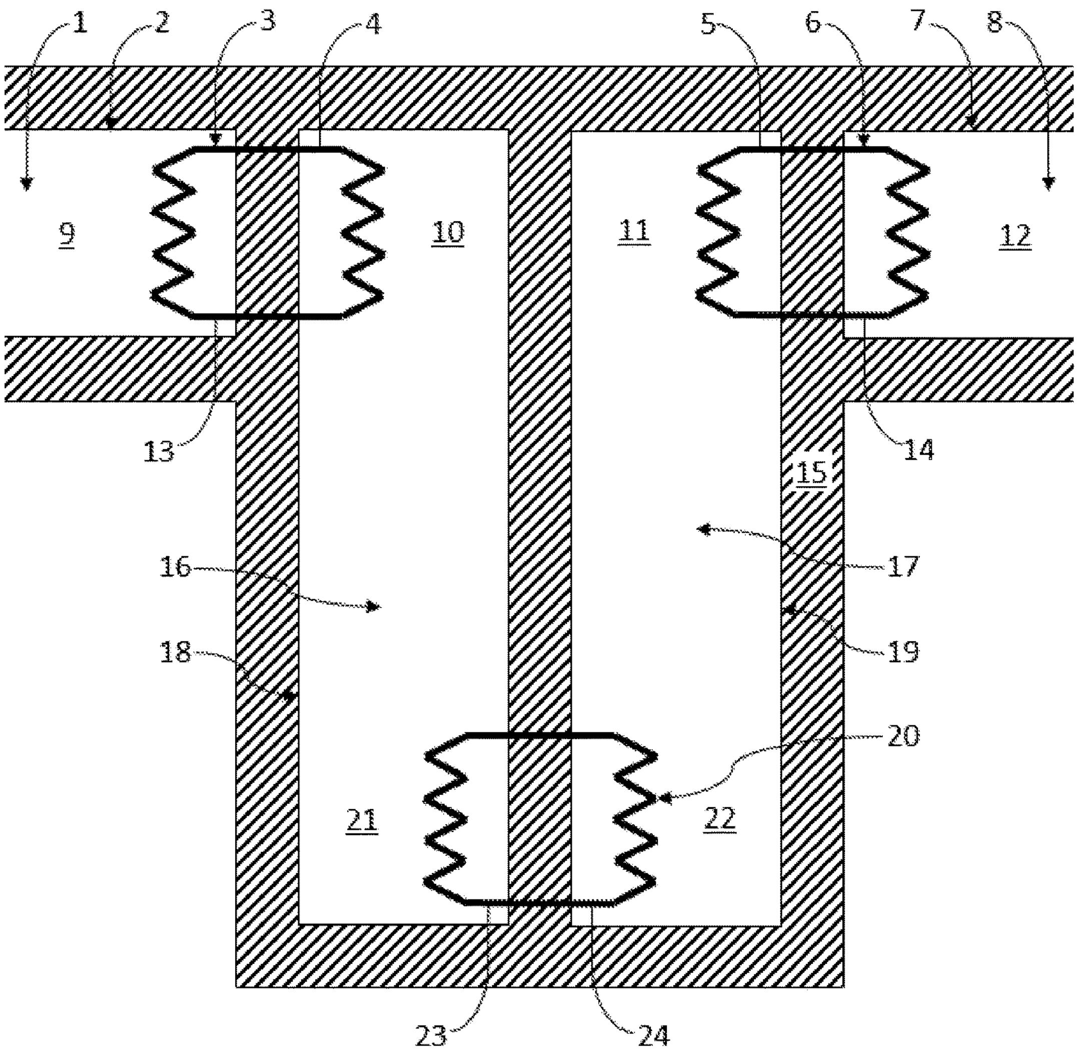


FIG. 1

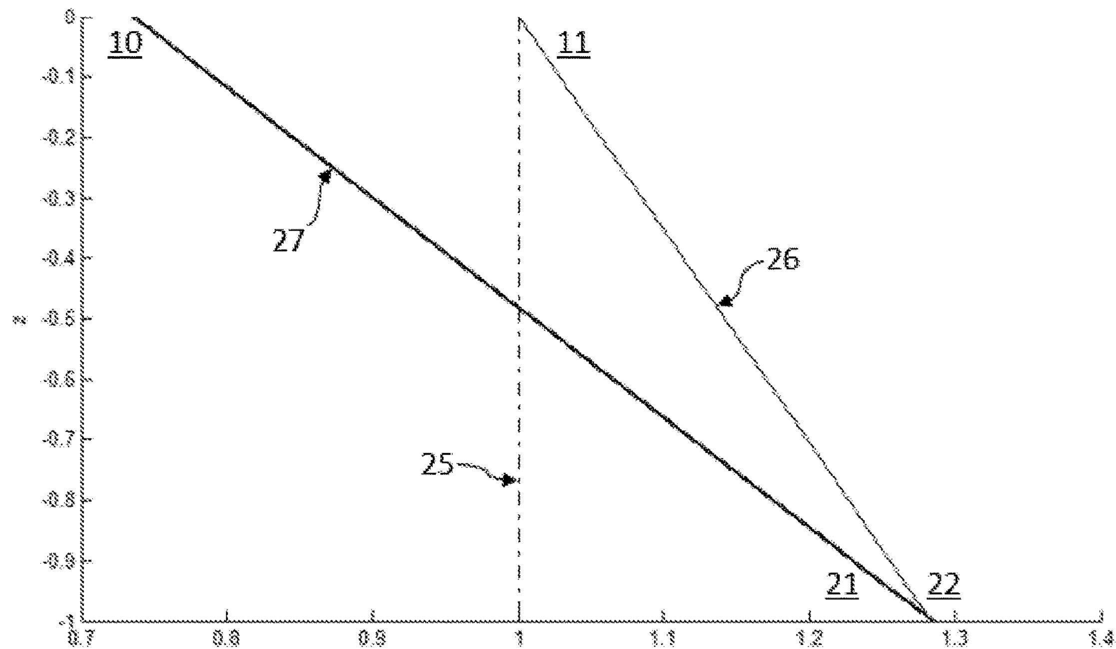

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FIG. 2

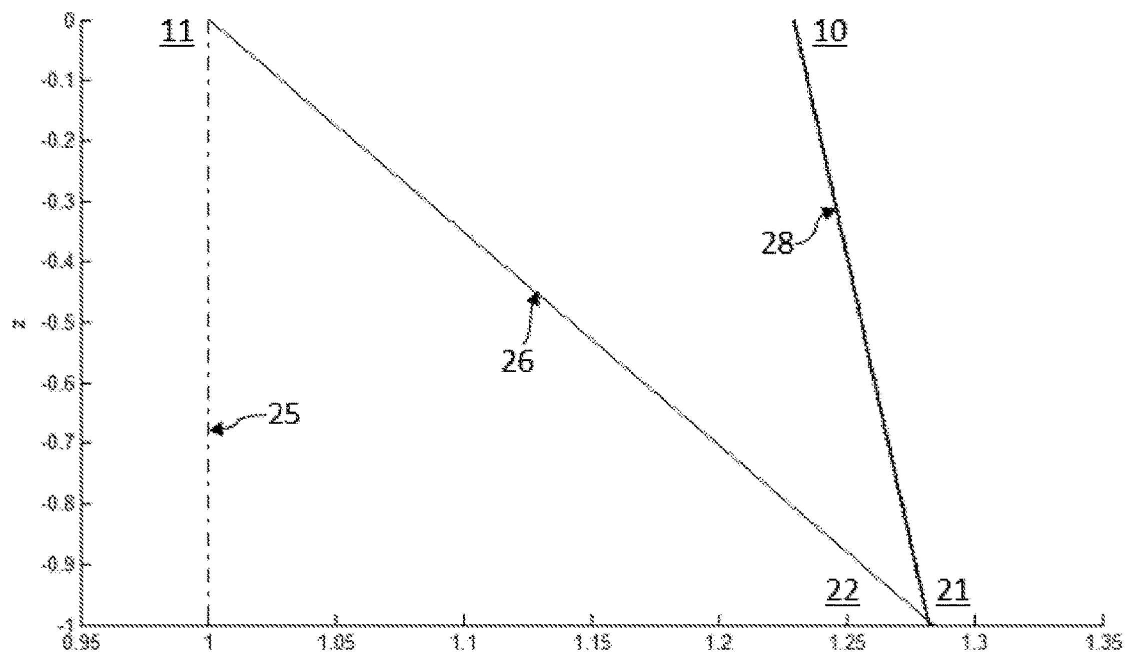
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FIG. 3

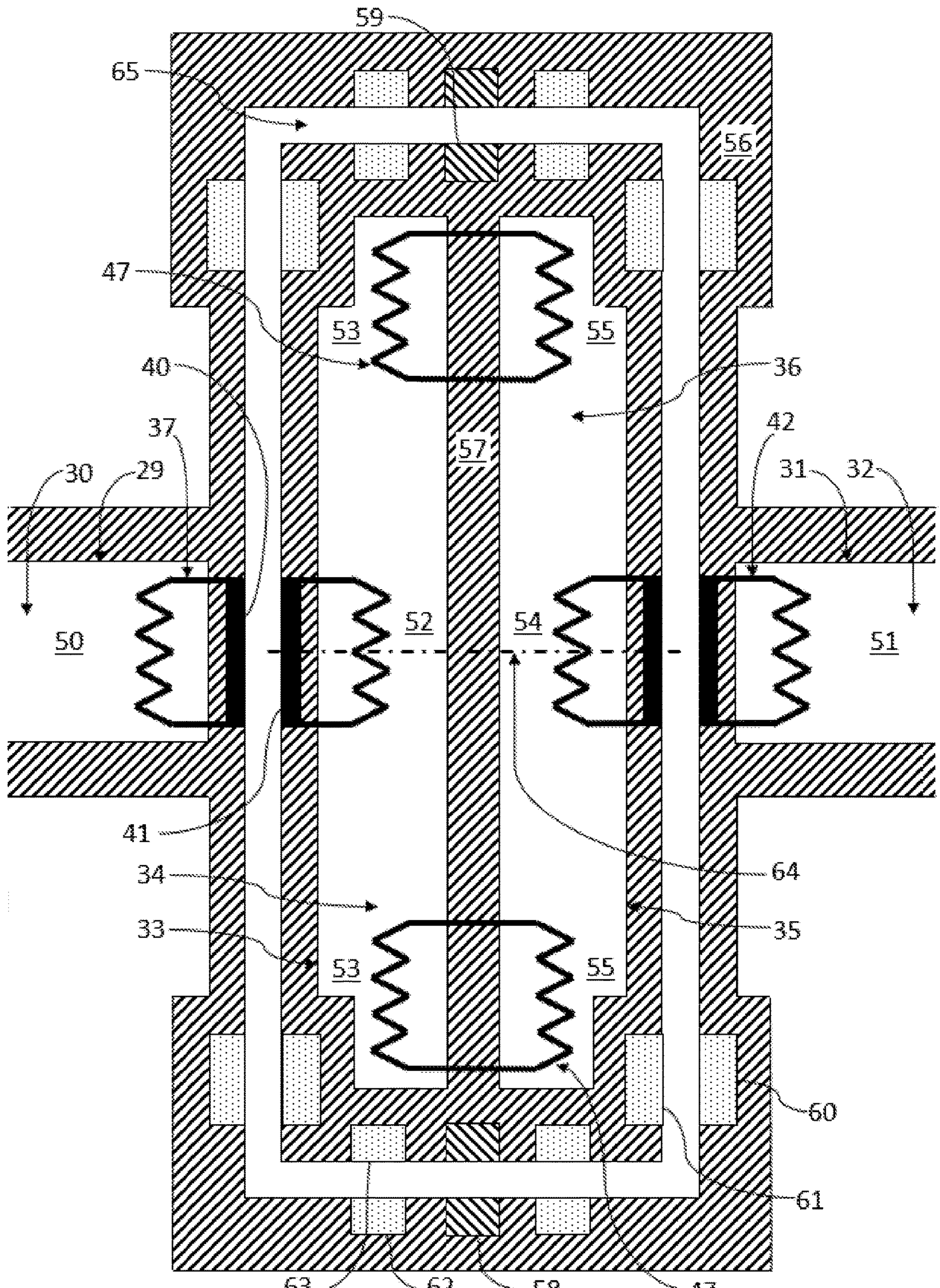
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FIG. 4

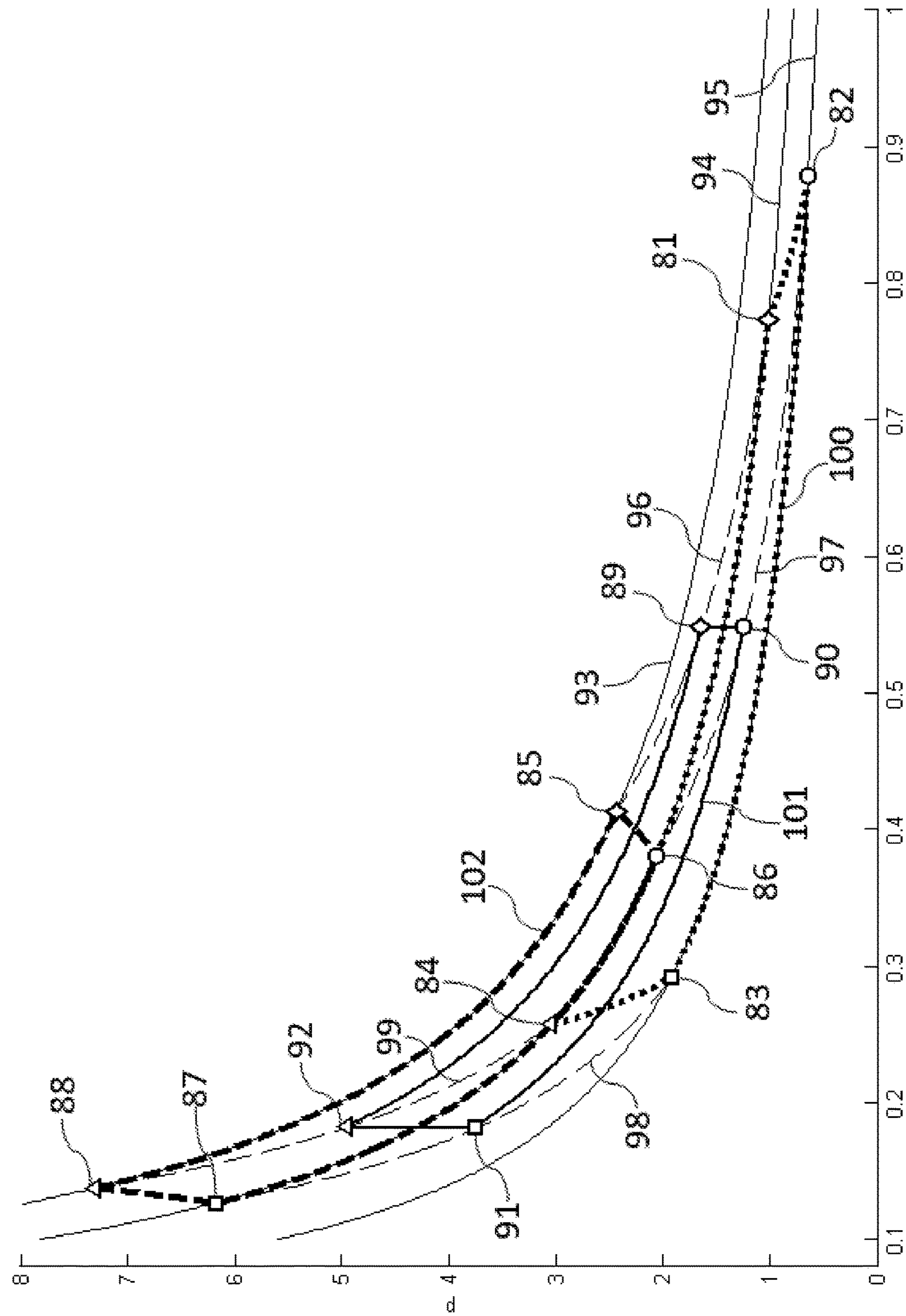
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FIG. 5

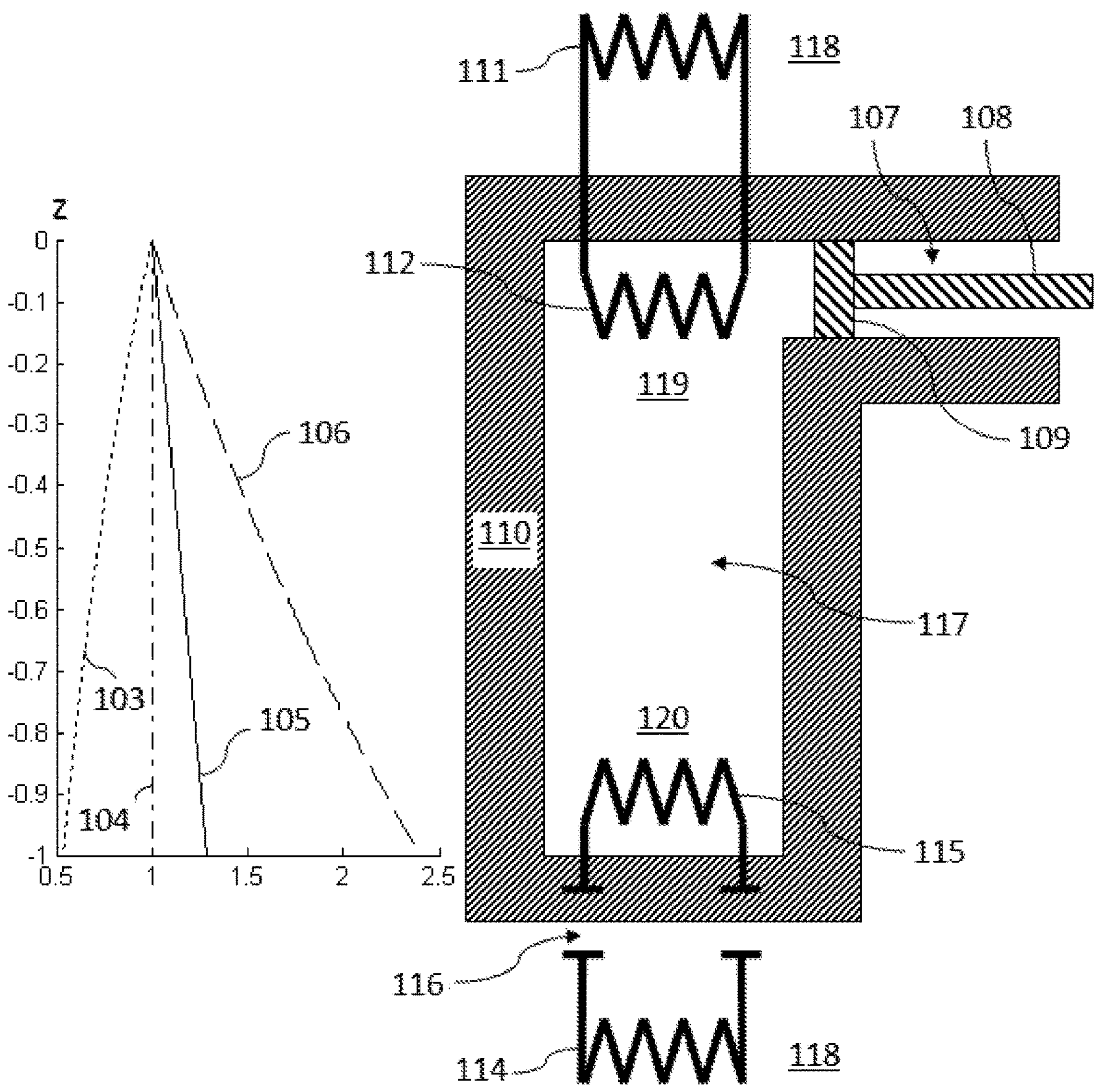
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FIG. 6A

FIG. 6B

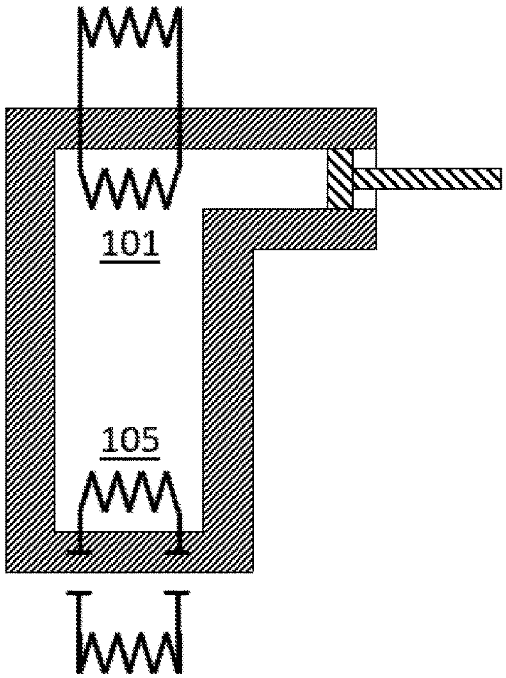

FIG. 7A

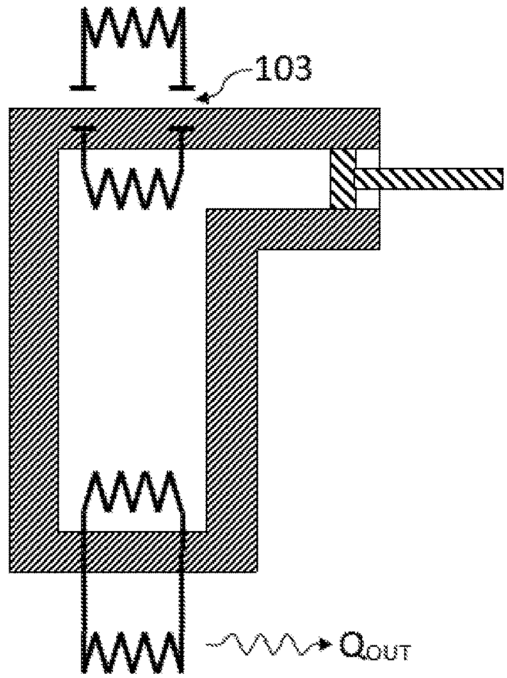

FIG. 7B

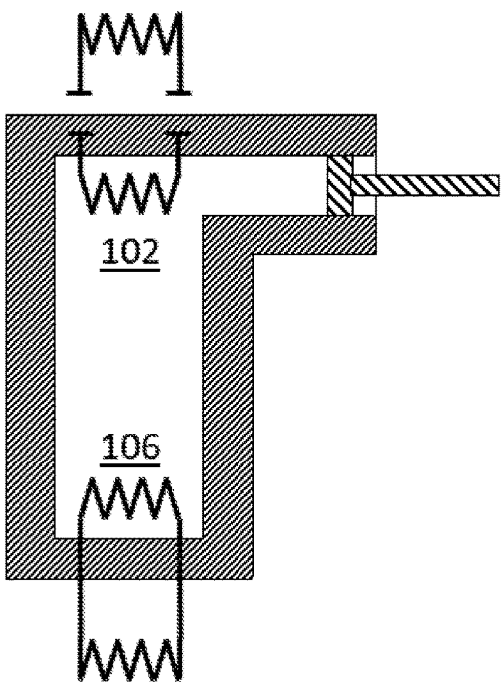

FIG. 7C

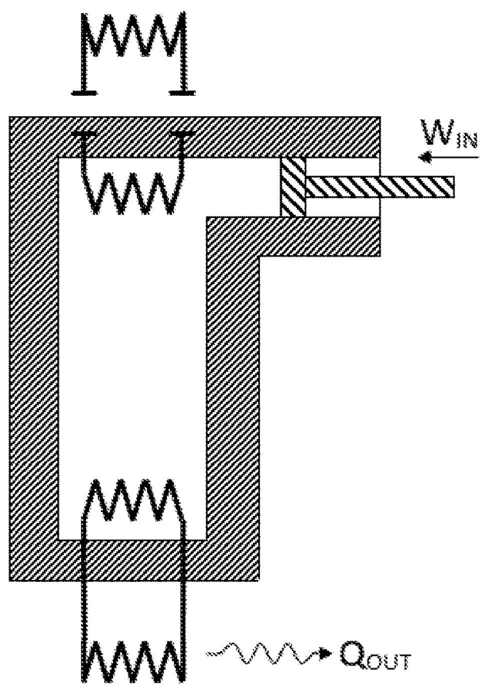

FIG. 7D

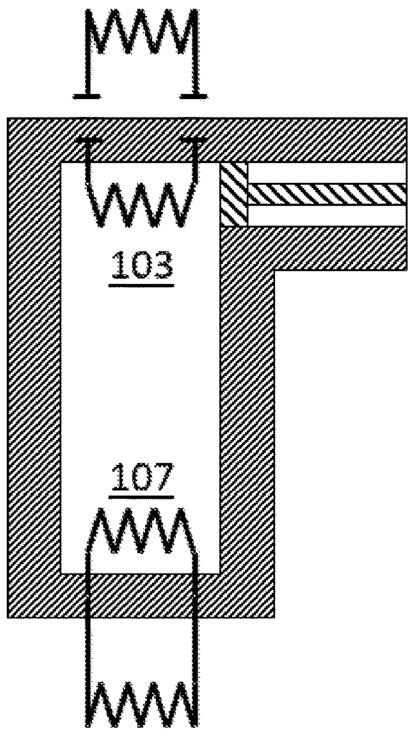

FIG. 7E

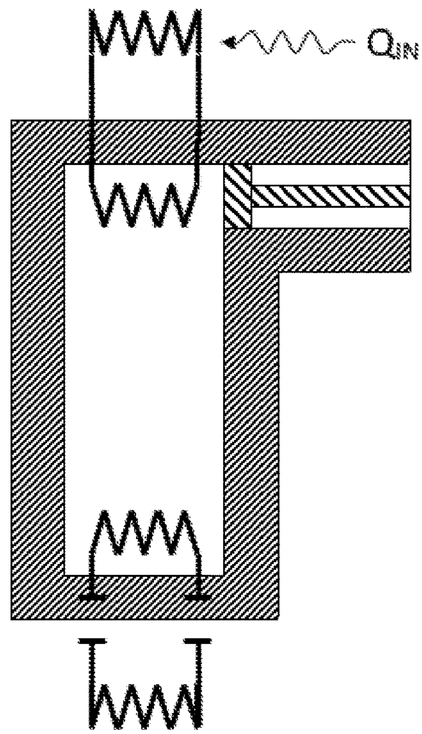

FIG. 7F

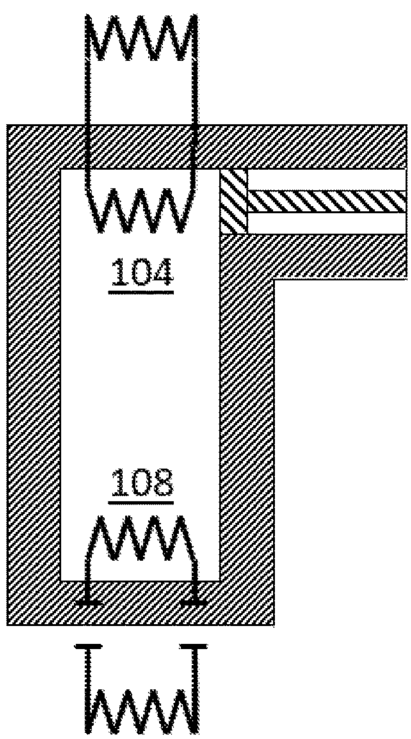

FIG. 7G

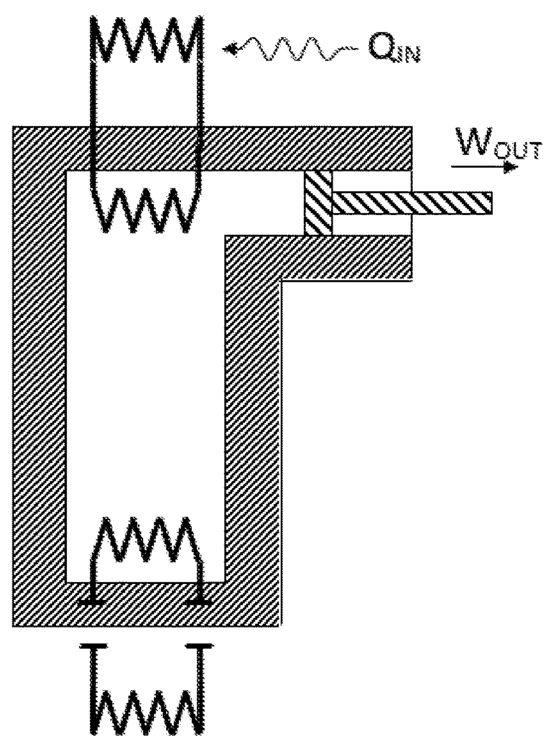

FIG. 7H

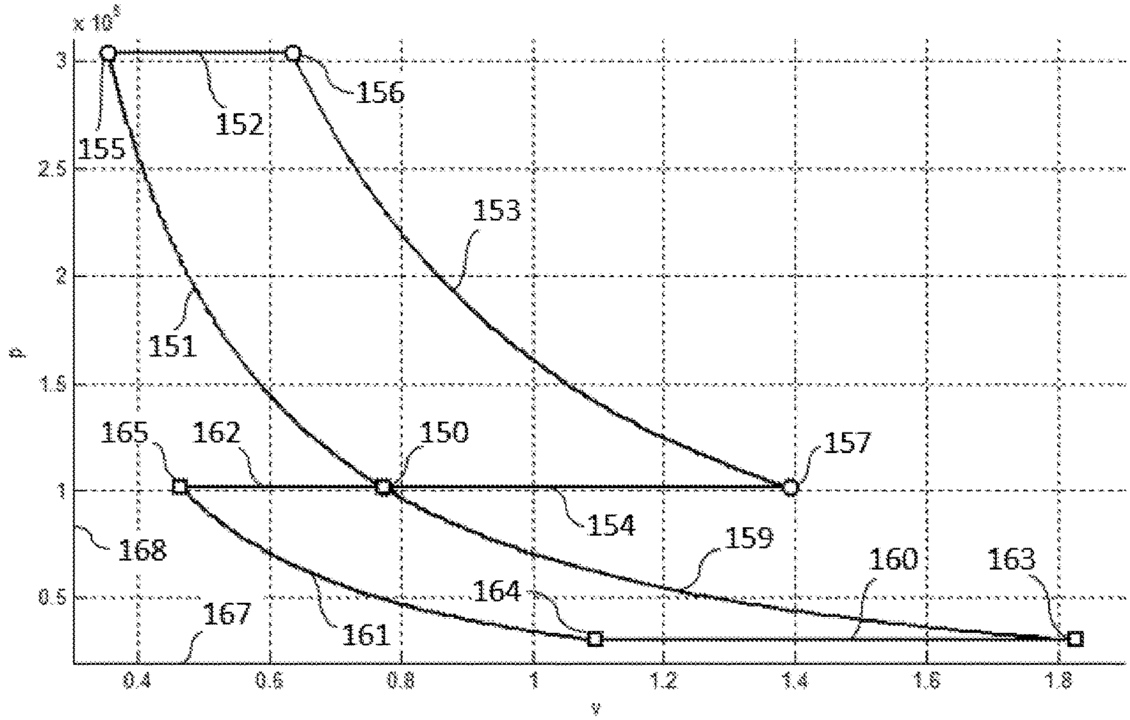
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FIG. 8

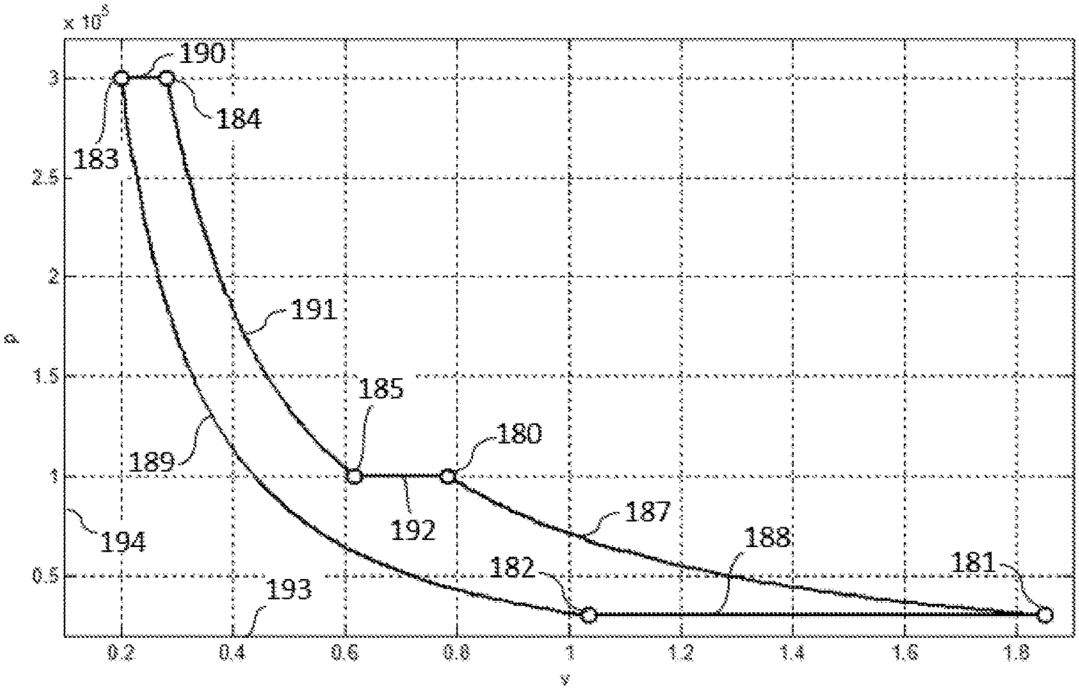
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FIG. 9

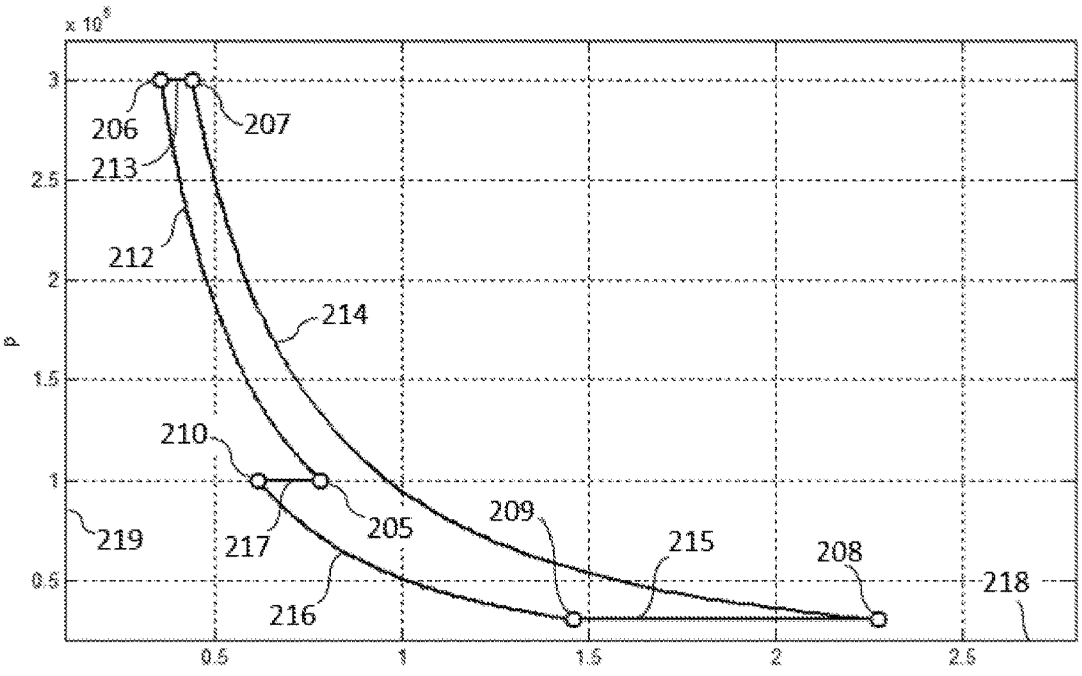
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FIG. 10

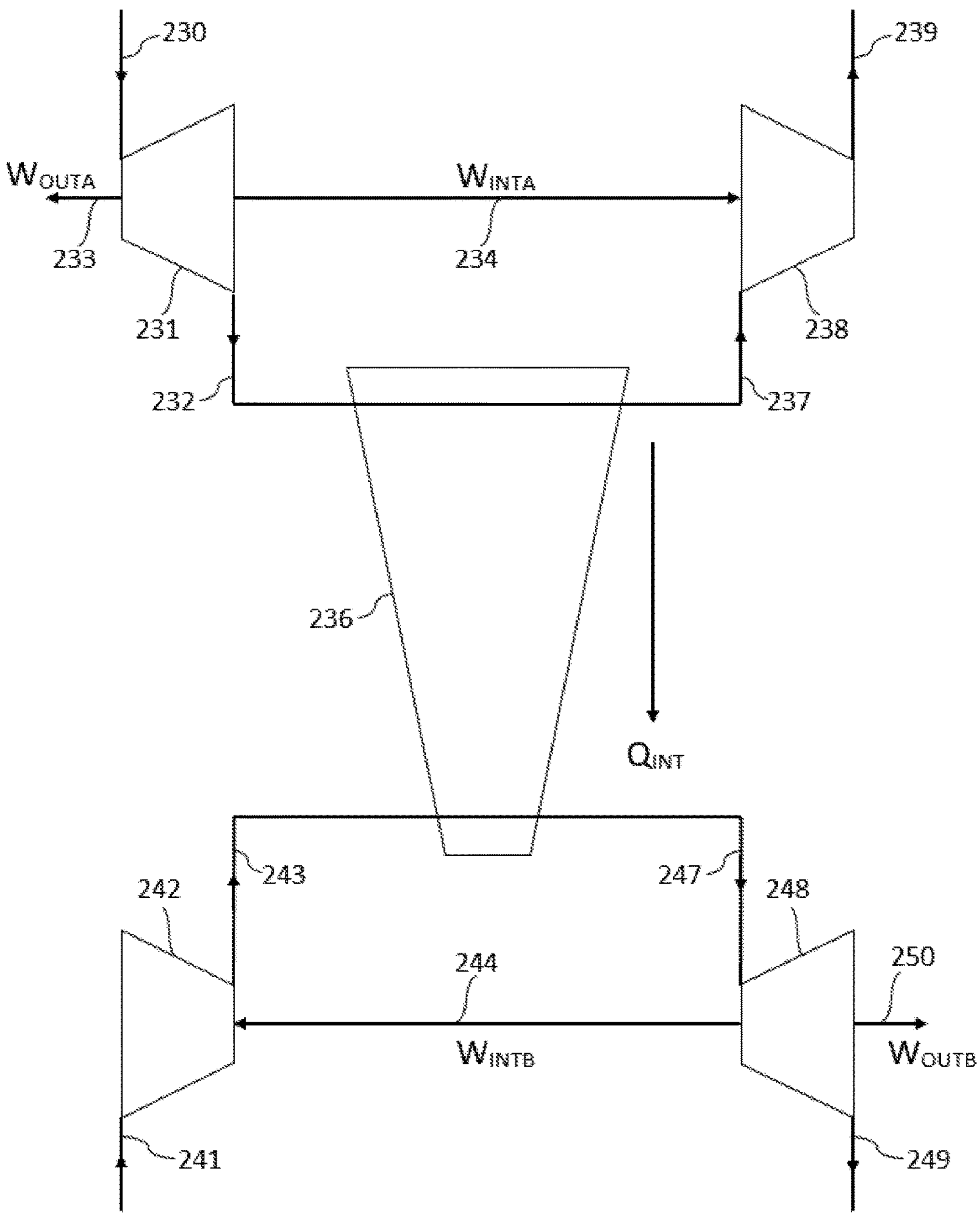
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FIG. 11

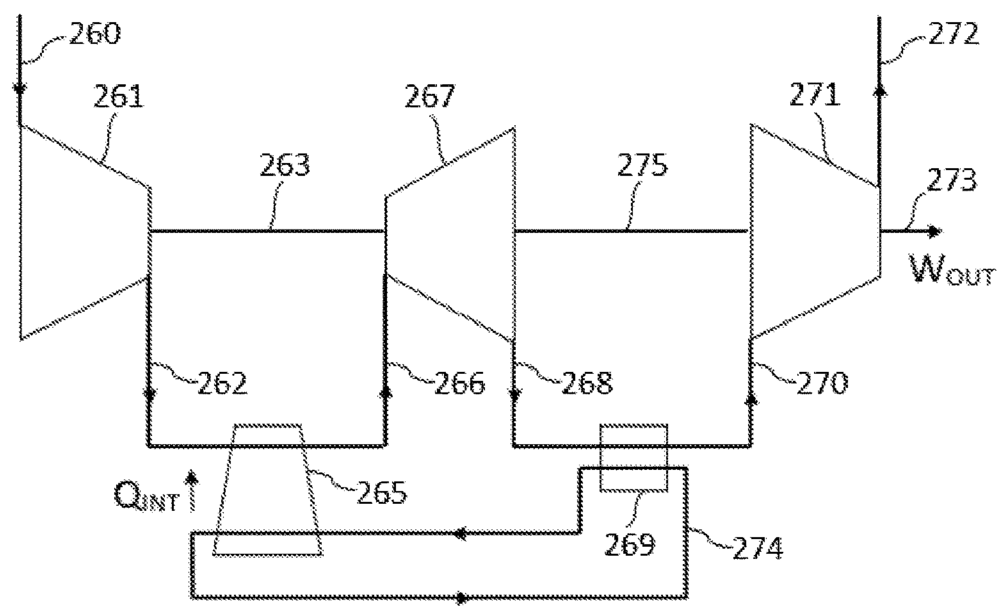
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FIG. 12

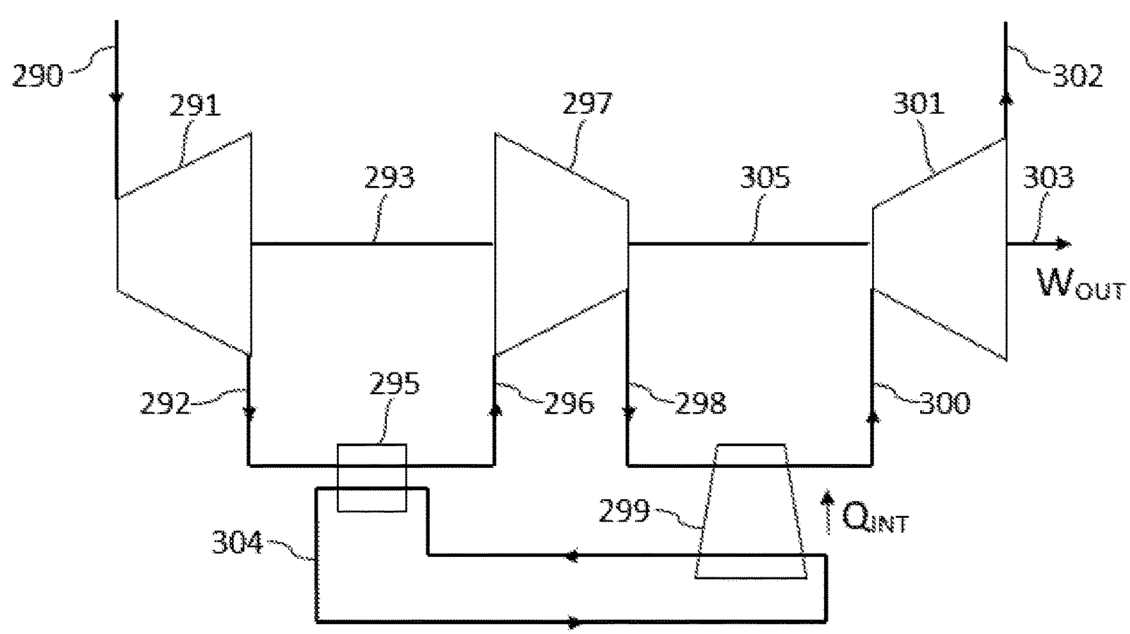
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FIG. 13

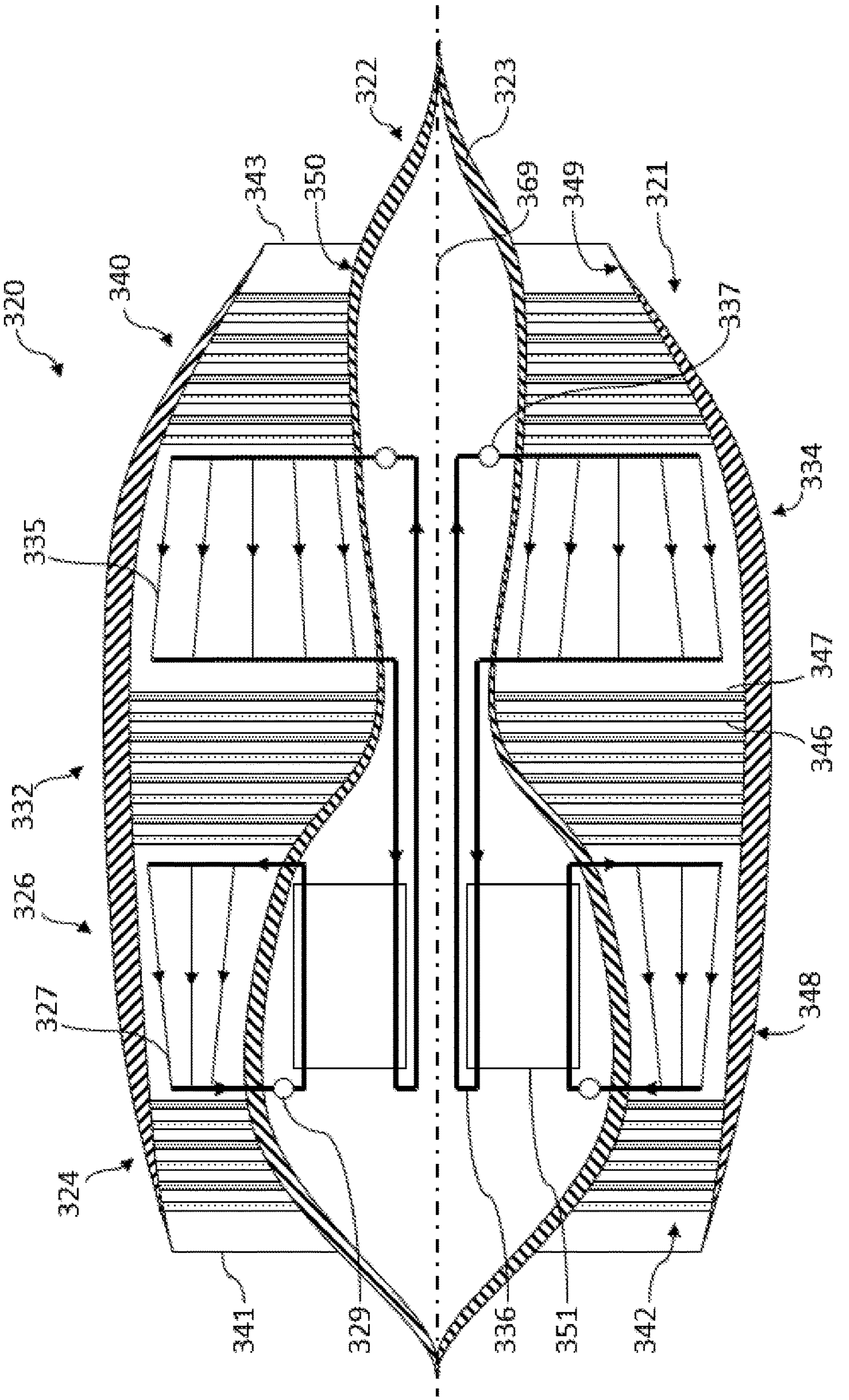
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FIG. 14

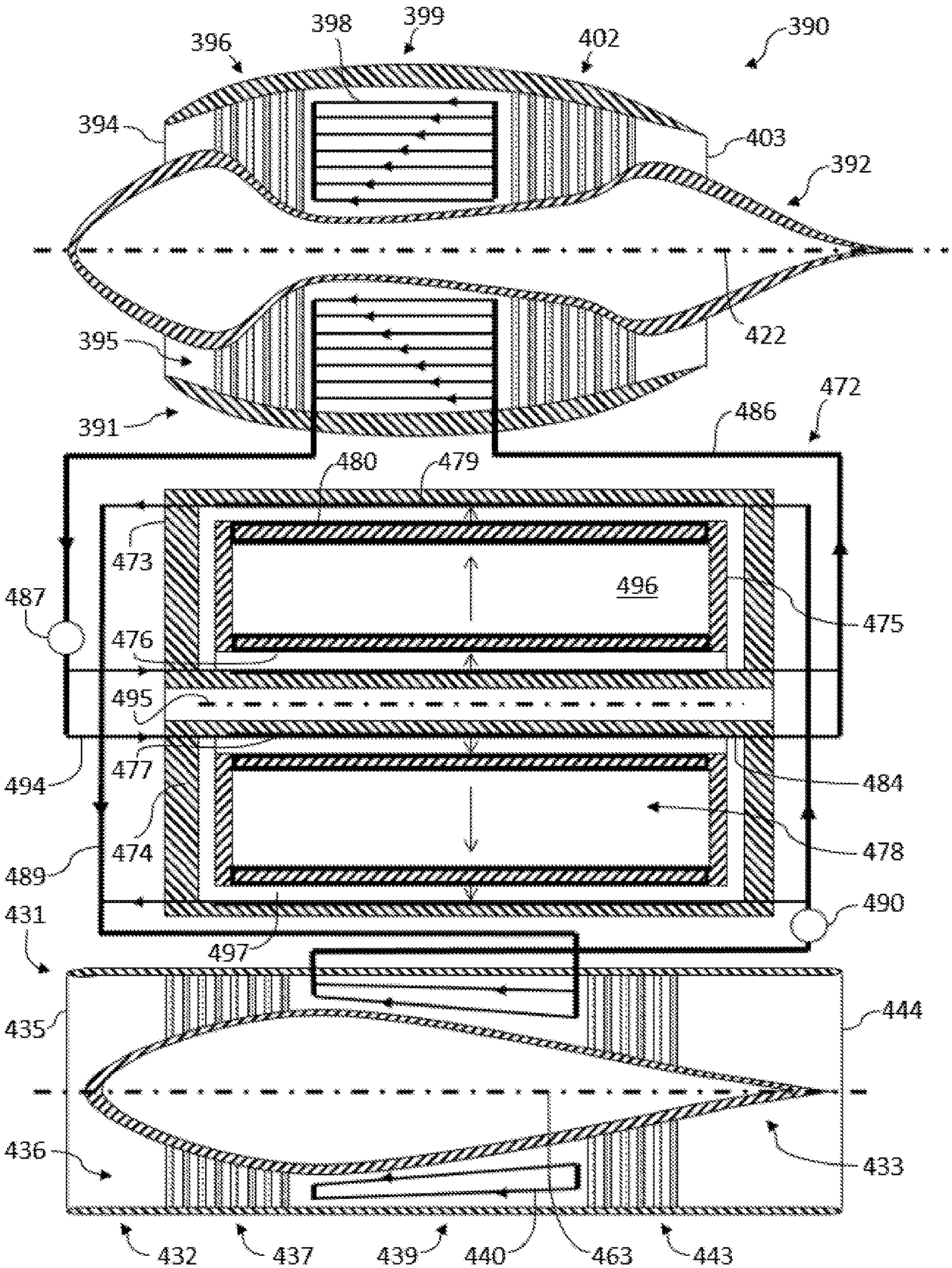
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FIG. 15

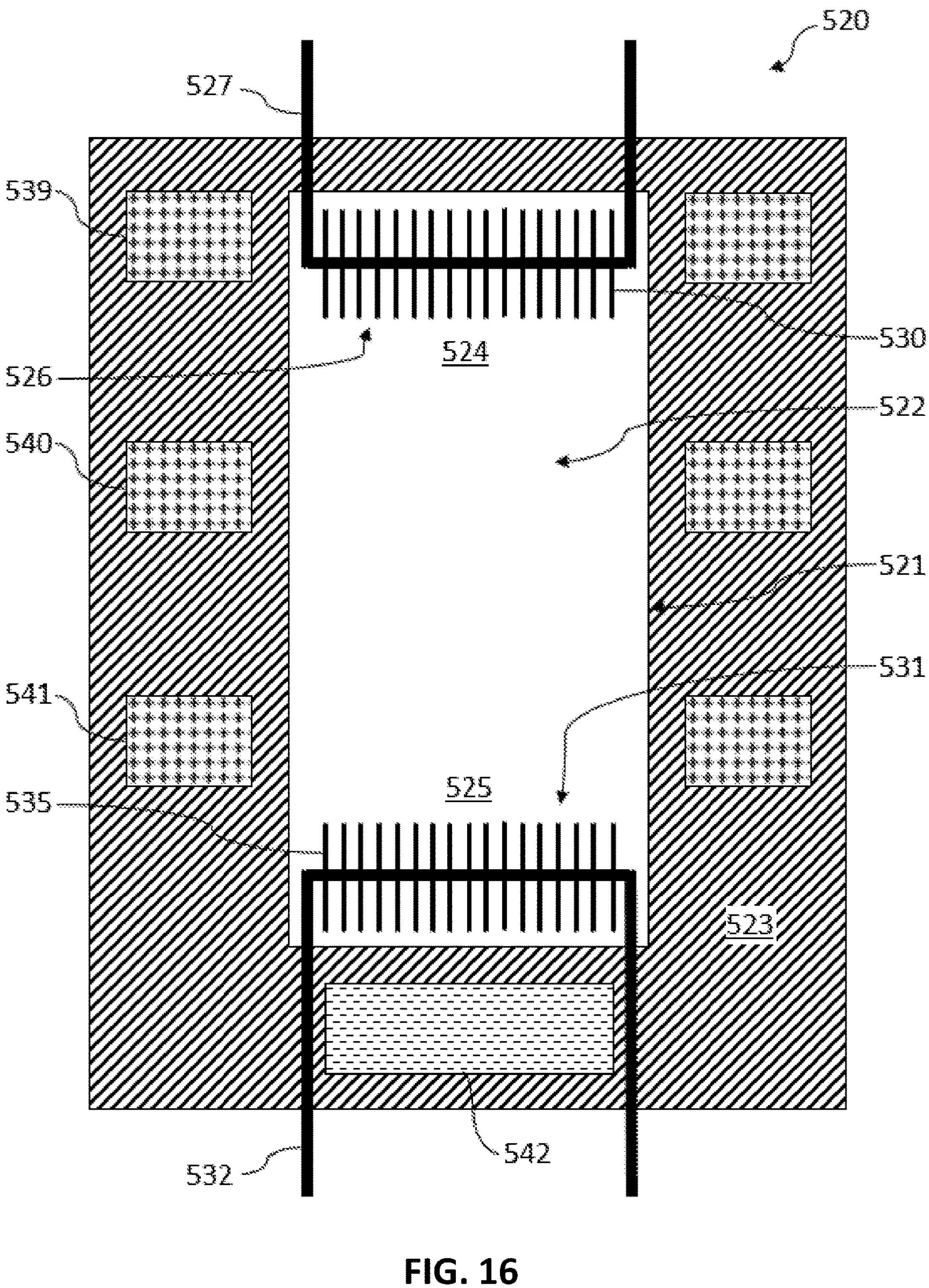

FIG. 16

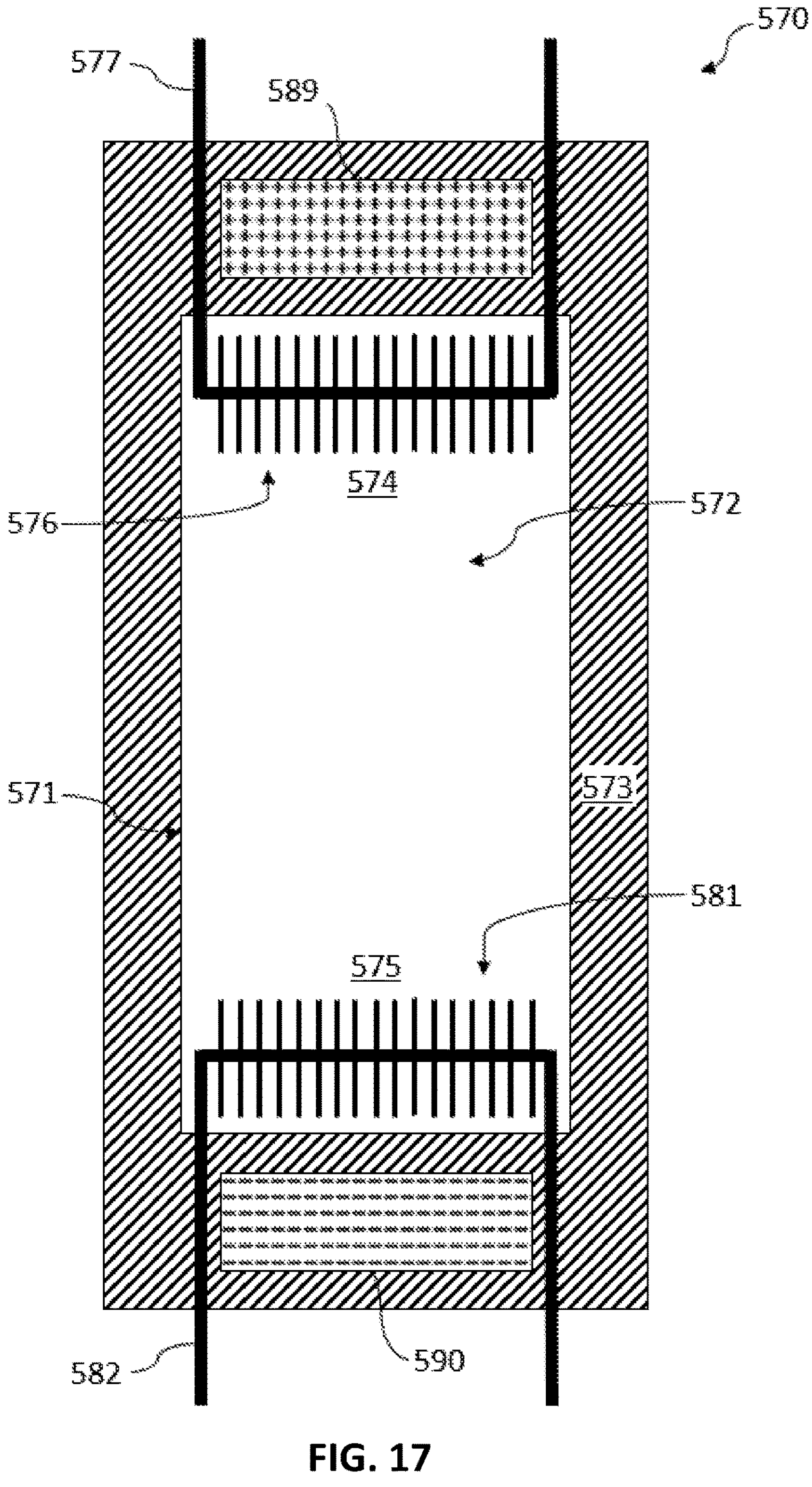

FIG. 17

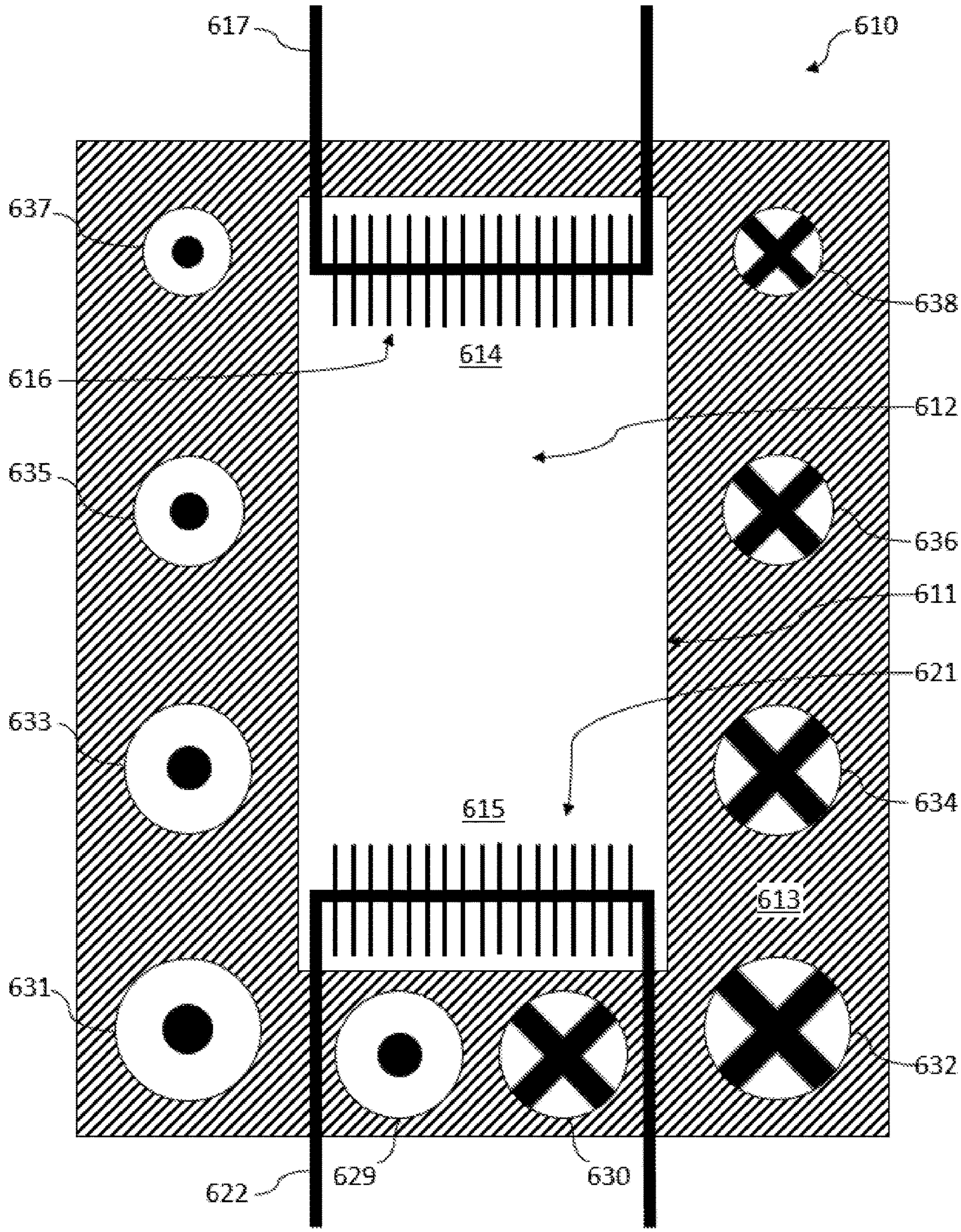
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FIG. 18

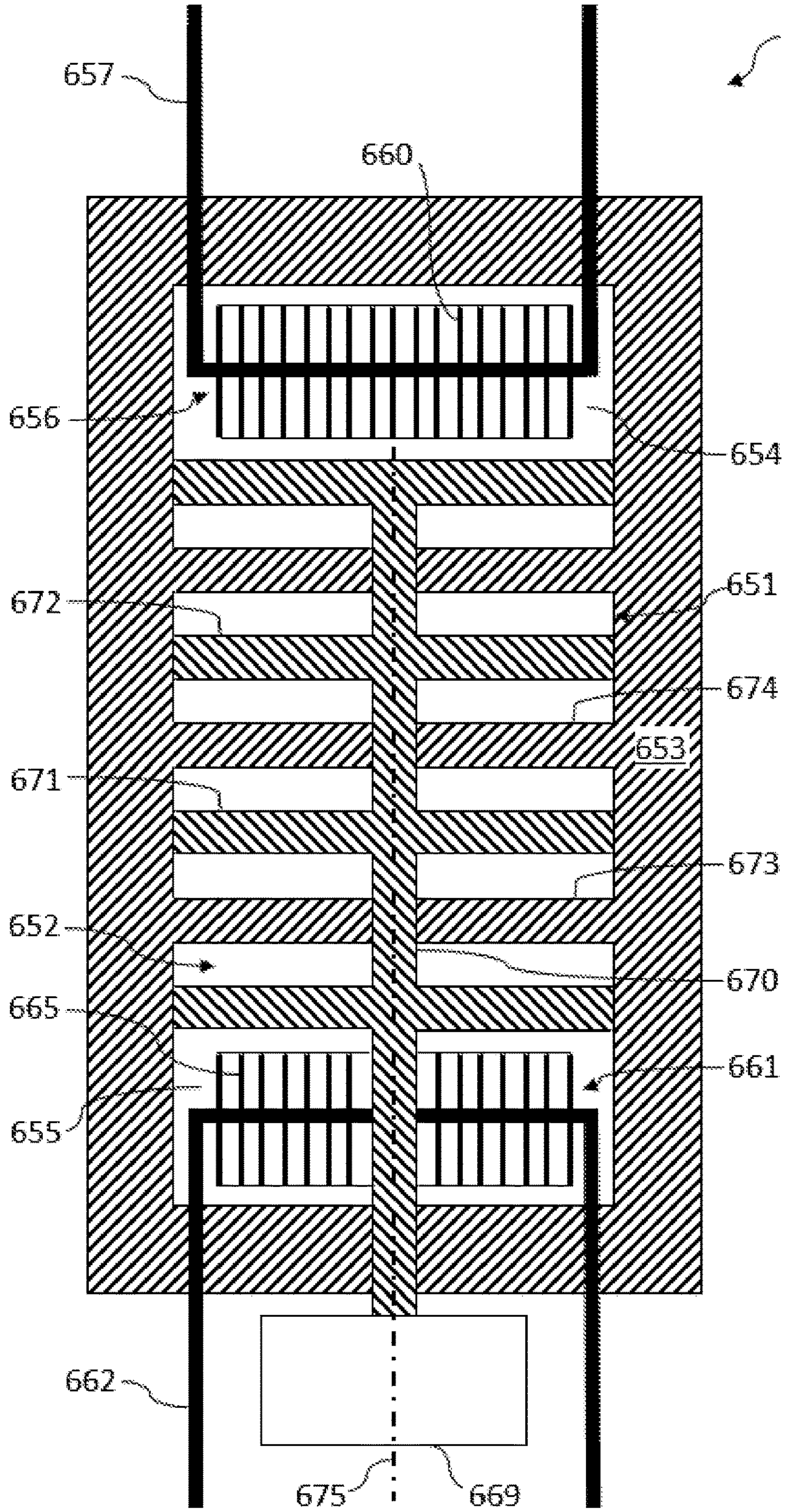
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FIG. 19

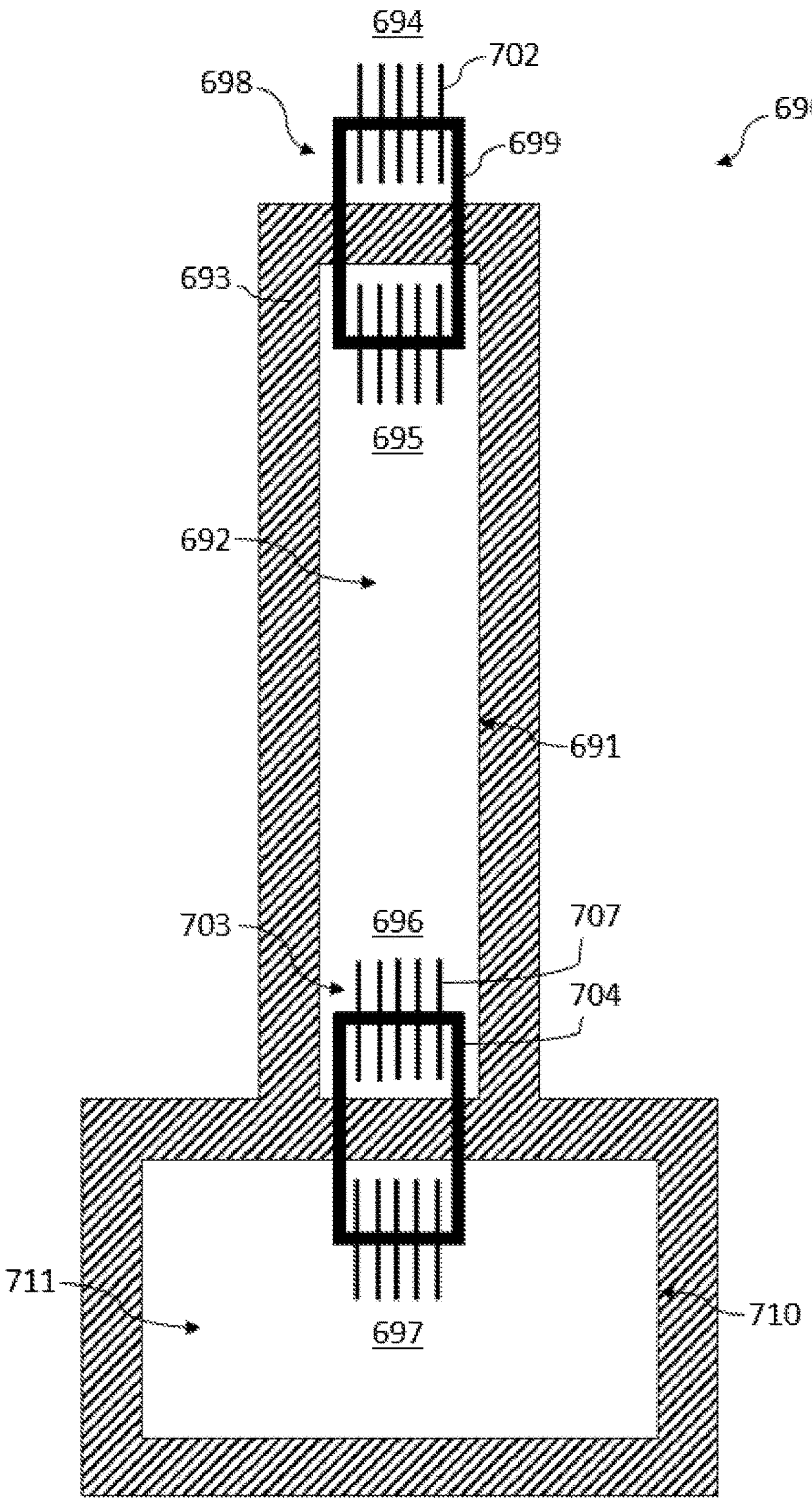

FIG. 20

REFRIGERATION APPARATUS AND METHOD

CLAIM OF PRIORITY

[0001] The present patent application is a non-provisional of, and claims the benefit of priority of US Provisional Patent Application Nos. 62/584,125 filed on Nov. 10, 2017 (Attorney Docket No. 5161.001PRV); 62/708,959 filed on Jan. 2, 2018 (Attorney Docket No. 5161.001PV2); and 62/766,143 filed on Oct. 3, 2018 (Attorney Docket No. 5161.001PV3); each of which is hereby incorporated by reference herein in its entirety.

BACKGROUND

[0002] Heat typically flows from a hot thermal reservoir to a cold thermal reservoir when these two thermal reservoirs are in thermal contact with each other. This heat can be transferred via conduction, for instance.

[0003] A conventional heat pump requires mechanical work to be done in order to transfer heat from a cold reservoir to a hot reservoir. For example, a conventional refrigerator consumes electricity in order to remove heat from the cold interior and deliver heat to the warm exterior, such as the room in which the refrigerator is located.

[0004] A conventional heat engine performs mechanical work by absorbing heat from a hot reservoir and transferring heat to a cold reservoir. For example, in a marine steam engine, the working material absorbs heat from a hot reservoir in the boiler, and subsequently performs mechanical work, e.g. on a steam turbine, whereupon the steam transfers heat to a cold reservoir, e.g. the ocean, in the condenser.

[0005] It would be desirable to provide improved thermal systems.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] In the drawings, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

[0007] FIG. **1** is a cross-sectional view of one exemplary embodiment of a heat transfer apparatus.

[0008] FIG. **2** is a plot of material properties for the exemplary embodiment of FIG. **1** in equilibrium.

[0009] FIG. **3** is a plot of material properties for another example of the embodiment of FIG. **1** in equilibrium.

[0010] FIG. **4** is a cross-sectional view of another exemplary embodiment of a heat transfer apparatus.

[0011] FIG. **5** depicts a plot of pressure versus specific volume, which indicates the variation of parameters at different locations within an exemplary embodiment shown in FIGS. **6**A-**6**B and at different points in time during one example thermodynamic cycle during operation.

[0012] FIG. **6**A shows a plot of normalized material properties as a function of position along a length of the apparatus at a particular instant in time and FIG. **6**B portrays a cross-sectional view of one exemplary apparatus.

[0013] In FIGS. **7**A-**7**H a cross-sectional view of the example apparatus of FIGS. **6**A-**6**B is shown in different configurations in accordance with different points in time during one example method of operation shown in FIG. **5**.

[0014] FIG. **8** is a plot of material properties for one example embodiment during one example method of operation of any embodiment, including FIG. **8** or **11**.

[0015] FIG. **9** is a plot of material properties for one example embodiment during one example method of operation of any embodiment, including FIGS. **9** and **13**.

[0016] FIG. **10** is a plot of material properties for one example embodiment during one example method of operation of any embodiment, including FIGS. **10** and **12**.

[0017] FIG. **11** is a schematic representation of several embodiments of the invention.

[0018] FIG. **12** is a schematic representation of several embodiments of the invention.

[0019] FIG. **13** is a schematic representation of several embodiments of the invention.

[0020] FIG. **14** is a cross-sectional view of one exemplary embodiment of the refrigeration apparatus.

[0021] FIG. **15** is a cross-sectional view of several components of another exemplary embodiment of the refrigeration apparatus.

[0022] FIG. **16** is a cross-sectional view of one exemplary embodiment of a heat transfer apparatus.

[0023] FIG. **17** is a cross-sectional view of one exemplary embodiment of a heat transfer apparatus.

[0024] FIG. **18** is a cross-sectional view of one exemplary embodiment of a heat transfer apparatus.

[0025] FIG. **19** is a cross-sectional view of one exemplary embodiment of a heat transfer apparatus.

[0026] FIG. **20** is a cross-sectional view of one exemplary embodiment of an artificial heat source or artificial heat sink comprising a heat transfer apparatus.

DETAILED DESCRIPTION

[0027] Heat typically flows from a hot thermal reservoir to a cold thermal reservoir when these two thermal reservoirs are in thermal contact with each other. This heat can be transferred via conduction, for instance.

[0028] A conventional heat pump requires mechanical work to be done in order to transfer heat from a cold reservoir to a hot reservoir. For example, a conventional refrigerator consumes electricity in order to remove heat from the cold interior and deliver heat to the warm exterior, such as the room in which the refrigerator is located.

[0029] A conventional heat engine performs mechanical work by absorbing heat from a hot reservoir and transferring heat to a cold reservoir. For example, in a marine steam engine, the working material absorbs heat from a hot reservoir in the boiler, and subsequently performs mechanical work, e.g. on a steam turbine, whereupon the steam transfers heat to a cold reservoir, e.g. the ocean, in the condenser.

[0030] According to the literature, the sum of the entropies of the thermodynamic systems interacting with each other in a thermodynamic process increases or remains constant.

[0031] In some situations it would be desirable to provide thermal systems where heat flows from colder to hotter regions or where heat flows faster than existing systems. It would be desirable to provide improved thermal systems. At least some of these challenges are addressed by the exemplary embodiments disclosed herein.

[0032] FIG. **1** is a cross-sectional view of one exemplary embodiment of a heat transfer apparatus. Various heat flows are described but this is not intended to be limiting. One of skill in the art will appreciate that the embodiment may include heat flow between any two points and may include heat flow between any other two points. In this particular depiction, the apparatus is configured to exchange heat between two points in a reservoir or between a first reservoir **2** and a second reservoir **7**. The first reservoir **2** contains material A **1**, while the second reservoir **7** contains material B **8**. Also shown is a third reservoir **18**, containing material C **16**, and a fourth reservoir **19**, containing material D **17**.

[0033] FIG. **1** shows a heat exchanging apparatus **3**, which is configured to facilitate heat flow between one set of two points as described below, or between any or all of the two points described below. Heat flow may be between the first reservoir **2** and the third reservoir **18**, a heat exchanging apparatus **20**, which is configured to establish a thermal contact and facilitate heat flow between the third reservoir **18** and the fourth reservoir **19**, and a heat exchanging apparatus **6**, which is configured to establish a thermal contact and facilitate heat flow between the fourth reservoir **19** and the second reservoir **7**.

[0034] Heat exchanging apparatus **3** comprises an element **13** which is in thermal contact with material A **1** in the first reservoir **2**, as well as an element **4** which is in thermal contact with material C **16** in the third reservoir **18**. Heat exchanging apparatus **6** comprises an element **5** which is in thermal contact with material D **17** in the fourth reservoir **19**, as well as an element **14** which is in thermal contact with material B **8** in the second reservoir **7**. Heat exchanging apparatus **20** comprises an element **23** which is in thermal contact with material C **16** in the third reservoir **18**, as well as an element **24** which is in thermal contact with material D **17** in the fourth reservoir **19**. Each element represents the portion of the associated heat exchanging apparatus which is in direct thermal contact with the material in the associated reservoir. In FIG. **1**, one can consider an element to be the portion of a heat exchanging apparatus which is not enveloped by insulating apparatus **15**.

[0035] The three heat exchanging apparatuses **3**, **6**, and **20** are configured substantially identically. In other embodiments, this need not be the case. In the embodiment shown in FIG. **1**, the heat exchanging elements **4**, **5**, **13**, **14**, **23**, and **24** are configured to exchange heat with the respective materials via conduction and via electromagnetic waves. For example, the aforementioned heat exchanging elements may be solid, and may be made of a material such as copper. In other embodiments, other methods of establishing the thermal contact between the heat exchanging elements and the respective materials in the associated reservoirs, such as element **23** and material C **16** in the third reservoir **18**, may be employed.

[0036] The thermal contact between the elements of a particular heat exchanging apparatus, such as element **23** and element **24** of heat exchanging apparatus **20**, can be arranged in several ways. In FIG. **1**, heat flow between related elements is enabled by thermal conduction. In other words, heat absorbed by element **23** is able to flow to element **24** via the physical contact between said elements. In FIG. **1**, this physical contact is provided by a third element of a heat exchanging apparatus, where the third element extends through, and is enveloped by, insulating apparatus **15**. In FIG. **1**, all three elements of a heat exchanging apparatus are made of the same material. In this case, a heat exchanging apparatus may be constructed of a single piece of material.

[0037] In other embodiments, the thermal contact between the elements of a particular heat exchanging apparatus can be facilitated via forced convection. For example, a heat exchanging element such as element **23** may comprise a fluid which can be configured to flow through a cavity within the heat exchanging element. The heat exchanging element may take the shape similar to the shapes shown in FIG. **1**, with the exception that the elements do not have a solid cross-section but rather a tubular cross-section enclosing the aforementioned fluid. A separate pump can be configured to move the fluid around a closed path, such as the path formed by the elements of a heat exchanging apparatuses shown in FIG. **1**. Said fluid can be employed to absorb heat as it travels through a particular heat exchanging element such as element **23**. The fluid can be subsequently or simultaneously pumped to the second heat exchanging element of the heat exchanging apparatus, such as element **24** of heat exchanging apparatus **20**. While traveling through the second heat exchanging element the fluid can transfer heat via conduction to the second heat exchanging element and subsequently to the adjacent material, such as material D **17** in the fourth reservoir **19**. The aforementioned fluid can be water or a gas such as air, or any other suitable fluid. Those skilled in the art will be able to identify a suitable fluid for a given application, such as a fluid with a high coefficient of thermal conductivity and a low viscosity. Alternatively, the fluid and cavity within a heat exchanging element can also be configured to allow for natural convection of the fluid through the cavity. For example, the absorption of heat may reduce the density of the fluid, which may lead to the natural convection of the fluid from one element, such as element **23**, to another element, such as element **24**, due to buoyancy effects.

[0038] In other embodiments, the thermal contact between the elements of a particular heat exchanging apparatus can be facilitated via electromagnetic waves. For example, a first heat exchanging element, such as element **23**, may be separated from a second heat exchanging element, such as element **24**, by a vacuum. The interface between the vacuum and each heat exchanging element may be configured in such a way, that a specified fraction of photons emitted by the first heat exchanging element are absorbed by the second heat exchanging element, and vice versa. For some embodiments, the gap between the first and second heat exchanging elements could be made as small as practical considerations will allow. The interface area between the vacuum and each heat exchanging element could be determined by a specified heat flow rate. The geometry of said interface can also be can be subject to considerations regarding the reduction of heat losses during heat flow between the first and second heat exchanging elements. The optimal configuration of the heat exchanging apparatus depends on the application or intended use of the invention. In other embodiments, the gap between a first and second heat exchanging elements need not form a vacuum, but could be occupied by a fluid, such as a gas like air, or a liquid like oil. In this case, the thermal contact may not only involve photons, but also conduction, and, in some embodiments, convection.

[0039] In some embodiments, there may be a relative motion between the heat exchanging elements of any one heat exchanging apparatus, such as element **5** and element **14** of heat exchanging apparatus **6**. This may arise from relative motion between the fourth reservoir **19** and the second reservoir **7**. This relative motion can be facilitated and controlled by an electric motor, for example. The mechanical connection can be established by roller bearings, or magnetic levitation bearings. In this case, additional considerations affect the configuration and design of the heat exchanging apparatus. For example, an additional objective may be the reduction of frictional losses associated with the relative motion. The aforementioned use of electromagnetic waves or a fluid as a thermal medium between the heat exchanging elements may be favorable in that regard. Note that any apparatus which mechanically or electromagnetically connects a thermal reservoir with another thermal reservoir may also be employed to facilitate a thermal connection between the reservoirs. For example, the related heat exchanging elements may be placed in thermal contact by means of solid materials, such as metals found in roller bearings.

[0040] Those skilled in the art will be able to find an appropriate type, configuration, as well as an appropriate method of operation of each heat exchanging apparatus for the objective and constraints of the intended application.

[0041] Any one heat exchanging apparatus may also comprise an apparatus for regulating or modifying the rate of heat flow through the heat exchanging apparatus. Such apparatuses and methods are well known in the art. For instance, the heat flow rate through a heat exchanging apparatus can be regulated by modifying the overall coefficient of thermal conductivity of the heat exchanging apparatus. This can be accomplished by placing a material of selected thermal conductivity in the path of the heat flow between the two thermal reservoirs. For instance, two heat exchanging elements of a heat exchanging apparatus, such as elements **23** and **24** of heat exchanging apparatus **20**, may be placed in thermal contact with each other via a third element with a selected thermal conductivity. The thermal conductivity of the third element can be selected in a way in which the overall thermal conductivity of the heat exchanging apparatus is modified in the desired manner. Alternatively or concurrently, the area of physical contact between two elements of a heat exchanging apparatus can be adjusted to control the heat flow rate. The length of the insulated portion of the heat exchanging apparatus, i.e. the portion connecting the first and second heat exchanging elements that is enveloped by insulating apparatus **15**, can also be used to modify the heat flow rate.

[0042] In the case in which the heat flow through a heat exchanging apparatus involves the forced convection of a fluid within the heat exchanging apparatus, the heat flow rate can be controlled by regulating the flow rate of the fluid, which in turn can be modified by controlling the operation of the pump responsible for circulating the fluid through the heat exchanging apparatus. In the case in which the fluid involved in the heat transfer process is subject to natural convection, the flow rate can be modified by regulating the cross-sectional area at a suitable point along the path of the fluid throughout the convection process.

[0043] There are numerous ways for controlling the heat flow rate in the case in which there is an exchange of electromagnetic waves between a first surface area of a first heat exchanging element and a second surface area of a second heat exchanging element of a particular heat exchanging apparatus. For example, the fraction of photons emitted by the first surface area which are absorbed by the second surface area can be adjusted. This can be accomplished in several ways. For instance, a third material with a high reflectivity can be placed between the first and second surface area, such that the third material reflects a portion or all of the photons emitted by the first surface area back towards the first surface area, and a portion or all of the photons emitted by the second surface area back towards the second surface area. Other methods for regulating the heat flow rate for these and other types of heat exchanging apparatuses are well known in the art.

[0044] FIG. **1** shows an insulating apparatus **15**. One of the criteria for selecting and configuring insulating apparatus **15** may be the ability of the material to reduce the unintended heat flow rate from a particular reservoir contained within or enclosed by the insulating apparatus **15**, such as the third reservoir **18**, to another enclosed reservoir, such as the fourth reservoir **19**, or to an open reservoir, such as the outside environment, or vice versa. In the embodiment shown, insulating apparatus **15** is a solid material with a low coefficient of thermal conductivity. While explaining the operation of the apparatus shown in FIG. **1**, insulating apparatus will be treated as a substantially perfectly insulating material. In reality, insulating apparatus **15** may not be perfectly insulating.

[0045] In some embodiments, insulating apparatus **15** may comprise an inside layer and an outside layer, with the outside layer separated from the inside layer by a vacuum. In other embodiments, the outside layer may be separated from the inside layer by another suitable material, such as a fluid. A vacuum may improve the ability of insulating apparatus **15** to suppress unintended heat flow. A vacuum or other suitable material in the space between the outside layer and the inside layer may also be useful for reducing frictional losses in embodiments involving relative motion between the outside and inside layer. For instance, the outside layer may interface with a reservoir, such as the outside environment or the second reservoir **7**. The inside layer may interface with a different reservoir, such as the fourth reservoir **19**, which may move relative to the stationary reservoir. Those skilled in the art will be able to find a suitable material, such as a fluid with a low thermal conductivity and a low viscosity.

[0046] In the simplified example shown in FIG. **1**, material A **1** in the first reservoir **2** and material B **8** in the second reservoir **7** are gases. Material C **16** in the third reservoir **18**, and material D **17** in the fourth reservoir **19** are also gases, which, for simplicity, will be treated as ideal gases.

[0047] In accordance with the present exemplary embodiment, materials A **1**, B **8**, C **16**, and D **17** are configured to be "thermal media". The term "thermal medium" used herein refers to any physical medium which can facilitate the transport of energy. A thermal medium is therefore not limited to the aforementioned gaseous embodiments, but can comprise any of a large number of different materials or take any of a large number of forms. A thermal medium may be a solid or a fluid, for example. A thermal medium may be any type of solid, such as a crystal or glass, as well as any type of fluid, such as a liquid, gas, plasma or ferrofluid. A thermal medium may also comprise individual sub-molecular particles, such as electrons or protons. In some embodiments a thermal medium may also consist substantially of photons. In this case the reservoir containing the thermal medium may be described as a vacuum. In other words, a thermal medium may also be modeled as an object capable of emitting or absorbing electromagnetic waves. Note that a thermal medium may consist of a collection or mixture of different types of materials. For example, one type of material in a thermal medium may be a particular type of molecule in gaseous form, such as dinitrogen, while another type of material in the same thermal medium may be a photon. Note that a thermal medium may also consist of an assembly of distinct collections of a particular type or form of material. For example, a portion of a thermal medium may be a solid such as copper, while another portion may be a liquid such as water, while yet a third portion may be steam, i.e. water in a gaseous phase. In the context of materials A **1**, B **8**, C **16**, and D **17**, as well as heat exchanging apparatuses **3**, **6** and **20**, the terms "material" and "thermal medium" are used interchangeably in this paper, since the associated materials are configured to be thermal media. Note that this also applies to cases in which a particular thermal medium may not frequently, commonly, or conventionally be referred to as a material. For instance, a photon is a thermal medium, but may not conventionally be referred to as a material. Note that material D **17** may be one type of material, such as a solid such as a metal such as copper or aluminum, while material C **16** may be another type, such as a gas such as argon or air. Note that there may be constraints on some of the material properties of material D **17** and C **16**. These constraints depend on the intended use of the apparatus, as will be explained later.

[0048] The heat flow within a particular reservoir, such as the third reservoir **18**, can take several forms. The heat can be transported within a reservoir by thermal conduction, for example. This may apply to a scenario where material D **17** consists of a solid such as copper, for instance. In the embodiment shown in FIG. **1**, heat can be transported via natural convection, as well as other mechanisms. In other embodiments, forced convection may be employed to facilitate heat flow within a particular thermal reservoir. For example, a fan may be used to circulate a fluid within a reservoir. In yet other embodiments, photons may be used to transport thermal energy throughout a reservoir. In this case, the interior wall of insulating apparatus **15** at the interface to a particular reservoir may be endowed with a large coefficient of reflectivity, or with similar properties conducive to the reflection of photons, in order to reduce any unintended heat flow rate from the reservoir into insulating apparatus **15**.

[0049] In FIG. **1** there is a body force per unit mass acting on material C **16** in the third reservoir **18** and material D **17** in the fourth reservoir **19**. In this simplified example, the body force is constant in time, as well as constant in magnitude and direction within the entire volume of, and equal for, each of said reservoirs. The body force is directed vertically downwards, towards the bottom of the page. In the configuration shown, this direction is also parallel to the long axis of the cross-section of the third reservoir **18**. In other embodiments, the body force need not be distributed uniformly in space, or be constant in time. The body force acts on at least a subset of particles within material C **16** and D **17**. In other words, a subset of particles of material C **16** and material D **17** are subject to an acceleration contribution. The term "acceleration contribution" is used to distinguish the contribution of the body force per unit mass to the instantaneous net acceleration of a particle within a thermal medium from the instantaneous net acceleration per se. There are numerous ways in which such body forces per unit mass can be generated.

[0050] One type of such a body force per unit mass is the gravitational acceleration acting on a thermal medium.

[0051] A body force may arise from the existence of a potential field gradient. One such example is the force which arises from the gradient of an electric potential. For example, the elements of a thermal medium can be configured to be electrically charged. In the context of a thermal medium, the term "elements" refers to the constituent parts of the thermal medium, such as sub-molecular particles, molecules, or a distinct or specified collection of molecules, for example. In the case of a gas, the molecules could be positively or negatively ionized, for instance. The thermal medium may also comprise a collection of mobile electrons. Note that this collection may be contained in a solid, such as a conductor, or it may be described as a gas. By applying an electric field within a reservoir, body forces per unit mass can be generated on the electrically charged elements of the thermal medium inside the reservoir.

[0052] For other embodiments it may be impossible or inconvenient to use, procure, or create a thermal medium with mobile electrical charges. In this case, elements of the thermal medium may be polarized by applying an electric field, or these elements may already have an intrinsic polarization, as in the case of polar molecules, such as dihydrogen monoxide. When placed in an electric field gradient, these polarized elements can experience a body force. Note that the magnitude of said force depends on the orientation of the polarization axis relative to the electric field, amongst other parameters. Thus an electric field can be configured to generate body forces per unit mass on the polar elements in the thermal medium in a reservoir, as well as polarize elements in the thermal medium, if necessary. The electric field can be applied in a myriad of ways known in the art.

[0053] Magnetism can also be employed to generate body forces. The thermal medium may comprise diamagnetic, paramagnetic, or ferromagnetic elements. When magnetized, the individual elements in the thermal medium may form magnetic dipoles, or these elements may already have an intrinsic magnetic dipole, such as an electron. When these magnetic dipoles are placed in a magnetic field with a non-zero curl or gradient, they can experience a body force. Note that the magnitude of the body force is a function of the orientation of the magnetic dipole relative to the local magnetic field, amongst other parameters. Thus an external magnetic field can be configured to generate body forces per unit mass on the magnetized elements in the thermal medium in a reservoir, as well as magnetize the elements in the thermal medium, if necessary. The magnetic field can be generated by ferromagnets other at least instantaneously magnetized elements, or by an electrical current flowing through an electromagnet, amongst other methods known in the art.

[0054] The body forces per unit mass may also arise from inertial effects. For instance, a reservoir may be subject to an acceleration in an inertial frame. This results an acceleration of the thermal medium relative to the reservoir. When accelerating a reservoir at a constant rate of acceleration in an inertial frame in a direction vertically upwards towards the top of the page in FIG. **1**, the thermal medium inside the reservoir will experience an acceleration relative to the reservoir, where the acceleration is directed vertically downwards towards the bottom of the page. Inertial forces can be generated by linear acceleration, i.e. motion of the reservoir along a straight line in the inertial frame. Inertial forces can also be generated by angular acceleration, i.e. motion of the reservoir along a curved path. In general, inertial forces can be generated by any accelerating motion in an inertial frame. Consider the aforementioned case in which the depicted apparatus undergoes circular motion in an inertial frame, where the radius and angular velocity remain constant. In the embodiment shown in FIG. **1**, the axis of rotation could be parallel to and coincident with a horizontal line passing through the centroid of the depicted portion of the cross-section of the first reservoir **2** and the second reservoir **7**, for example. Note that the centripetal acceleration varies linearly with radius in this embodiment. If a substantially uniform body force per unit mass of thermal medium is desired, the depicted apparatus can be located at a larger radius, where the radial dimension of the apparatus is only a fraction of said radius. For instance, the radius can be increased by placing the horizontal axis of rotation further upwards towards the top of the page in FIG. **1**. In some embodiments, the direction vector of the axis of rotation can lie anywhere in a plane perpendicular to the plane of the page and intersecting the plane of the page horizontally. Other embodiments can have different locations and orientations of the axis of rotation, as well as different rotational velocities. These parameters may also vary in time. Embodiments employing other types of forces or combinations thereof are within the spirit and scope of the invention.

[0055] One can define a potential as the integral of the value of the body force per unit mass over a displacement relative to a specified reference point. Note that the potential in this context is a mathematical construct, and need not have a physical manifestation. One can define the position within any thermal reservoir which is subject to a body force per unit mass in terms of the value of a potential at that position. For a given potential, there is a set of possible points within the reservoir at which the value of the potential is the value of the given potential. In general, this set describes a three dimensional equipotential surface. For example, consider a simplified case in which a thermal medium inside a thermal reservoir is subject to a body force per unit mass, where the body force is uniform in magnitude and direction throughout the reservoir and constant in time. The thermal reservoir is an isolated system, i.e. closed and perfectly insulated, and has the shape of a cylinder with length L and radius R, for instance. One can define a Cartesian reference frame, with the z-axis parallel to the length L of the cylinder, and parallel to, and directed in the opposite direction of, the body force per unit mass. The origin of the reference frame is the center of the circular area at the top of the cylinder, where the "top" is defined relative to the z-axis. In this case, the equipotential surfaces are planes perpendicular to the z-axis. A reference point may be defined to be the origin of the reference frame. The value of the potential at the top of the cylinder is therefore zero, while the value of the potential at the bottom of the cylinder is equal to the negative value of the product of the body force per unit mass and the length L of the cylinder. The equipotential surfaces for other embodiments can be found using similar principles.

[0056] Provided is an apparatus and method for facilitating heat flow. The apparatus comprises a first and second thermal reservoir, where each reservoir contains a first and second thermal medium respectively, and where the first reservoir is at least partially insulated from the second reservoir as well as any other reservoir, such as the outside environment, and vice versa. The thermal medium in each reservoir is subject to a body force per unit mass, which, in general, does not have a uniform magnitude or direction for different points in space and may not be constant in time.

[0057] For illustrative purposes, a specific mode of operation of such an apparatus will be considered. In this mode of operation, the body force per unit mass distribution is assumed to be constant in time, and each reservoir is assumed to be in thermal equilibrium with its surroundings. The objective during this mode of operation is to establish a difference in temperature between a point A in the first thermal reservoir and a point D in the second thermal reservoir, where point A and point D are located on the same equipotential surface defined by a first potential level.

[0058] In accordance with the invention, at least one heat exchanging apparatus is configured to place a point B in the first thermal medium into thermal contact with a point C in the second thermal medium. By convention, point B and point C are located on the same equipotential surface defined by a second potential level. The second potential level may be larger or smaller than, but not equal to, the first potential level. Since this mode of operation assumes a thermal equilibrium, the temperatures at point B and point C are identical. Note that the existence of said heat exchanging apparatus is a matter of definition. The definition of the first or second thermal media can be extended to encompass the heat exchanging apparatus. This approach may be favorable in embodiments in which a distinct heat exchanging apparatus is not readily identified. In these instances, the thermal media and reservoirs may be defined in a way in which a point B and a point C coincide.

[0059] In accordance with the invention, the defining material properties of the first thermal medium within the first reservoir are configured relative to the defining material properties of the second thermal medium within the second reservoir in a way in which the change in temperature, or some other specified material property of interest, between points A and B in the first reservoir and between points D and C in the second reservoir is not equal. The "defining material properties" are defined as the properties of a thermal medium which determine the change of the material properties of interest for a given change in potential for a given thermal medium. As a result of the identical temperatures at point B and C and a difference in the change in temperature between points A and B as well as the change in temperature between points D and C, the aforementioned objective is met.

[0060] Note that the extent of a thermal reservoir or the definition of the boundary between the first and second thermal medium is a matter of definition, and not limited to the geometry or configuration of a particular apparatus, or a discontinuity in the type of material occupying a given region in space. As mentioned previously, a thermal medium may comprise many different types of materials, where the materials may exist as a mixture, or as an assembly of distinct materials or distinct phases of the same material. Along varying potential levels, a particular thermal medium may consist of different types of material. For example, a thermal medium may be a solid such as copper for a certain range of potential levels, and gas such as air along a different range of potential levels within the associated reservoir.

[0061] The aforementioned principles of operation will now be described in the context of the simplified example embodiment shown in FIG. **1**. The first thermal medium is material C **16** in the third reservoir **18**, and the second thermal medium is material D **17** in the fourth reservoir **19**. Materials C **16** and D **17** are ideal gases, insulated by insulating apparatus **15**. For simplicity, these reservoirs are assumed to be perfectly insulated along the length of the reservoirs. Recall that there is a body force per unit mass acting on material C **16** in the third reservoir **18** and material D **17** in the fourth reservoir **19**, where, for simplicity, the body force per unit mass is equal for both reservoirs, constant in time and constant in direction and magnitude throughout each reservoir, and directed vertically downwards. One can define a height z, which decreases linearly along the direction vector of the body force per unit mass, i.e. in the vertically downwards direction, towards the bottom of the page. Since the body force per unit mass is constant, all points within a thermal medium at the same height z within a reservoir lie on the same equipotential surface.

[0062] In the operating mode mentioned above, all four reservoirs shown in FIG. **1** are assumed to be in thermal equilibrium, i.e. there is a zero heat flow rate between any two reservoirs. In such an operating mode, the objective of the depicted apparatus is the establishment of a difference in temperature between station **10**, i.e. point A, in the third reservoir **18** and station **11**, i.e. point D, in the fourth reservoir **19**. Note that point A and point D are located on the same equipotential surface defined by a first potential level. This is evident from the fact that the height z of station **10** is equal to height z of station **11**.

[0063] In the aforementioned equilibrium configuration, heat exchanging apparatus **20** ensures that the temperature at station **21**, i.e. point B, is equal to the temperature at station **22**, i.e. point C. As before, the position of stations **21** and **22** along height z is identical, and points B and C are located on the same equipotential surface defined by a second potential level. In this case, the second potential level is lower than the first potential level.

[0064] Due to the thermal insulation and the body force per unit mass, the properties of the ideal gas inside the third reservoir **18** and the fourth reservoir **19** vary adiabatically along the vertical length of the reservoir. Thus, as the height z of an element of a material in such a reservoir, such as material C **16** in the third reservoir **18**, decreases temperature of the element increases. In this simplified model, the temperature increases linearly as height z decreases within the reservoir. In this case, the material property of interest is the temperature, while the defining material property for an ideal gas is the specific heat capacity at constant pressure. For other embodiments, such as a scenario in which a material in a reservoir, such as material D **17** in the fourth reservoir **19**, is not an ideal gas, but a solid, other material properties may affect the change in temperature of the material along the height z of the associated reservoir. In the apparatus in FIG. **1**, the configuration of the defining material properties comprises selecting as material C **16** an ideal gas with a specific heat capacity a constant pressure which is different to that of a selected material D **17**. The sign and the magnitude of the difference in the defining material properties between materials C **17** and D **17** is determined by the desired sign and magnitude of the difference in the change in the material properties of interest, i.e. the temperature. In FIG. **1**, the change in the material properties of interest is measured between stations **10** and **21** for material C **17**, and between stations **11** and **22** for material D **17**.

[0065] Due to the difference in the defining material properties between material D **17** and C **16**, the temperature change between stations **10** and **21** is not equal to the temperature change between stations **11** and **22**. It follows, therefore, that the temperature at station **10** is not equal to the temperature at station **11**. Thus the objective is met. Note that heat exchanging apparatus **3** ensures that the temperature at station **10** is equal to the temperature at station **9** in thermal equilibrium, and heat exchanging apparatus **6** ensures that the temperature at station **11** is equal to the temperature at station **12** in thermal equilibrium. Thus, the temperature at station **9** is also not equal to the temperature at station **12** in thermal equilibrium. The apparatus shown in FIG. **1** will have a tendency to restore this equilibrium configuration when there are slight deviations from this equilibrium configuration.

[0066] Consider a configuration in which the temperature at station **9** is lower than the temperature at station **12** when all four depicted reservoirs are in thermal equilibrium. In this case the temperature at station **10** is equal to the temperature at station **9**, and the temperature at station **11** is equal to the temperature at station **12**. The specific heat capacity at constant pressure of material C **16** is lower than the same of material D **17**. For example, material C **16** may be argon, while material D **17** may be air. Given that material C **16** and material D **17** are in thermal equilibrium at stations **21** and **22**, the temperature at station **10** must be lower than the temperature at station **11**.

[0067] This scenario is shown in FIG. **2**. The y-axis of the plot in FIG. **2** is the height z. Note that the units of height z are arbitrary in this case. Line **25** indicates the variation of the body force per unit mass along height z, where the body force per unit mass has been normalized by its value at the point where the height z is zero. Similarly, line **26** portrays the variation of the normalized temperature of material D **17** in the fourth reservoir **19** along height z, where the temperature has been normalized by its value at station **11**. Line **27** illustrates the variation of the temperature of material C **16** in the third reservoir **18** along height z, where the temperature has also been normalized by the value of the temperature of material D **17** at station **11**. As shown in FIG. **1** and FIG. **2**, station **11** describes the state of material D **17** at the point where the height z is zero, while station **22** designates the state at the minimum height z. Stations **10** and **21** label the corresponding states of material C **16**.

[0068] In this configuration, the apparatus shown in FIG. **1** can be used as an artificial heat sink for the first reservoir **2**. Consider the case in which the first reservoir **2** is the interior of a refrigeration unit, and material A **1** comprises the air contained in the interior of the refrigeration unit, as well as other materials, such as the items to be refrigerated. The second reservoir **7** may be the room in which the refrigeration unit is located, and material B **8** may be the air contained in that room. Consider an initial configuration in which all four reservoirs are in thermal equilibrium, similar to the scenario shown in FIG. **2**. Now consider an instantaneous increase in temperature in the first reservoir **2**, which may arise from the placement of an item to be cooled in the refrigeration chamber. The departure from the initial equilibrium condition results in an instantaneously larger temperature at station **9** compared to station **10**. As a result, heat flows through heat exchanging apparatus **3**, which in turn increases the temperature at station **10**. Similarly, this increase in temperature at station **10** propagates through the thermal medium C **16**, heat exchanging apparatus **20**, thermal medium D **17**, and heat exchanging apparatus **6** to station **12**. This heat flow from the first reservoir **2** to the second reservoir **7** via the third reservoir **18** and the fourth reservoir **19** will continue until a thermal equilibrium is reached once more.

[0069] In another embodiment, the apparatus shown in FIG. **1** may be used as an artificial heat source for the first reservoir **2**. Consider a configuration in which the temperature at station **9** is higher than the temperature at station **12** when all four depicted reservoirs are in thermal equilibrium. As before, the temperature at station **10** is equal to the temperature at station **9**, and the temperature at station **11** is equal to the temperature at station **12**. In this embodiment, the specific heat capacity at constant pressure of material C **16** is larger than the same of material D **17**. For example, material C **16** may be helium, while material D **17** may be air. Given that material C **16** and material D **17** are in thermal equilibrium at stations **21** and **22**, the temperature at station **10** must be larger than the temperature at station **11**. This scenario is shown in FIG. **3**. Line **28** illustrates the variation of the temperature of material C **16** in the third reservoir **18** along height z, where the temperature has also been normalized by the value of the temperature of material D **17** at station **11**. The operation of the apparatus shown in FIG. **1** as an artificial heat source is similar in principle to the aforementioned operation of the apparatus as an artificial heat sink.

[0070] Note that for some embodiments, there may be a negligible change in temperature between station **21** and station **10**. This may be the case for some gases with a very large specific heat capacity at constant pressure, or for some liquids and some solids. For instance, element **23** of heat exchanging apparatus **20** may be rigidly connected to element **4** of heat exchanging apparatus **3** by a solid material C **16**, where the solid material may be identical to the material of heat exchanging elements **23** and **4**.

[0071] FIG. **4** shows another exemplary embodiment. In this case the body force per unit mass is generated by means of centripetal acceleration of a material C **34** inside a third reservoir **33**, which is confined by an inside insulation apparatus **56**. A material D **36** inside a fourth reservoir **35**, which also confined by inside insulation apparatus **56** is subject to the same body force per unit mass distribution as material C **34**. Note that the magnitude and direction of the body force per unit mass is not constant throughout reservoirs **33** and **35**, but is instead determined by the local value of the centripetal and Coriolis accelerations, amongst other possible sources of acceleration. As in FIG. **1**, there is a first reservoir **29**, comprising a material A **30**, and a second reservoir **31**, comprising a material B **32**. A heat exchanger **37** is configured to exchange heat between the first reservoir **29** and the third reservoir **33**. In order to transfer heat from one element of the heat exchanger in the first reservoir to another element of the heat exchanger in the third reservoir, electromagnetic waves are exchanged between an outside plate **40** and an inside plate **41**. The plate may be made of a solid material specially selected and configured for a given desired heat flow rate. The material could be a metal such as copper. Heat exchanger **42** is configured similarly and performs a similar function, albeit for the fourth reservoir **35** and the second reservoir **31**. Stations **9**, **10**, **21**, **22**, **11**, and **12** in FIG. **1** correspond to stations **50**, **52**, **53**, **55**, **54**, and **51** in FIG. **4**, respectively. Heat exchanging apparatus **47** is configured to facilitate heat flow between the third reservoir **33** and the fourth reservoir **35**, similar to heat exchanging apparatus **20** in FIG. **1**. The apparatus shown in FIG. **4** is cylindrically symmetric about the axis of rotation **64** of the inside insulating apparatus **56**. Inside insulating apparatus **56** is separated from an outside insulating apparatus **57** by a gap **65** which can be described as a vacuum in this embodiment. In other embodiments, the gap may comprise a different material, such as a fluid. The inside insulating apparatus **56** contains the third reservoir **35** and the fourth reservoir **35**, and is configured to rotate about axis **64** within outside insulating apparatus **57**. The mechanical support of inside insulating apparatus **56** is provided by magnetic levitation apparatus in this particular embodiment. In other embodiments, conventional mechanical bearings, such as roller bearings, or fluid bearings may be used. The magnetic levitation apparatus comprises axial inside magnets **61** and axial outside magnets, as well as radial inside magnets **63** and radial outside magnets **62** for stability. An electric motor with a stator **59** and a rotor **58** provides the torque required for angular acceleration and deceleration, as well as for overcoming any sources of friction. In order to transfer angular acceleration to the materials contained within reservoirs **35** and **33**, there may be baffles arranged radially within these reservoirs. In other words, there may be several circumferentially arranged chambers. In this case, each chamber can be considered a reservoir in its own right. Alternatively, the angular acceleration can also be transferred using viscous friction between the walls of the reservoirs and the materials within the reservoirs. The operation of the apparatus shown in FIG. **4** follows the same principles and concepts elucidated in the context of FIG. **1**.

[0072] FIGS. **6A-6B** are a cross-sectional view of one example apparatus shown together with a plot of normalized material properties as a function of position along a length of the apparatus at a particular point in time.

[0073] The example apparatus comprises a fully enclosed chamber **117**, which contains a working material, which can be a fluid or solid, or a combination thereof. The working fluid can be a liquid, such as water, or a gas, such as air. The working fluid can also be a mixture of vapor and gas, such as a combination steam and liquid water. The working fluid or solid can be any suitable material, where suitability is a function of material properties, which can be evaluated by those skilled in the art. In the depicted example embodiment, the working fluid is an ideal gas. Chamber **117** forms a closed system around the working material. In other embodiments the working material and the apparatus employing it can form an open system.

[0074] Chamber **117** is isolated from the environment by an insulating material **110**, which prevents any unintended heat exchange between the working material in chamber **117** and the outside environment, in the ideal case.

[0075] Elements of the outside environment are able to do work on the working material via a work exchange apparatus **107**. Such elements could comprise separate actuators, such as an electric motor, for example. The actuators, as well as their associated energy supply or reservoir, are not shown for simplicity. Such apparatuses are well known in the art. In this particular embodiment, work exchange apparatus **107** is a piston, with head **109** and circular shaft **108**. In other embodiments, work exchange apparatus **107** can take other forms, such as an axial turbine or nozzle. These examples are particularly suitable in the case where the working material and the apparatus employing it form an open system, for instance. Work exchange apparatus **107** is furthermore insulated in order to prevent or minimize any unintended heat exchange between the working material in chamber **117** and the outside environment.

[0076] Piston head **109** features a surface in contact with the working material, as well as an opposing surface connected to shaft **108**. In the depicted embodiment the opposing surface is in contact with the outside material **118**. In other embodiments, the opposing surface is isolated from the surrounding material **118** by an extension of the insulating material **110**, for example. The volume thus created by the opposing surface and the extension of the insulating material is denoted the "second chamber". The second chamber and outside material **118** would be part of the aforementioned outside environment. In some embodiments, the second chamber is evacuated. This could improve the effectiveness of the insulation and reduce the energy consumed by friction during the motion of the piston. In other embodiments, the second chamber is pressurized, where the pressure is independent of the pressure of the surrounding material. The pressure of the second chamber could be modified in a way in which improvements in efficiency of the actuator operating the work exchange apparatus **107** are attained. For example, the pressure of the second chamber can be controlled in a way in which the average force being exerted by the actuator on the working material in chamber **117** during one thermodynamic cycle is reduced or substantially zero. This could reduce the average power consumption of the actuator. Alternatively, this function could be performed by a separate apparatus, such as an adjustable spring which is configured to apply a desired average force on the piston over one cycle.

[0077] At location **119** in chamber **117** there is a first inside heat exchanging apparatus **112**. Similarly, at location **120** in chamber **117** there is a second inside heat exchanging apparatus **115**. There is also a first outside heat exchanging apparatus **111** and a second outside heat exchanging apparatus **114**. In the depicted example, the heat exchanging apparatuses are embodied by a coil with a high thermal conductivity. An example material for the coil could be copper. In other embodiments, the heat exchanging apparatus can comprise a second working fluid specially selected for heat exchange. The heat exchanging apparatus could also comprise a pump or other actuator for moving the second working fluid through the heat exchanging apparatus in order to facilitate a higher rate of heat transfer between the heat exchanging apparatus and the working material or outside material **118**. The second working fluid need not be contained by the heat exchanging apparatuses in a closed system. For example, the outside material **118** can be employed as the second working fluid, which is allowed to enter and exit the heat exchanging apparatuses in an open thermodynamic system. The second working fluid can pass through the heat exchanging apparatuses via natural or forced convection. The heat exchanging apparatuses can also be specially adapted for irradiative heat transfer to and from outside material **118**, or to and from the working material. A vast number of alternative types and configurations of such a heat exchanging apparatuses are known in the art. The first and second heat exchanging apparatuses need not be identical.

[0078] The connection between the outside heat exchanging apparatus and the corresponding inside heat exchanging apparatus can be modified, such that the heat flow between these two apparatuses can be controlled. In the depicted embodiment, each outside heat exchanging apparatus can be disconnected or insulated from the corresponding inside heat exchanging apparatus. As shown, an insulating gap **116** can be formed between the second outside heat exchanging apparatus **114** and the second inside heat exchanging apparatus **115**. Similarly, as shown in FIG. **7**B, an insulating gap **113** can also be formed between the first outside heat exchanging apparatus **111** and the first inside heat exchanging apparatus **112**. In this embodiment, therefore, no heat is able to flow between the outside and corresponding inside heat exchanging apparatus when these two heat exchanging apparatuses are disconnected. In other embodiments, the amount of heat flow between the outside and corresponding inside heat exchanging apparatuses is modified without necessarily achieving a complete disconnection or insulation between these two heat exchanging apparatuses. The heat flow can be modified in numerous ways. For example, the surface area of an outside heat exchanging apparatus can be reduced in order to reduce the rate of heat transfer between the working material inside chamber **117** and the outside material **118**. In the case in which a second working fluid is employed by a heat exchanging apparatus, the flow rate of the second working fluid through the heat exchanging apparatus can be modified in order to control the rate of heat transfer between chamber **117** and the outside material **118**. Alternatively, a second material with a different thermal conductivity can be inserted into, or removed from, the thermal circuit connecting the outside and corresponding inside heat exchanging apparatuses. For example, when the thermal conductivity of the second material is lower than the thermal conductivity of the material used in the heat exchanging apparatuses, the rate of heat transfer between chamber **117** and outside material **118** is reduced when the second material is inserted. There are a large number of other configurations and methods available for modifying and controlling the heat flow of a heat exchanger for a given temperature difference between two thermal reservoirs, i.e. the working material and outside material **118**.

[0079] Outside material **118** can also be any type of material, such as a gas, liquid, or solid. For example, the outside material can be the contents of a thermal reservoir which is to be cooled, as exemplified by the inner chamber of a refrigerator. When the depicted apparatus is operated as an artificial heat source, outside material **118** is the thermal reservoir which is to be heated. Outside material **118** may also be modeled as an object capable of emitting or absorbing electromagnetic waves.

[0080] In accordance with exemplary embodiments, a force per unit mass is acting on the working material in chamber **117** and the force may be a body force or a mechanical force. In FIGS. **6**A-**6**B, the force is a body force per unit mass. In a simplified example, the body force per unit mass is constant in position and time throughout chamber **117**. This configuration is shown in FIGS. **6**A-**6**B, where the body force per unit mass is directed vertically downwards towards the bottom of the page. Note that this description of the direction is relative to the page only, and is unrelated to the orientation of the apparatus relative to an inertial frame, such as an inertial frame located on the surface of the earth. The plot on the left side of FIGS. **6**A-**6**B, illustrates the resulting variation of thermodynamic properties of the working material along the length "z" of chamber **117**, where the length is measured parallel to and indicated by the y-axis of said plot. In this plot, line **104** indicates the variation of the body force per unit mass along length z, where the body force per unit mass has been normalized by its value at the point where the length z is equal to zero. Similarly, line **103** portrays the variation of the normalized specific volume along length z, while line **105** illustrates the variation of the normalized temperature, and line **106** the variation of the normalized pressure along length z. In this example, the first outside heat exchanging apparatus **111** is connected to the first inside heat exchanging apparatus **112**. Therefore the temperature of the working material inside chamber **117** at location **119** is substantially equal to the temperature of the outside material **118** at this location. In the depicted examples, the temperature of outside material **118** is uniform in space and time, for simplicity. Since the body forces acting on the working material are directed towards the bottom of the page in FIGS. **6**A-**6**B, the working material is compressed as the length z is decreased. Thus the pressure rises and the specific volume decreases. The insulating material **110** around chamber **117** ensures a substantially adiabatic compression in this case, resulting in an increased temperature at location **120** compared to location **119**, as indicated by line **105**.

[0081] In other embodiments, the walls may not be perfectly insulating, resulting in a distribution of thermodynamic properties which lies in between the adiabatic case and the isothermal case. In other embodiments, the force need not be constant in space or time in chamber **117**.

[0082] In other embodiments, the force generation apparatus comprises the work exchange apparatus. In other words, the force generation apparatus or mechanism can be configured relative to chamber **117** in a manner in which the force can be made to vary with time, such that work can be done on and by the working material. For example, during a portion of time during which the purpose of the work exchange apparatus is to compress the working material, the force inside chamber **117** can be increased. Throughout the compression process work will be done by the body force actuation mechanism on the working material. An expansion process involving the work exchange apparatus would follow similar principles of operation.

[0083] As mentioned, body forces can be generated by a variety of methods. One type of body force is the gravitational force acting on the working material.

[0084] Another type of body force is an inertial force, which can be generated by accelerating the depicted apparatus, comprising chamber **117** and insulating material **110**, in an inertial reference frame. When accelerating the apparatus at a constant acceleration in an inertial frame in a direction vertically upwards towards the top of the page, the working material inside chamber **117** will experience an apparent acceleration relative to chamber **117** and insulating material **110**, where the apparent acceleration is directed vertically downwards towards the bottom of the page. Inertial forces can be generated by linear acceleration, i.e. motion of the apparatus along a straight line in the inertial frame. Inertial forces can also be generated by angular acceleration, i.e. motion of the apparatus along a curved path. In general, inertial forces can be generated by any accelerating motion in an inertial frame. Consider the aforementioned embodiment in which the depicted apparatus undergoes circular motion in an inertial frame, where the radius and angular velocity remain constant. In the embodiment shown in FIGS. **6**A-**6**B, the axis of rotation could be parallel to and coincident with the centerline of a circular piston shaft **108**, for example. Note that the centripetal acceleration varies linearly with radius in this embodiment. If a substantially uniform body force per unit mass of working material is desired, the depicted apparatus can be located at a larger radius, where the radial dimension of the apparatus is only a fraction of said radius. For instance, the radius can be increased by placing the axis of rotation further upwards towards the top of the page in FIGS. **6**A-**6**B. In other embodiments, the direction vector of the axis of rotation can have components parallel to the plane described by the vector pointing perpendicularly out of the page containing FIGS. **6**A-**6**B, as well as the vector parallel to the centerline of piston shaft **108**. Other embodiments can have different locations and orientations of the axis of rotation, as well as different rotational velocities. These parameters may also vary in time.

[0085] A further type of body force is an electromagnetic force. For example, the elements of the working material in chamber **117** can be configured to be electrically charged. In the context of a material, the term "elements" refers to the constituent parts of the material, such as subatomic particles, atoms, molecules, or a distinct or specified collection of molecules, for example. In the case of a gas, the atoms or molecules could be positively or negatively ionized, for instance. The working material may also comprise a collection of mobile electrons. Note that this collection may be contained in a solid, such as a conductor, or it may be described as a gas. By applying an electric field within chamber **117**, body forces can be generated on the electrically charged elements of the working material. When at least a subset of these elements are mobile in the sense that they can move relative to each other and be compressed, a pressure and temperature gradient can be generated inside chamber **117** in accordance with the aforementioned principles.

[0086] Embodiments employing other types of forces or combinations thereof are within the spirit and scope of the invention. In one embodiment of the invention, there is provided a method for exchanging heat between two reservoirs, where the range of relative average temperatures of the reservoirs for which heat can be made to flow in a specified direction is increased compared to heat exchangers in the prior art. In the following method, the first reservoir is denoted the "working material" while the second reservoir is denoted the "external reservoir". The method comprises: subjecting the material in at least one of the two reservoirs, defined as the working material, to a body force per unit mass, such that a difference in temperature can be generated between at least two different points in the working material, where the two points can are distinct in space or time; enclosing at least a portion of the working material with an insulating material, where the enclosure and the insulating material are configured to inhibit or reduce heat flow between the working material and the external reservoir in an unintended direction, as well as facilitate the heat transfer between the external reservoir and the working material in the intended direction, where the facilitation can comprise thermally connecting a point in the working material as well as a point in the external reservoir, such that the temperature difference between these two points allows heat to flow between the two reservoirs in the intended direction, where the thermal connection can comprise placing the two reservoirs in physical contact at these two points, where physical contact can refer to electromagnetic radiation emitted by one reservoir to be absorbed by the other, where the two points may or may not be substantially coincident, or it can refer to individual material elements coming into direct contact to allow thermal conduction to take place, where the two points are substantially coincident, or it can refer to the exchange of material between the reservoirs in a convection process, or placing at least one heat exchanging apparatus between the two points, where the heat exchanging apparatus is configured to enable the heat transfer between the external reservoir and the working material in the intended direction, where the two points may or may not be substantially coincident. Note that the aforementioned external reservoir can also be subjected to forces in a similar fashion as the working material. This could further increase the range of relative average temperatures between the reservoirs for which heat can be made to flow between the reservoirs in a specified direction. In some embodiments, the difference in the average temperature of a heat source and the average temperature of a heat sink can be less than or equal to zero. This method can be employed to operate an artificial heat sink or artificial heat source, for example. As shown in the drawings and as will be described in the following paragraphs, said method can also be applied to the operation of a heat pump, such as a refrigerator, or heat engine.

[0087] Note that in the case in which the external reservoir is in physical contact with the working material, the material properties of the external reservoir and working material may need to be specially configured. For example, when placed in direct contact, the pressure of the external reservoir at the location of contact should match the pressure of the working material, if a steady equilibrium configuration is desired. If diffusion of the two reservoirs is to be avoided or reduced, provisions can be made. For example, the material of one reservoir could be in a different phase than the material of the other. One reservoir could contain solid material, while the other contains gaseous material, for instance.

[0088] FIG. **5** is a plot of pressure versus specific volume, which indicates the variation of said parameters at different locations within one example apparatus and at different points in time during one example method of operation.

[0089] In FIGS. **7A-7H** a cross-sectional view of the example apparatus of FIGS. **6A-6B**, is shown in different configurations in accordance with different points in time during the example method of operation shown in FIG. **5**.

[0090] In FIG. **7A**, the example apparatus of FIGS. **6A-6B**, is shown in a configuration that can be described as follows. The first outside heat exchanging apparatus **111** and the first inside heat exchanging apparatus **112** form a closed thermal circuit, allowing heat exchange between outside material **118** and working material in chamber **117**. The thermodynamic properties of the working material are constant in time in the configuration shown in FIG. **7A**, and the outside material and working material are in thermal equilibrium. Thus, the temperature of the working material at location **119** in FIGS. **6A-6B**, is equal to the temperature of outside material **118**. The thermodynamic state **81** of the working material at location **119** in FIGS. **6A-6B**, is indicated in FIG. **7A** and shown in FIG. **5**. In this configuration, an insulating gap **116** is present between the second outside heat exchanging apparatus **114** and the second inside heat exchanging apparatus **115**. A uniform body force per unit mass is acting on the working material in chamber **117**, where the body force is directed vertically downwards towards the bottom of the page. In this simplified example, insulating material **110** prevents any exchange of heat between the working material and outside material **118**. The insulating material **110** also spatially confines the working material, i.e. it is exerting a pressure on the working material. In other embodiments, the working material can be confined by action of body forces, or interaction with other elements of the working material. As a result, the working material is compressed along the negative length z of chamber **117** as indicated in the plot on the left of FIGS. **6A-6B**. Since no heat is exchanged with the environment, the compression can be modeled as an adiabatic compression, resulting in an increase in temperature along the negative length z, as shown in FIGS. **6A-6B**. This adiabatic compression is also illustrated by the light dashed line **96** in FIG. **5**. The thermodynamic state **85** of the working material at location **120** in FIGS. **6A-6B**, is shown in FIG. **7A** and shown in FIG. **5**. The average thermodynamic state **89** of the entire working material enclosed in chamber **117** in the configuration shown in FIG. **7A** is also shown in FIG. **5**. The piston of work exchange apparatus **107** is in a retracted position, as shown.

[0091] In FIG. **7B**, the equilibrium configuration shown in FIG. **7A** has been disturbed by closing insulating gap **116**, allowing the second outside heat exchanging apparatus **114** and the second inside heat exchanging apparatus **115** to form a closed thermal circuit. The first outside heat exchanging apparatus **111** has also been disconnected from the first inside heat exchanging apparatus **112** with insulating gap **113**. In the configuration shown in FIG. **7A** the thermodynamic state **85** featured a higher temperature than thermodynamic state **81**, which featured the same temperature as outside material **118**. Therefore, following the elimination of insulating gap **116**, there is an instantaneous temperature difference between the working material at state **85** at location **120** and outside material **118**. As indicated by "QOUT", heat will flow from the working material to outside material **118** until a new equilibrium configuration is reached.

[0092] FIG. **7C** illustrates the new equilibrium configuration. In this particular example it is assumed, for simplicity, that the temperature change of outside material **118** is negligible throughout this process. This would be a valid assumption when there is a large ratio of the mass of outside material **118** to the mass of the working material, or when there is an external energy source or sink regulating the internal energy of outside material **118**. In other embodiments, there may be a non-negligible change in temperature of outside material **118** throughout one cycle. This would be desirable when the apparatus is operated as an artificial heat source or sink. Similar to the configuration in FIG. **7A**, the temperature of thermodynamic state **86** is now equal to the temperature of outside material **118**. In FIG. **5**, this is illustrated by the fact that state **86** and state **81** lie on isothermal line **94**. Due to the action of the body forces, and the temperature boundary condition provided by thermodynamic state **86**, the temperature at thermodynamic state **82** is lower compared to state **86**. Adiabatic line **97** illustrates the variation of the thermodynamic properties between state **86** and state **82** along length z of the apparatus. Note that the position of piston head **109** is unchanged in FIGS. **7A-C**. Since the working material has lost thermal energy without a change in volume, the average pressure and temperature of the working material in chamber **117** have been reduced while the average specific volume has remained constant. The new average thermodynamic state **90** is therefore connected by a vertical line to the previous average thermodynamic state **89** in FIG. **5**. In other embodiments, this line need not be vertical, but can have any other orientation, such as a horizontal orientation.

[0093] In FIG. **7**D work exchange apparatus **107** is employed to do work on the working material, where the work is indicated by "WIN". In this particular embodiment, piston head **109** is employed by an actuator to compress the working material. Note that the configuration of the first and second heat exchanging apparatuses is unchanged compared to FIGS. **7**B-**7**C. Therefore any increase in temperature of the working material as a result of work being done on it leads to an increase in the rate of heat flow from the working material through the second inside and outside heat exchanging apparatuses **115** and **114** to outside material **118**, as indicated by "QOUT". The rate of work input into the working material is controlled in such a manner, that it substantially equals the rate of heat flow from the working material to outside material **118** at all instants of time during the compression. In this case, the compression would be isothermal. In other embodiments, the compression need not be isothermal, as will be explained later.

[0094] FIG. **7**E illustrates the new equilibrium position once work exchange apparatus **107** is no longer doing work on the working material. As in FIGS. **7**C-**7**D, the temperature at state **87** is equal to the temperature of outside material **118**. In this embodiment, the temperature at state **83** is substantially equal to the temperature at state **82**. Isothermal line **95** connects state **82** and state **83**. The new average thermodynamic state **91** is also shown in FIG. **5**. Adiabatic line **98** describes the variation of the thermodynamic properties between state **83** and state **87** along length z of the apparatus. Note that the temperature at state **83** is lower than the temperature at state **87**, and hence the temperature of outside material **118**.

[0095] In FIG. **7**F the equilibrium configuration shown in FIG. **7**E has been disturbed by closing insulating gap **113**, which allows the first outside heat exchanging apparatus **111** and the second inside heat exchanging apparatus **112** to form a closed thermal circuit. The second outside heat exchanging apparatus **114** has also been disconnected from the second inside heat exchanging apparatus **115** by insulating gap **116**. Due to the instantaneous temperature difference between the working material at state **83** at location **119** and outside material **118**, heat will flow from outside material **118** to the working material to until a new equilibrium configuration is reached. The heat flow is indicated by "QIN".

[0096] FIG. **7**G illustrates the new equilibrium configuration. The temperature at state **84** is now equal to the temperature of outside material **118**. Adiabatic line **99** illustrates the variation of the thermodynamic properties between state **84** and state **88** along length z of the apparatus. Note that the position of piston head **109** is unchanged in FIGS. **7**E-**7**G. The new average thermodynamic properties **92** are indicated in FIG. **5**.

[0097] In FIG. **7**H the working material does work on work exchange apparatus **107**, where the work is indicated by "WOUT". Note that the actuator operating the work exchange apparatus **107** is configured to be able to do work on the working material, as well as extract work from the working material. Thus, the actuator and its associated energy reservoir is configured to extract or recover energy from the work done by the working material on work exchange apparatus **107**. Following similar principles of operation described in the context of FIG. **7**D, the expansion process shown in FIG. **7**H and FIG. **5** is isothermal. Thus any decrease in temperature of the working material as a result of its expansion results in an increase in the rate of heat flow from outside material **118** through the first outside and inside heat exchanging apparatuses **111** and **112** into the working material, as indicated by "QIN". The thermodynamic properties of the working material at location **120** throughout the isothermal expansion are described by isothermal line **93** in FIG. **5**.

[0098] Once piston head **109** has reached its original position, the motion of the piston can be stopped. The new equilibrium configuration would then be identical to the initial configuration shown in FIG. **7**A. Thus one complete, repeatable thermodynamic cycle has been described. The aforementioned processes which form the cycle can also be carried out in reverse order.

[0099] Throughout this cycle, the thermodynamic properties of the working material at location **120** are described by bold dashed line **102** in FIG. **5**. The thermodynamic properties of the working material at location **119** are described by bold dotted line **100** in FIG. **5**. The average thermodynamic properties of the working material in chamber **117** are described by bold line **101**.

[0100] Note that the aforementioned isothermal compressions or expansions need not be isothermal. They can be adiabatic, for example. In the adiabatic case, the shape or configuration of the thermodynamic properties shown in FIG. **5** will have to be changed or adapted to a new shape. For example, the temperature at the corresponding state **81** of the new shape may be configured to be lower than the corresponding temperature of the outside material, while temperature at the corresponding state **84** of the new shape can be less than or equal to the temperature of the corresponding outside material. This would ensure a closed line similar to line **100** in FIG. **5**. The other closed lines shown in FIG. **5** can be adapted accordingly in the aforementioned adiabatic case.

[0101] In FIG. **5**, the values of the pressure and specific volume shown on the axes are arbitrary and only selected to provide an example. They are not intended to limit the scope of the invention to a particular type of fluid or to a particular range of pressures of specific volumes.

[0102] FIG. **8** is a plot of material properties for one example embodiment during one example method of operation. The horizontal x-axis **167** denotes the specific volume of the working material in question, and the vertical y-axis **168** denotes the pressure of the working material. Note that the units shown are arbitrary and included only for the sake of example, and are not intended to limit the scope of the invention to a particular method of operation or type of working material.

[0103] FIG. **8** shows a first cycle and a second cycle. The first cycle comprises an adiabatic compression **151** between a first station **150** and a second station **155**, an isobaric expansion **152** with heat addition between second station **155** and third station **156**, an adiabatic expansion **153** between third station **156** and fourth station **157**, and an isobaric compression **154** with heat removal between fourth station **157** and a fifth station, which is identical to first station **150**. In some embodiments, first station **150** describes the properties of a working material in the free stream, i.e. at ambient pressure and specific volume, and fourth station **157** approximately describes the properties of a working material at the outlet or the exhaust of a thermodynamic apparatus. The isobaric compression **154** can thus occur in the wake, i.e. downstream, of an embodiment of the invention. In other embodiments, the first cycle can be a closed cycle. Note that the first cycle is similar to a conventional Brayton cycle. In other embodiments, the first cycle can be similar to an Otto cycle. In other embodiments, the first cycle can be similar to a Diesel cycle. A wide variety of different shapes or forms of the first cycle are readily conceivable. For example, the compression between station **150** and station **155** can be isothermal instead of adiabatic.

[0104] The second cycle comprises an adiabatic expansion **159** between a first station **150** and a second station **163**, an isobaric compression **160** involving heat removal between second station **163** and third station **164**, an adiabatic compression **161** between third station **164** and fourth station **165**, and an isobaric expansion **162** between fourth station **165** and a fifth station, which is identical to first station **150**. In some embodiments, first station **150** describes the properties of a working material in the free stream, i.e. at ambient pressure and specific volume, and fourth station **165** approximately describes the properties of a working material at the outlet or the exhaust of a thermodynamic apparatus, such as a turboshaft engine. The isobaric expansion **162** can thus occur in the wake, i.e. downstream, of an embodiment of the invention. In other embodiments, the second cycle can be a closed cycle.

[0105] Both the first cycle and the second cycle produce a positive mechanical work output.

[0106] In some embodiments described by FIG. **8**, the rate of heat removed from the working material in the second cycle during isobaric compression **160** is substantially equal to the rate of heat added to the working material in the first cycle during isobaric expansion **152**. Note that the mass flow rate of working material in the first cycle need not be equal to the mass flow rate of working material in the second cycle. In some embodiments, the heat removed from the working material in the second cycle is the same heat which is added to the working material in the first cycle. The heat transfer from the colder working material between stations **163** and **164** to the hotter working material between stations **155** and **156** is facilitated by a heat transfer apparatus.

[0107] The working material in the first cycle need not be of the same type as the working material of the second cycle. The working material of the first cycle can be air, while the working material of the second cycle can be helium, for example.

[0108] In other embodiments, expansion **159** can be a compression instead, and compression **161** can be an expansion instead, where the pressure at the equivalent second station **163** of the second cycle is lower than the pressure at the second station **155** of the first cycle. In such embodiments, the first cycle produces a net mechanical work output, while the second cycle consumes work. In other words, the working material does work on the environment in the first cycle, and the environment does work on the working material in this particular second cycle. The first cycle and the second cycle can be configured in a manner in which the combined power output of the first and second cycles is positive.

[0109] FIG. **9** is a plot of material properties for one example embodiment during one example method of operation. Some features of the cycle shown in FIG. **9** as well as some of the principles of operation of the associated thermodynamic apparatuses share similarities with features and principles of operation described by the other figures, and will therefore not be described in the same detail in the context of FIG. **9**, and vice versa.

[0110] The horizontal x-axis **193** denotes the specific volume of the working material in question, and the vertical y-axis **194** denotes the pressure of the working material.

[0111] The depicted thermodynamic cycle comprises a first adiabatic expansion **187** between first station **180** and second station **181**, a first isobaric compression **188** to third station **182**, a first adiabatic compression **189** to fourth station **183**, a first isobaric expansion **190** to fifth station **184**, a second adiabatic expansion **191** to sixth station **185**, and a second isobaric expansion **192** to a seventh station, which is equal to first station **180**.

[0112] In some embodiments, first station **180** describes the properties of a working material in the free stream, e.g. air at ambient pressure and ambient specific volume, and sixth station **185** approximately describes the properties of a working material at the outlet or the exhaust of a thermodynamic apparatus. The isobaric expansion **192** can thus occur in the wake, i.e. downstream, of an embodiment of the invention. In other embodiments, the first cycle can be a closed cycle.

[0113] The depicted thermodynamic cycle produces a net positive mechanical work output, i.e. the working a material does work on the environment.

[0114] In some embodiments described by FIG. **9**, the rate of heat removed from the working material during isobaric compression **188** is substantially equal to the rate of heat added to the working material in the first cycle during isobaric expansion **190**. In some embodiments, the heat removed from the working material during isobaric compression **188** is the same heat which is added to the working material during isobaric expansion **190**. The heat transfer from the colder working material between stations **181** and **182** to the hotter working material between stations **183** and **184** is facilitated by a heat transfer apparatus.

[0115] The working material can be a compressible gas such as air or carbon dioxide. The thermodynamic apparatus performing the compression or expansion processes can be a compressor or turbine of the axial flow type, or of the centrifugal type, for example. These processes can also be carried out in a piston.

[0116] FIG. **10** is a plot of material properties for one example embodiment during one example method of operation. Some features of the cycle shown in FIG. **10** as well as some of the principles of operation of the associated thermodynamic apparatuses share similarities with features and principles of operation described by the other figures, and will therefore not be described in the same detail in the context of FIG. **10**, and vice versa.

[0117] The horizontal x-axis **218** denotes the specific volume of the working material in question, and the vertical y-axis **219** denotes the pressure of the working material.

[0118] The depicted thermodynamic cycle comprises a first adiabatic compression **212** between first station **205** and second station **206**, a first isobaric expansion **213** to third station **207**, a first adiabatic expansion **214** to fourth station **208**, a first isobaric compression **215** to fifth station **209**, a second adiabatic compression **216** to sixth station **210**, and a second isobaric expansion **217** to a seventh station, which is equal to first station **205**.

[0119] In some embodiments, first station **205** describes the properties of a working material in the free stream, e.g. air at ambient pressure and ambient specific volume, and sixth station **210** approximately describes the properties of a working material at the outlet or the exhaust of a thermodynamic apparatus. The isobaric expansion **217** can thus occur in the wake, i.e. downstream, of an embodiment of the invention. In other embodiments, the first cycle can be a closed cycle.

[0120] The depicted thermodynamic cycle produces a net positive mechanical work output, i.e. the working a material does work on the environment, i.e. the thermodynamic apparatus it interacts with.

[0121] In some embodiments described by FIG. **9**, the rate of heat removed from the working material during isobaric compression **215** is substantially equal to the rate of heat added to the working material during isobaric expansion **213**. In some embodiments, the heat removed from the working material during isobaric compression **215** is the same heat which is added to the working material during isobaric expansion **213**. The heat transfer from the colder working material between stations **208** and **209** to the hotter working material between stations **206** and **207** is facilitated by a heat transfer apparatus.

[0122] FIG. **11** is a schematic representation of a heat engine or heat pump. Some features of the cycles shown in FIG. **11** as well as some of the principles of operation of the associated thermodynamic apparatuses share similarities with features and principles of operation described by the other figures, such as FIG. **8** or FIG. **15** in particular, and will therefore not be described in the same detail in the context of FIG. **11**, and vice versa.

[0123] A first thermodynamic cycle comprises an inflow **230** of a working material into a expander **231**, the outflow **232** of which is cooled by heat transfer apparatus **236**, the outflow **237** of which flows into a compressor **238** which is powered via work “WINTA” **234** by expander **231**, and the outflow **239** of which is released into the same reservoir which provides the inflow **230**. This reservoir can be the atmosphere, for example. The surplus work **233** of the thermodynamic cycle is available as “WOUTA”.

[0124] An expander, such as expander **231**, can by any thermodynamic apparatus which can reduce the pressure of a working material. For example, an expander can be a piston, an axial or centrifugal turbine, or a duct or nozzle. Typically, the working material will do mechanical work on the expander. Typically, a portion of this mechanical work can be recovered to do useful work, e.g. power an electric generator or produce thrust.

[0125] A second thermodynamic cycle comprises an inflow **241** of a working material into a compressor **242**, which is powered via a work “WINTB” **244** by expander **248**, and the outflow **243** of which is heated by heat transfer apparatus **236**, the outflow **247** of which flows into a expander **248**, the outflow **249** of which is released into the same reservoir which provides the inflow **241**. This reservoir can be the atmosphere, for example. The surplus work **250** of the thermodynamic cycle is available as “WOUTB”.

[0126] The rate of heat flow “QINT” is flowing through heat transfer apparatus **236**.

[0127] The first thermodynamic cycle shown in FIG. **8** corresponds to the second thermodynamic cycle shown in FIG. **11** for some embodiments. The second thermodynamic cycle shown in FIG. **8** corresponds to the first thermodynamic cycle shown in FIG. **11** for some embodiments.

[0128] FIG. **12** is a schematic representation of a heat pump or a heat engine. Some features of the cycle shown in FIG. **12** as well as some of the principles of operation of the associated thermodynamic apparatuses share similarities with features and principles of operation described by the other figures, such as FIG. **14** or FIG. **10** in particular, and will therefore not be described in the same detail in the context of FIG. **12**, and vice versa.

[0129] The depicted thermodynamic cycle comprises an inflow **260** of working material into a first compressor **261**, which is powered via a shaft **263** by expander **267**, and the outflow **262** of which is heated by a heat transfer apparatus **265**, the outflow **266** of which flows into a expander **267**, the outflow **268** of which is cooled by a conventional heat exchanger **269**, the outflow **270** of which flows into a second compressor **271**, which is powered via a shaft **275** by expander **267**, and the outflow **272** of which is released into the same reservoir which provides the inflow **260**. A thermal fluid within a pipe apparatus **274** is circulated by a pump in order to enhance the heat transfer from heat exchanger **269** to heat transfer apparatus **265**. Heat flow “QINT” flows through heat transfer apparatus **265**. The surplus work of the thermodynamic cycle is available “WOUT” **273**.

[0130] FIG. **13** is a schematic representation of a heat pump or a heat engine. Some features of the cycle shown in FIG. **13** as well as some of the principles of operation of the associated thermodynamic apparatuses share similarities with features and principles of operation described by the other figures, such as FIG. **9** in particular, and will therefore not be described in the same detail in the context of FIG. **13**, and vice versa.

[0131] The depicted thermodynamic cycle comprises an inflow **290** of working material into a first expander **291**, the outflow **292** of which is cooled by a conventional heat exchanger **295**, the outflow **296** of which flows into a compressor **297**, which is powered via a shaft **293** by first expander **291** and/or via shaft **305** by second expander **301**, and the outflow **298** of which is heated by a heat transfer apparatus **299**, the outflow **300** of which flows into a second expander **301**, the outflow **302** of which is released into the same reservoir which provides the inflow **290**. A thermal fluid within a pipe apparatus **304** is circulated by a pump in order to enhance the heat transfer from heat exchanger **295** to heat transfer apparatus **299**. Heat flow “QINT” flows through heat transfer apparatus **299**. The surplus work of the thermodynamic cycle is available “WOUT” **303**.

[0132] In other embodiments, the location of the exchanger can be reversed with the location of the heat transfer apparatus. In other words, the heat exchanger can be located downstream of compressor **297** and upstream of second expander **301**, and the heat transfer apparatus can be located downstream of first expander **291** and upstream of compressor **297**.

[0133] In general, the heat can be transported from outflow **292** to outflow **298** via any number of heat exchangers and any type of heat transport mechanism, such as radiation, natural or forced convection, or conduction, as long as at least one suitably configured heat transfer apparatus, such as the heat transfer apparatuses shown in FIG. **1**, FIG. **4**, or

FIG. **15**, is located along the thermal path between outflow **292** and outflow **298**. The same applies to FIG. **11** and FIG. **12**. In the example shown in FIG. **13**, for instance, the heat is transferred from outflow **262** via forced convection of a thermal fluid through a pipe apparatus **304**, and subsequently via conduction into the heat transfer apparatus **299**, from which the heat is delivered to outflow **298** via conduction, radiation.

[0134] FIG. **14** is a cross-sectional view of one embodiment of the invention. Some features of the cycle shown in FIG. **14** as well as some of the principles of operation of the associated thermodynamic apparatuses share similarities with features and principles of operation described by the other figures, such as FIG. **12** and FIG. **10** in particular, and will therefore not be described in the same detail in the context of FIG. **14**, and vice versa.

[0135] Engine **320** shares features and principles of operation with a conventional turbojet or turboshaft engines. Engine **320** comprises a duct apparatus **321** and an inside apparatus **322**.

[0136] Several components of engine **320** are substantially axially symmetric about axis **369**.

[0137] Bulk material **323** of engine **320** can comprise several different material types. For example, bulk material **323** can comprise metals such as titanium or aluminum, ceramics, or composites, such as carbon fiber composites or fiberglass.

[0138] Inside apparatus **322** comprises an optionally annular shaped channel **342** between annular inlet **341** and annular outlet **343**, and between outer inside surface **349** and interior inside surface **350**. The outside surface **348** of duct apparatus **321** is indicated.

[0139] A working material flows through channel **342** from inlet **341** to outlet **343**. The working material can be a compressible fluid. The fluid can be a gas such as air or carbon dioxide for example. Note that liquids such as water are also compressible.

[0140] After passing through inlet **341**, the working material flowing through channel **342** sequentially encounters a first compressor **324**, a first heat exchanger **326**, a turbine **332**, a second heat exchanger **334**, and a second compressor **340** before exiting through the outlet **343**.

[0141] In this embodiment, the first compressor **324** and the second compressor **340** can be described as axial flow compressors. Other embodiments can comprise other types of compressors. The compressors can be centrifugal compressors, for example.

[0142] In this embodiment, the turbine **332** is an axial flow turbine. Other embodiments can comprise other types of turbines. The turbines can be centrifugal turbines, for example.

[0143] The compressors and turbine may comprise several rotor blades, such as rotor blade **346**, and several stator blades, such as stator blade **347**. The rotor blades of a rotor disc are arranged circumferentially about the axis rotation, i.e. axis **369**. The stator blades area also arranged circumferentially. A rotor disc and the downstream stator disc form a stage. In the depicted embodiment, the turbine has 4 stages. In other embodiments, the compressors and the turbine can have at least one stage. In other embodiments, the compressors and the turbine can have at least one rotor disc, where each rotor disc has at least one rotor blade.

[0144] In the depicted embodiment, the individual compressor rotor blades of the first and second compressors and the individual turbine rotor blades are connected to the same shaft. Engine **320** can therefore be described as a single spool engine.

[0145] In other embodiments, the engine can be a multi-spool engine. In other words, there can be more than one drive shaft being driven by at least one turbine rotor disc. For example, consider the following embodiment. The first two turbine rotor discs counted in a downstream direction can be connected to a first drive shaft which is connected to the second and third compressor rotor discs of the first compressor **324**. The third turbine rotor disc can be connected to a second drive shaft which is connected to the first compressor rotor disc of the first compressor **324**. The third turbine rotor disc can be connected to a third drive shaft, which can power an electric generator, the propeller apparatus of a turboprop aircraft, or the fan of a turbofan aircraft, for instance. The fourth turbine rotor disc can be connected to a fourth drive shaft, which is connected to all of the compressor rotor discs of the second compressor **340**.

[0146] First heat exchanger **326** is configured to transfer heat from a heat transfer apparatus **351** to the working material in channel **342** during nominal operations. The location of heat exchanger **326** inside channel **342**, i.e. the portion of channel **342** located downstream of first compressor **324** and upstream of turbine **332** is denoted the heating chamber. In this particular embodiment, this is accomplished via forced convection of a thermal fluid by a pump, such as pump **329**, through a pipe apparatus. The thermal fluid can be water, oil, molten salt, or a fluid specially adapted for the application of transferring heat from a first reservoir, such as the radially outward portion of the heat transfer apparatus **351**, to a second reservoir, such as the working material in the heating chamber, via forced convection. In some embodiments, the thermal fluid can undergo a phase change throughout the pipe apparatus. The pipe apparatus and pump **329** facilitate the transport of said thermal fluid through the heat transfer apparatus **351** and through the working material in the heating chamber. In this particular embodiment, the portion of the pipe apparatus within channel **342** can be described as a counter-current heat exchanger. In other embodiments, the heat exchanger can be a co-current heat exchanger, or a cross-flow heat exchanger, for example. The portion of the pipe apparatus which is in contact with the working material in channel **342** comprises several smaller pipes, such as pipe **327**, in order to increase the contact area and enhance the heat flow rate from the thermal fluid to the working material. The portion of the pipe apparatus of first heat exchanger **326** which is enclosed by the annular, cylindrical heat transfer apparatus **351** indicates the location where heat is transferred from the heat transfer apparatus **351** to the thermal fluid inside the pipe apparatus of first heat exchanger **326**. Once the heat has been transferred from the heat transfer apparatus **351** to the thermal fluid inside the pipe apparatus, the pipe apparatus transports the thermal fluid back to the heating chamber, where heat is transferred from the thermal fluid to the working material.

[0147] Note that the thermal fluid heats the working material and transfers heat from the radially outward portion of the heat transfer apparatus **351** during nominal operations. The term "thermal" is used only to indicate the transport of heat by the fluid, and should not be interpreted to indicate the magnitude or direction of the change of temperature of any thermal reservoirs associated with, or in thermal contact with, the thermal fluid. The thermal fluid can also be described as a cooling fluid, or a refrigerant. Since the channel **342** is annular, the heat exchanger **326** is axially symmetric about axis **369**.

[0148] Second heat exchanger **334** is configured in a similar manner as first heat exchanger **326**, and vice versa. Second heat exchanger **334** is configured to transfer heat from the working material in channel **342** to the radially inward portion, or the base, of heat transfer apparatus **351** during nominal operations. The location of heat exchanger **334** inside channel **342**, i.e. the portion of channel **342** located downstream of turbine **332** and upstream of second compressor **340** is denoted the cooling chamber. As before, this is accomplished via forced convection of a thermal fluid by a pump, such as pump **337**, through a pipe apparatus **336**. Note that the thermal fluid in the second heat exchanger **334** need not be identical to the thermal fluid in the first heat exchanger **326**. The pipe apparatus **336** and pump **337** facilitate the transport of said thermal fluid through the heat transfer apparatus **351** and through the working material in the cooling chamber. In this particular embodiment, the portion of the pipe apparatus within channel **342** can be described as a counter-current heat exchanger. The portion of the pipe apparatus which is in contact with the working material in channel **342** comprises several smaller pipes, such as pipe **335**. The portion of the pipe apparatus **336** which is enclosed by heat transfer apparatus **351** indicates the location where heat from the thermal fluid inside pipe apparatus **336** is transferred to the heat transfer apparatus **351**. Once the heat has been transferred from the thermal fluid to the heat transfer apparatus **351**, the pipe apparatus **336** transports the thermal fluid back to the pump and the cooling chamber, where heat is transferred from the working material to the thermal fluid.

[0149] Heat transfer apparatus **351** is configured to be able to transfer heat from a first thermal reservoir to a second thermal reservoir, where the temperature of the first thermal reservoir is lower than the temperature of the second thermal reservoir. During nominal operations, the temperature of the first thermal reservoir of heat transfer apparatus **351** is lower than the temperature of the second thermal reservoir. Thus the first thermal reservoir can be denoted the cold reservoir, and the second thermal reservoir can be denoted the hot reservoir. In engine **320**, the cold reservoir comprises the working material in the cooling chamber, and the hot reservoir comprises the working material in the heating chamber.

[0150] The temporal variation of the thermodynamic properties of the working material flowing through channel **342** is similar to the variation depicted in FIG. **10**, and the thermodynamic system is also described by the schematic diagram shown in FIG. **12**.

[0151] Following a compression, the working material is heated, expanded, cooled, and compressed once more before passing through outlet **342**. In the wake of engine **320**, the working material having passed through channel **342** is heated by the surrounding working material and returned to substantially the original, free stream thermodynamic properties. This thermodynamic cycle can be described as an open cycle, since work, matter and heat are exchanged with the environment, i.e. the region outside of channel **342**. Other embodiments can fully enclose a working material, resulting in a closed thermodynamic cycle. Some such embodiments can comprise an apparatus similar to engine **320**, in addition to a channel section which connects outlet **343** with inlet **341**, where said channel section comprises a third heat exchanger which is configured to transfer heat from the environment outside of the closed channel into the closed channel. Depending on the temperature of the outside environment, the third heat exchanger can be configured to transfer heat from a cold reservoir outside to a hot reservoir inside the closed channel, or from a hot reservoir outside to a cold reservoir inside the closed channel, as long as heat is transferred from the outside environment into the closed channel by the third heat exchanger.

[0152] Note that the aforementioned embodiments are configured to convert thermal energy into mechanical work. In FIGS. **8-10**, the amount of work is determined by the areas enclosed by the closed curves, where the sign of the work done by the working material is positive for a clockwise cycle and negative for an anti-clockwise cycle. The thermal energy is determined by the net thermal energy absorbed from the external reservoir. This is the heat absorbed during the isobaric expansion **192** in FIG. **9**, or the isobaric expansion **217** in FIG. **10**, or the heat absorbed during the isobaric expansion **162** from which the heat released during the isobaric compression **154** is subtracted. When neglecting friction, the net heat absorbed by the working material during one cycle, i.e. the heat absorbed during isobaric expansion **192**, for example, is equal to the net mechanical work done by the working material. In this idealized scenario, from the point of view of the external reservoir, i.e. the reservoir providing the thermal energy during isobaric expansion **192**, for example, the thermal energy is converted into mechanical work. Note that the thermodynamic system need not be closed. In other words, the mass can be exchanged with an external reservoir, as discussed in the context of FIGS. **11-15**. For some embodiments, the working material is identical to and sourced from the material found in the aforementioned external reservoir.

[0153] In other embodiments, mechanical work can be converted into thermal energy. In such embodiments, the heat flow direction between the working material and the heat exchangers can be reversed compared to the aforementioned embodiments. The direction of the cycles shown in FIGS. **8-10** can be reversed, i.e. a compression can be replaced by an expansion, and vice versa, resulting in a sign change of the work done by the working material and the thermal energy absorbed by the working material. In other words, work is now done on the working material, and thermal energy is released by the working material into an external reservoir. The term “engine” used herein refers to both a heat engine and a heat pump.

[0154] The rate of heat extracted from the working material in the cooling chamber is substantially equal to the rate of heat added to the working material in the heating chamber in the depicted embodiment.

[0155] In other embodiments, there can be alternative or additional heat sources or heat sinks which can contribute to heat transferred to the working material in the heating chamber, or contribute to heat removed from the working material in the cooling chamber. For example, when an engine similar to engine **320** is employed to power an aircraft or a ship, a portion of the wetted surface area of the fuselage or the hull of the ship can be configured to extract heat from the surrounding fluid. Thus, a portion of the outside environment or a portion of the fluid not flowing through channel **342** can be cooled, and act as a heat source to the working material in the heating chamber in a similar manner in which the working material in the cooling chamber acts as a heat source to the working material in the heating chamber. Alternatively or concurrently, a portion of the fluid in contact with the fuselage or hull of the ship can be configured to transfer heat into the surrounding fluid. Thus, a portion of the outside environment or a portion of the fluid not flowing through channel **342** can be heated, and act as a heat sink to the working material in the cooling chamber in a similar manner in which the working material in the heating chamber acts as a heat sink to the working material in the cooling chamber.

[0156] The principles of the invention can also be applied to other types of thermodynamic apparatuses, such as turboshaft engines, turboprop engines, turbofan engines, piston engines, refrigerators, or air-conditioning systems, for example.

[0157] In another embodiment, the first and second compressors of engine **320** are replaced by a first and second turbine through which the working material is expanded, and the turbine of engine **320** is replaced by a compressor. The temporal variation of the thermodynamic properties of the working material flowing through such an embodiment is similar to the variation depicted in FIG. **9**, and the thermodynamic system is also described by the schematic diagram shown in FIG. **13**.

[0158] In engine **320**, the compressors and the turbine change the properties of the working material adiabatically. In other embodiments, there can be an exchange of heat with the environment during the compression or expansion of the working material. In some embodiments, the first compression, second compression, or expansion can be isothermal. The heat transfer from the working material during an isothermal compression or to the working material during an isothermal expansion can be arranged in a similar manner as the heat transfer from the cooling chamber to the heating chamber in engine **320**, or from the outside environment, as mentioned.

[0159] In other embodiments, the first engine **390** can be replaced by a conventional heat exchanger which is configured to extract heat from a working material, such as the fluid surrounding the hull of a ship or the skin of an aircraft, such as the skin of the wing, fuselage or empennage, and transfer it to the heat transfer apparatus **472**, which in turn is configured to transfer the heat to at least one engine, such as engine **431**.

[0160] FIG. **15** is a cross-sectional view of three components of another embodiment of a heating or refrigeration system. Some features of the apparatus shown in FIG. **15**, as well as some of the principles of operation of the apparatus share similarities with the apparatus shown in the other figures, such as FIG. **8** and FIG. **11** in particular, and will therefore not be described in the same detail in the context of FIG. **15**, and vice versa.

[0161] The first component is a first engine **390**, the second component is a heat transfer apparatus **472**, and the third component is a second engine **431**.

[0162] First engine **390** comprises a duct apparatus **391** and an inside apparatus **392**. Several components of engine **390** are substantially axially symmetric about axis **422**.

[0163] Inside apparatus **392** comprises an optionally annular shaped channel **395** between annular inlet **394** and annular outlet **403**, and between the outer inside surface and the interior inside surface.

[0164] A working material flows through channel **395** from inlet **394** to outlet **403**. The working material can be a compressible fluid. As before, the fluid can be a gas such as air, for example.

[0165] After passing through inlet **394**, the working material flowing through channel **395** sequentially encounters a turbine **396**, a heat exchanger **398**, and a compressor **402** before exiting through the outlet **403**.

[0166] In this embodiment, the turbine **396** and the compressor **402** can be described as an axial flow turbine and compressor. Other embodiments can comprise other types of turbomachinery, such as centrifugal compressors or turbines, for example. The principles of the invention can also be applied to embodiments comprising pistons, such as those found in a reciprocating engine or pump.

[0167] Heat exchanger **398** is configured to transfer heat from the working material in channel **395** to heat transfer apparatus **472** during nominal operations. The location of heat exchanger **398** inside channel **395**, i.e. the portion of channel **395** located upstream of compressor **402** and downstream of turbine **396** is denoted the cooling chamber. In this particular embodiment, this is accomplished via forced convection of a thermal fluid by a pump, such as pump **487**, through pipe apparatus **486**. The thermal fluid can be water, or oil, or a fluid specially adapted for said forced convection. The pipe apparatus and pump **487** facilitate the transport of said thermal fluid through the heat transfer apparatus **398**. In this particular embodiment, the portion of the pipe apparatus **486** within channel **395** can be described as a countercurrent heat exchanger. The portion of the pipe apparatus which is in contact with the working material in channel **395** comprises several smaller pipes, such as pipe **399**, in order to increase the contact area and enhance the heat flow rate from the working material to the thermal fluid.

[0168] In other embodiments, the thermal fluid can transport heat through the heat exchanger **398** via natural convection. In other embodiments, the heat exchanger **398** can transport heat from the cooling chamber to the heat transfer apparatus **472** via thermal conduction. For example, the piping apparatus **486** can consist of a solid material such as copper or silver, or the piping apparatus can comprise a different suitable material, such as a material with a high coefficient of thermal conductivity. A wide variety of other methods for exchanging heat are available.

[0169] Second engine **431** comprises a duct apparatus **432** and an inside apparatus **433**. Several components of engine **431** are substantially axially symmetric about axis **463**.

[0170] Inside apparatus **433** comprises an annular channel **436** between annular inlet **435** and annular outlet **444**, and between the outer inside surface and the interior inside surface.

[0171] A working material flows through channel **436** from inlet **435** to outlet **444**. The working material can be a compressible fluid. As before, the fluid can be a gas such as air, for example.

[0172] After passing through inlet **435**, the working material flowing through channel **436** sequentially encounters a compressor **437**, a heat exchanger **439**, and a turbine **443** before exiting through the outlet **444**.

[0173] In this embodiment, the turbine **443** and the compressor **437** can be described as an axial flow turbine and compressor.

[0174] Heat exchanger **439** is configured to transfer heat from heat transfer apparatus **472** to the working material in channel **436** during nominal operations. The location of heat exchanger **439** inside channel **436**, i.e. the portion of channel **436** located downstream of compressor **437** and upstream of turbine **443** is denoted the heating chamber. In this particular embodiment, this is accomplished via forced convection of a thermal fluid by a pump, such as pump **490**, through pipe apparatus **489**. The thermal fluid can be water, or oil, or a fluid specially adapted for said forced convection. The pipe apparatus and pump **490** facilitate the transport of said thermal fluid through the heat transfer apparatus **439**. In this particular embodiment, the portion of the pipe apparatus **489** within channel **436** can be described as a counter-current heat exchanger. The portion of the pipe apparatus which is in contact with the working material in channel **436** comprises several smaller pipes, such as pipe **440**, in order to increase the contact area and enhance the heat flow rate from the thermal fluid to the working material.

[0175] The working material flowing through channel **436** during nominal operations is the same working material flowing through channel **395** in the depicted embodiment. For example, the working material can be air for both first engine **390** and second engine **431**. In other embodiments, the working material flowing through first engine **390** and second engine **431** need not be identical. Other embodiments can comprise at least one engine, such as engine **390** or engine **431**. Embodiments comprising a single engine can comprise a conventional heat exchanger. For example, the first engine **390** can be replaced by a conventional heat exchanger which is configured to exchange heat between the heat transfer apparatus **472** and a thermal reservoir. The medium within the thermal reservoir can be air surrounding an aircraft or the water surrounding a ship, for example. In some such embodiments the heat transfer apparatus **472** can be configured to transfer heat from said thermal reservoir into the heating chamber of engine **431**. In some such embodiments, the working material flowing through engine **431** can be a gas such as air, and the working material flowing through, or interacting with, or exchanging heat with, the conventional heat exchanger can be a gas, a liquid, or any other thermal reservoir. In other embodiments, the second engine **431** can be replaced by a conventional heat exchanger, and the heat transfer apparatus **472** can be configured to transfer heat from the cooling chamber of engine **390** into a thermal reservoir in thermal contact with said heat exchanger.

[0176] In other embodiments, heat can also be transferred to the working material within heating chamber of engine **431** by external heat or matter sources, such as the heat provided by the chemical reactions, such as a chemical reaction between fuel and portions of the working material.

[0177] Heat transfer apparatus **472** is configured to be able to transfer heat from a first thermal reservoir to a second thermal reservoir, where the temperature of the first thermal reservoir is lower than the temperature of the second thermal reservoir. During nominal operations, the temperature of the first thermal reservoir of heat transfer apparatus **472** is lower than the temperature of the second thermal reservoir. Thus the first thermal reservoir can be denoted the cold reservoir, and the second thermal reservoir can be denoted the hot reservoir. For the embodiment depicted in FIG. **15**, the cold reservoir comprises the working material in the cooling chamber in engine **390**, and the hot reservoir comprises the working material in the heating chamber in engine **431**.

[0178] Heat transfer apparatus **472** comprises a casing apparatus **473** and an annular rotating apparatus **475**, which is configured to rotate relative to casing apparatus **473** during nominal operations about axis **495**. Casing apparatus **473** is cylindrical in shape, with the central axis of symmetry being coincident with axis **495** in this embodiment. In other words, the cross-section of casing apparatus **473** is circular when viewed along axis **495**. Casing apparatus **473** also comprises a hollow central shaft **484**. Rotating apparatus **475** is also axially symmetric about axis **495**. Rotating apparatus **475** encloses a central volume **496**, which is annular about axis **495** and rectangular in cross-section when viewed along an axis perpendicular to axis **495**, as shown.

[0179] Central volume **496** comprises a material which, when compressed adiabatically, can experience an increase in temperature. In the depicted embodiment, central volume **496** comprises a compressible gas such as helium, hydrogen, or air. It can be advantageous to select a central material with a large coefficient of thermal conductivity. This can increase the rate of heat flow from the cooling chamber to the heating chamber for a given apparatus operating condition, and thus increase the net power output, ceteris paribus. A small specific heat capacity at constant pressure can help reduce the mass of the heat transfer apparatus **472** for some embodiments. For instance, a smaller specific heat capacity can lead to a smaller angular rate of rotation of rotating apparatus **475**, reducing the size of load carrying members. In some embodiments, central volume **496** can comprise a solid such as a metal or a liquid such as water. Note that the material in central volume **496**, denoted the central material, can be of the same type as the working material flowing through channel **436** or channel **395**.

[0180] In order to minimize viscous friction due to the relative motion of the casing apparatus and the rotating apparatus **475**, the separation volume **497** between the rotating apparatus **475** and the casing apparatus **473** is evacuated in the depicted embodiment. In other embodiments, the separation volume **497** can comprise a fluid. For example, the fluid can be helium or lubricating oil. Such a fluid can increase the pressure within separation volume **497** and reduce the mass of casing apparatus **473**, without increasing the energy losses associated with the relative motion of casing apparatus **473** and rotating apparatus **475** by an unnecessarily large amount.

[0181] The geometry of rotating apparatus **475** can also be adapted to the large centripetal loads within the walls of rotating apparatus **475** in a manner which reduces the mass of the rotating apparatus **475** for a given heat flow rate or radius. For example, the cross-section of annular rotating apparatus **475** can be a teardrop shape, or share similarities to a teardrop shape, when viewed along an axis perpendicular to rotation axis **497**, where the long axis of the teardrop is perpendicular to the rotation axis **497**, and where the nominally rounded, blunt end of the teardrop is located in a radially outward direction compared to the nominally sharper end. In such embodiments, the casing apparatus can have a spherical shape. In other such embodiments, the casing apparatus can have a cylindrical shape, where the central portion of the outside surface is parallel to axis **495**, and the end portions are convex, i.e. rounded outwards, or concave, i.e. rounded inwards. A wide variety of other geometries of the casing apparatuses and of the rotating apparatuses are available.

[0182] The preferred path of the heat flow from pipe apparatus **494** to pipe apparatus **489** is from to interior inside surface **477** to interior outside surface **476** via the adjoining portion of the separation volume, through the interior wall of rotating apparatus **475** which is parallel to axis **495**, through central volume **496**, through the exterior wall of rotating apparatus **475** which is parallel to axis **495**, from exterior inside surface **480** to exterior outside surface **479** via the adjoining portion of the separation volume, as indicated by the arrows perpendicular to axis **495**.

[0183] The thermal fluid is transported through pipe apparatus **486** to an interior inside surface **477** via several smaller pipes, such as pipe **494**. Heat can be delivered from a pipe apparatus to the interior inside surface **477** via thermal conduction. Interior inside surface **477** is configured to transfer heat to the interior outside surface **476** via thermal radiation through the evacuated separation volume **497**. In other embodiments, at least a portion of said heat transfer can comprise conduction through a material, such as a gas or a liquid, contained within separation volume **497**. In some embodiments, at least a portion of said heat transfer can comprise thermal conduction through the components of a roller bearing between and inside surface and an opposing outside surface.

[0184] Interior inside surface **477** is cylindrical in shape, and encloses a portion of central shaft **484**. Interior outside surface **476** is also cylindrical in shape and connected to the cylindrical interior surface of rotating apparatus **475**. The distance of separation between interior inside surface **477** and interior outside surface **476** is as small as possible in order to maximize the rate of heat flow between said surfaces. This also applies to the distance of separation between exterior inside surface **480** and exterior outside surface **479**. The aforementioned inside or outside surfaces can comprise metal, such as copper or aluminium.

[0185] In some embodiments, the inside surfaces and the outside surfaces comprise radial protrusions, where, in general, a protrusion of the inside surface is located between two protrusions of the outside surface. In this manner, the surface area of the interface between an inside surface and an outside surface can be artificially increased. A larger interface area can increase the rate of heat transfer between the inside surface and the outside surface for a given average circumferential footprint of the inside and outside surfaces. For example, a protrusion can be an annular, flat, metal disc, where the plane of the disc is perpendicular to axis **495**. The metal disc can be rigidly connected to the associated surface, such as an inside surface or an outside surface. A protrusion of an inside surface can be located between two protrusions of an outside surface, such that the protrusions of the inside surface and the outside surface interleave without touching. In order to maximize the interface area between an inside surface and an outside surface, the protrusions, or discs, or fins, can be configured to be thin, and the gap between protrusions can be minimized. The protrusions can be electrostatically charged such that the protrusions of an inside surface and the protrusions of an outside surface electrostatically repel. In this manner, thin and flexible protrusions of an inside surface can be placed in close proximity to the thin and flexible protrusions of an outside surface without the protrusions coming into contact, or touching. Contact would result in frictional losses due to the relative motion of the rotating apparatus **475** and the casing apparatus **473**. In other embodiments, the repulsive forces between adjacent protrusions can be provided by magnetic fields. Repelling permanent magnets can be embedded in the protrusions, for example. Alternatively, electric conductors can be embedded within the protrusions, such that electric current can be made to flow in the opposite circumferential direction in adjacent conductors of adjacent protrusions, resulting in a repulsive magnetic force. A wide variety of other methods are available to ensure separation between adjacent protrusions.

[0186] A bearing assembly prevents the rotating apparatus **475** from contacting the casing apparatus **473**. The bearing assembly is not shown in FIG. **15**. The bearing assembly can be located on exterior inside and outside surfaces, for example. Alternatively the bearing assembly can be located on the interior inside and outside surfaces.

[0187] The heat transferred to the interior outside surface **476** is conducted through the interior wall of the rotating apparatus **475** and into the central material in central volume **496**. The material of the inside wall can comprise material with a high coefficient of thermal conductivity, such as copper or silver. In other embodiments, the heat can be transferred through the interior wall by forced convection through a separate pipe apparatus by a pump, such that heat can be transferred from interior outside surface **476** to the central material. In other embodiments, the interior wall of central volume **496**, i.e. the wall closest to axis **495**, can also comprise protrusions, pins, fins, or plates in order to increase the surface area of the interior wall. This can increase the heat flow rate from the interior wall into the central material compared to a two dimensional cylindrical inside wall surface of central volume **496** shown in FIG. **15** for simplicity. The outside wall of central volume **496**, i.e. the wall facing in a radially inward direction, can also be endowed with protrusions in order to increase the surface area.

[0188] Baffles within central volume **496** ensure the fluid within central volume **496** rotates together with the walls of rotating apparatus **475**. This is particularly relevant during acceleration or deceleration of the rate of rotation of the walls of rotating apparatus **475**. Each baffle is planar in this embodiment, where each plane is parallel to axis **495** and parallel to a vector perpendicular to axis **495**. Other embodiments do not comprise baffles as described. For example, the material within central volume **496** can be a solid, or the viscous friction between the fluid and the walls of central volume **496** can be used to accelerate or decelerate the rate of rotation of the fluid within central volume **496** such that, in the steady state, the angular rate of rotation of the fluid matches the angular rate of rotation of the solid walls of the rotating apparatus **475**. In other embodiments, the central material can be confined by electrostatic or magnetic fields as opposed to the solid walls depicted in FIG. **15**.

[0189] Due to the rotation of the central material, there is a pressure gradient within central material, where the pressure increases in a radially outwards direction, as discussed in the context of FIG. **4** and FIG. **1**. In the depicted embodiment, the walls of rotating apparatus **475** are insulated. For simplicity, one can consider the walls to be perfect thermal insulators. In this simplified model, the compression of the central material in the radially outward direction relative to axis **495** can be considered to be adiabatic. As a result, the temperature of the central material increases in a radially outward direction, resulting in a larger temperature at the outside wall of central volume **496** than at the inside wall of the same. The difference of the temperature at the outside wall and the inside wall of central volume **496** is denoted the internal temperature difference. The magnitude of the internal temperature difference is a function of the material properties of the central material, such as the specific heat capacity at constant pressure, as well as the angular rate of rotation of the rotating apparatus **475**, as well as the geometry of the rotating apparatus **475**, in particular the radius of the inside wall and the radius of the outside wall, amongst other parameters. When the internal temperature difference is sufficiently large, heat can be made to flow from the cooling chamber of engine **390** to the heating chamber of engine **431**. When assuming, for the sake of example, perfect thermal conductivity between the inside wall of central volume **496** and the cooling chamber of engine **390** as well as between the outside wall of central volume **496** and the heating chamber of engine **431**, as well as instantaneous heat transfer between the pipe apparatuses and the working materials, the internal temperature difference should be larger than the temperature difference of the working material entering the heating chamber and the working material entering the cooling chamber. In this case, heat can be made to flow through the central volume **496** in the radially outward direction via thermal conduction from a cold reservoir to a hot reservoir.

[0190] Note that, in some embodiments, heat can be lost by conduction, convection, or radiation through separation volume **497**. These heat losses can be mitigated by separation volume **497** comprising a material with a low thermal conductivity, by minimizing the size of separation volume **497**, or by placing insulating material around the preferred path of the heat flow from pipe apparatus **494** to pipe apparatus **489**, for example.

[0191] Similarly to the transfer of heat from interior inside surface **477** to the inside wall of central volume **496**, heat can be transferred from the exterior inside surface **480** to the exterior outside surface **479**. At exterior outside surface **479**, the heat is transferred to a thermal fluid inside pipe apparatus **489** via thermal conduction. The thermal fluid inside pipe apparatus **489** is pumped by pump **490** to heat exchanger **439** in the heating chamber of engine **431**, where the heat is transferred to the working material inside channel **436**.

[0192] In some embodiments, the heat transfer apparatus **472** can be located within an engine, such as engine **431**. For example, axis **495** can be coincident with axis **463**, and heat transfer apparatus **472** can be located within the volume enclosed by channel **436**. In other embodiments, an engine can be located within heat transfer apparatus **472**. For example, a portion of engine **390** can be located within hollow central shaft **484**, with axis **422** being coincident with axis **495**.

[0193] The temporal variation of the thermodynamic properties of the working material flowing through channel **395** is similar to the variation depicted in the second cycle in FIG. **8**. The temporal variation of the thermodynamic properties of the working material flowing through channel **436** is similar to the variation depicted in the first cycle in FIG. **8**. The thermodynamic system in FIG. **15** is also described by the schematic diagram shown in FIG. **11**.

[0194] Both the first engine **390** and the second engine **431** produce a positive mechanical work output in this embodiment.

[0195] In some embodiments, axis **463**, axis **495**, and axis **422** are substantially coincident. For example, a portion of engine **390** can be located within hollow central shaft **484**, and heat transfer apparatus **472** can be enclosed by channel **436** of engine **431**. In other embodiments the order can be reversed. Heat transfer apparatus **472** can enclose engine **431**, both of which are enclosed by channel **395** of engine **390**.

[0196] In other embodiments, engine **390** can be configured in a similar manner as engine **431**. In other words, after passing through inlet **394**, the working material flowing through channel **395** sequentially encounters a compressor, a cooling chamber containing heat exchanger **398**, and a turbine before exiting through outlet **403**. In this case, the temperature of the working material exiting the compressor is lower than the temperature of the working material exiting compressor **437** in engine **431**. As before, heat transfer apparatus **472** is configured to transfer heat from the working material in the cooling chamber of engine **390** to the working material in the heating chamber of engine **431**. Note that engine **390** does work on the working material, while the working material does work on engine **431**. Combined, engine **390** and engine **431** can be configured to produce a net positive mechanical work output.

[0197] Note that, while the heat flow rate flowing out of the cooling chamber is substantially equal to the heat flow rate into the heating chamber, the mass flow rate of working material through engine **390** need not be equal to the mass flow rate through engine **431**. Therefore the amount of heat per unit mass removed from the working material in engine **390** need not be equal to the amount of heat per unit mass added to the working material in engine **431**. This allows for more flexibility in the optimization of the design of engine **431** and **390** for a particular application. For example, the mass flow rate of working material through engine **390** can be larger than the mass flow rate of working material through engine **431**. By increasing the mass flow rate through engine **390**, the minimum temperature of the working material in the cooling chamber can be increased. This can increase the temperature at the inside wall of central volume **496**, which can increase the average coefficient of thermal conductivity of the central material, which can increase the heat flow rate from the cooling chamber to the heating chamber, which can increase the net positive power output of the combined apparatus.

[0198] In some embodiments, a substantial portion of the working material exiting engine **431** through outlet **444** also enters engine **390** through inlet **394**. In some such embodiments, the working material having flown through engine **431** can be a small fraction of the total flow rate of working material entering engine **390**. In other words, ambient working material, such as ambient air, is ingested into engine **390** together with working material from the exhaust of engine **431**. This can increase the average temperature of the working material entering engine **390**, which can increase the temperature of the working material at the cooling chamber, which can increase the net power output of the combined apparatus, as mentioned.

[0199] In other embodiments, heat transfer apparatus **472** can be configured in a different manner. In FIG. **15**, the inertial loads on the central material can be considered to be a body force per unit mass which acts on elements of the central material in a radially outwards direction. The inertial loads arise from the circular motion of the molecules of the central material rotating with rotating apparatus **475**. This inertial load is also referred to as a centrifugal force, which is an apparent force. As mentioned, a wide variety of other methods and apparatuses are available for generating a body force per unit mass within a central material.

[0200] FIG. **16** is a cross-sectional view of one exemplary embodiment **520** of a heat transfer apparatus. Some features of the embodiment shown in FIG. **16** as well as some of the principles of operation of the embodiment share similarities with features and principles of operation described by the other figures, and will therefore not be described in the same detail in the context of FIG. **16**, and vice versa.

[0201] FIG. **16** shows a reservoir **521** comprising a thermal material **522**. In this particular example, the thermal material **522** is a gas, where the individual molecules or atoms can be electrically polarized by an applied electric field. The gas can be air, nitrogen, helium, or argon, for example. In other embodiments, thermal material **522** can be a liquid, or a solid. The thermal material can also comprise permanently polarized molecules, as is the case for water.

[0202] An electrically and thermally insulating material **523** encompasses reservoir **521**. Reservoir **521** is cylindrical in shape in this embodiment. In other embodiments, reservoir **521** can be rectangular or annular in shape, for example. Reservoir **521** can take any shape in general.

[0203] A first heat exchanger **526** is located in the proximity of a first point **524** in reservoir **521**. In this particular embodiment, first heat exchanger **526** comprises several fins, such as fin **530**, which can be described as a planar metal plate. A pipe **527** comprising a thermal fluid is rigidly attached to the fins, allowing heat to be conducted from the thermal material **522** to the fins, and from the fins into the thermal fluid within pipe **527**, and vice versa. The thermal fluid is pumped through the pipe by a pump, which is not shown. The pipe can thus transfer heat to heat exchanger **526**, or deliver heat from heat exchanger **526**. In other embodiments, heat exchanger **526** can be configured differently. For example, heat exchanger **526** can employ conduction, radiation, or natural convection, as opposed to the aforementioned forced convection of the thermal fluid through pipe **527**, to exchange heat between first point **524** in reservoir **521** with another reservoir, which is also not shown.

[0204] A second heat exchanger **531** is located in the proximity of a second point **525** in reservoir **521**. The second heat exchanger **531** is configured in a similar manner as first heat exchanger **526**. In other embodiments, the second heat exchanger **531** can be configured in a different manner compared to first heat exchanger **526**. The second heat exchanger **531** comprises plates or fins, such as fin **535**, and pipe **532**.

[0205] Heat transfer apparatus **520** comprises a body force generating apparatus configured to generate a body force per unit mass with a substantial component in the vertically downwards direction, towards the bottom of the page, where the body force per unit mass is acting on the thermal material **522** within reservoir **521**.

[0206] The body force generating apparatus comprises several collections of charge, such as a first positive collection of charge **539**, a second positive collection of charge **540**, a third positive collection of charge **541**, and a negative collection of charge **542**. These collections of charge can be contained within electrical conductors, such as a metal such as copper. A voltage difference applied between conductors, such as conductor **541** and conductor **542** will result in an accumulation of charge within both conductors. In the depicted embodiment, the net charge contained within the body force generating apparatus is zero. Electrical conductors **541**, **540**, and **539** are annular in shape and encompass the cylindrical reservoir **521**. Electrical conductor **542** is cylindrical in shape. The amount of charge contained within each collection of charge relative to other collections of charge can be regulated by regulating the voltage associated with said collection of charge relative to other collections of charge. A wide variety of other configurations of collections of charge can achieve the same effect as the depicted configuration. For example, collections of charge can be located within reservoir **521**.

[0207] As a result of the electric field within reservoir **521**, the thermal material **522** is electrically polarized. As a result of the collections of charge, the component of the electrical field along the longitudinal axis of the page increases in the direction towards the bottom of the page. Hence, the individual molecules of thermal material **522** experience a body force per unit mass towards the bottom of the page. In equilibrium, the pressure, density and temperature of the thermal material **522** increase towards the bottom of the page. The temperature at second point **525** is therefore larger than the temperature at first point **524**. The pressure and the electric field applied to the thermal material **522** are contained by the insulating material **523** in this particular embodiment.

[0208] Depending on the external temperature applied to first heat exchanger **526** and second heat exchanger **531**, heat can be made to flow through the thermal material **522** from first heat exchanger **526** to second heat exchanger **531**, or vice versa. For example, if the external temperatures of the first heat exchanger **526** and second heat exchanger **531** are identical, heat will flow from the first exterior reservoir thermally connected to the first heat exchanger **526** through the first heat exchanger **526** to first point **524** and through the thermal material **522** to second point **525** and through second heat exchanger **531** to the second external reservoir thermally connected to the second heat exchanger **531**. This is due to the artificially created temperature difference between the first point **524** and the second point **525** by the body force generating apparatus, where the temperature difference is preserved by the insulating material **523**. The higher temperature at second point **525** makes the first exterior reservoir appear to be hotter to the second exterior reservoir. Thus the heat transfer apparatus **520** can be employed to transfer heat from a first exterior reservoir to a hotter second exterior reservoir, provided the temperature difference between the first and second exterior reservoirs is smaller in magnitude than the temperature difference between the first point **524** and the second point **525** for the given operating condition.

[0209] When the temperature of the first exterior reservoir is greater than the temperature of the second exterior reservoir, the rate of heat transfer through the heat transfer apparatus configured in accordance with the invention can be greater than an equivalent heat exchanger of the prior art. An equivalent heat exchanger of the prior art can be an infinitely thin contact surface between the first reservoir and the second reservoir. The rate of heat transfer through the heat transfer apparatus is a function of the thermal conductivity, as well as the temperature gradient. The finite length of the heat transfer apparatus will reduce the temperature gradient by increasing the length over which the difference in temperature is measured compared to the theoretical equivalent heat exchanger and associated thermal boundary layer. The built-in temperature difference of the heat transfer apparatus, i.e. the temperature difference between a first point and a second point in equilibrium at zero heat flow, can offset this increase in length for some embodiments and some configurations, however, resulting in a larger temperature gradient and a larger rate of heat transfer from a hot reservoir to a cold reservoir.

[0210] FIG. **17** is a cross-sectional view of one exemplary embodiment **570** of a heat transfer apparatus. Some features of the embodiment shown in FIG. **17** as well as some of the principles of operation of the embodiment share similarities with features and principles of operation described by the other figures, and will therefore not be described in the same detail in the context of FIG. **17**, and vice versa.

[0211] FIG. **17** shows a reservoir **571** comprising a thermal material **572**. In this particular example, the thermal material **572** is a gas, where the individual molecules or atoms are positively or negatively charged. In other embodiments, thermal material **572** can be a liquid, or a solid. In other embodiments, thermal material **572** can comprise other types of mobile charges, such as free moving electrons.

[0212] An electrically and thermally insulating material **573** encompasses reservoir **571**. Reservoir **571** is cylindrical in shape in this embodiment. In other embodiments, reservoir **571** can be rectangular or annular in shape, for example. Reservoir **571** can take any shape in general.

[0213] A first heat exchanger **576** is located in the proximity of a first point **574** in reservoir **571** and comprises several fins and pipe **577**. A second heat exchanger **581** is located in the proximity of a second point **575** in reservoir **571** and comprises several fins and pipe **582**. These heat exchangers are configured in a similar manner as the heat exchangers shown in FIG. **16**.

[0214] Heat transfer apparatus **570** comprises a body force generating apparatus configured to generate a body force per unit mass with a substantial component along the long axis of the page, where the body force per unit mass is acting on the thermal material **572** within reservoir **571**.

[0215] The body force generating apparatus comprises several collections of charge, such as a positive first collection of charge **589**, a negative second collection of charge **590**. A wide variety of other configurations of a body force per unit mass generating apparatuses can be devised and employed to produce an electrical potential energy difference for elements of the thermal material **572** between the first point **574** and the second point **575**.

[0216] The electrical potential energy difference results in a temperature difference between the first point **574** and the second point **575** during thermal equilibrium, i.e. zero heat flow between the first point **574** and the second point **575**. For example, when the thermal material comprises positively charged ions, the ions will experience a body force per unit mass directed towards the bottom of the page within reservoir **571**. As described in the context of FIG. **16**, this results in a larger temperature at second point **575** compared to the first point **574**. Thus, embodiment **570** can be operated as a heat transfer apparatus in the same manner as embodiment **520** and other heat transfer apparatuses mentioned herein.

[0217] By reversing the polarity of the charge contained within the collections of charge, the direction of the body force within thermal material **572** can be reversed. This can be used to control the direction of heat flow through the heat transfer apparatus. For example, this can be used to change the mode of operation of the heat transfer apparatus **570** from the mode corresponding to an artificial heat source to the mode corresponding to an artificial heat sink.

[0218] By regulating the magnitude of the potential difference applied to the first collection of charge **589** relative to the second collection of charge **590**, the magnitude of the body force per unit mass within the reservoir **571** can be controlled. In this manner, the magnitude of the temperature difference between the first point **574** and the second point **575** can be controlled. This allows the rate of heat flow through the thermal material **571** and through the heat transfer apparatus **570** to be controlled. Other methods for controlling the heat flow through heat transfer apparatus **570** are also available. For example, the mass flow rate of the thermal fluid through pipe **582** can be modified.

[0219] FIG. **18** is a cross-sectional view of one exemplary embodiment **610** of a heat transfer apparatus. Some features of the embodiment shown in FIG. **18** as well as some of the principles of operation of the embodiment share similarities with features and principles of operation described by the other figures, and will therefore not be described in the same detail in the context of FIG. **18**, and vice versa.

[0220] FIG. **18** shows a reservoir **611** comprising a thermal material **612**. In this particular example, the thermal material **612** is a gas, where the individual molecules or atoms can be magnetically polarized. In other embodiments, thermal material **612** can be a liquid, or a solid. In other embodiments, thermal material **612** can comprise other types of magnetic dipoles, such as free moving electrons. In other embodiments, the magnetic dipoles can be permanent as opposed to induced by an externally applied magnetic field.

[0221] An electrically and thermally insulating material **613** encompasses reservoir **611**. Reservoir **611** is cylindrical in shape in this embodiment. In other embodiments, reservoir **611** can be rectangular or annular in shape, for example. Reservoir **611** can take any shape in general.

[0222] A first heat exchanger **616** is located in the proximity of a first point **614** in reservoir **611** and comprises several fins and pipe **617**. A second heat exchanger **621** is located in the proximity of a second point **615** in reservoir **611** and comprises several fins and pipe **622**. These heat exchangers are configured in a similar manner as the heat exchangers shown in FIG. **16**.

[0223] Heat transfer apparatus **610** comprises a body force generating apparatus configured to generate a body force per unit mass with a substantial component along the long axis of the page, where the body force per unit mass is acting on the thermal material **612** within reservoir **611**.

[0224] The body force generating apparatus comprises several current coils, such as coil **629** forming a loop with conductor **630**, coil **631** forming a loop with conductor **632**, coil **633** forming a loop with conductor **634**, coil **635** forming a loop with conductor **636**, or coil **637** forming a loop with conductor **638**. Each coil carries a current which is directed out of the page on the left side of the page and into the page on the right side of the page, as indicated. Each coil is made of an electrical conductor, such as copper. In some embodiments, a coil comprises superconducting material.

[0225] A wide variety of other configurations of a body force per unit mass generating apparatuses can be devised and employed to produce an potential energy difference for elements of the thermal material **612** between the first point **614** and the second point **615**.

[0226] The potential energy difference results in a temperature difference between the first point **614** and the second point **615** during thermal equilibrium. Due to the increasing magnetic field strength component along the direction parallel to the long axis of the page towards the bottom of the page, the magnetic dipoles induced within thermal material **612** will experience a body force per unit mass with a non-zero component towards the bottom of the page within reservoir **611**. As described in the context of FIG. **16**, this results in a larger temperature at second point **615** compared to the first point **614**. Thus, embodiment **610** can be operated as a heat transfer apparatus in the same manner as embodiment **520** and other heat transfer apparatuses mentioned herein.

[0227] FIG. **19** is a cross-sectional view of one exemplary embodiment **650** of a heat transfer apparatus. Some features of the embodiment shown in FIG. **19** as well as some of the principles of operation of the embodiment share similarities with features and principles of operation described by the other figures, and will therefore not be described in the same detail in the context of FIG. **19**, and vice versa.

[0228] FIG. **19** shows a reservoir **651** comprising a thermal material **652**. In this particular example, the thermal material **652** is a gas, such as air, helium, or argon. In other embodiments, thermal material **652** can be a liquid.

[0229] A thermally insulating material **653** encompasses reservoir **651**. Reservoir **651** is cylindrical in shape in this embodiment. In other embodiments, reservoir **651** can be rectangular or annular in shape, for example. Reservoir **651** can take any shape in general, provided the force generating apparatus is configured to allow the heat transfer apparatus to be operated as intended.

[0230] A first heat exchanger **656** is located in the proximity of a first point **654** in reservoir **651** and comprises several fins and pipe **657**. A second heat exchanger **661** is located in the proximity of a second point **655** in reservoir **651** and comprises several fins and pipe **662**. The fins of the heat exchangers, such as fin **660** or fin **665** are arranged cylindrically around axis **675** in order to provide little resistance to the swirling of the thermal material **652** within reservoir **651** during nominal operations.

[0231] Heat transfer apparatus **650** comprises a force generating apparatus configured to generate a force with a substantial component along the long axis of the page, directed towards the bottom of the page, where the force is acting on the thermal material **652** within reservoir **651**.

[0232] The force generating apparatus comprises an axial compressor, which is configured in a similar manner as an axial compressor of a conventional turbojet engine. Note that during nominal operations of the depicted embodiment, there is no net flow of the thermal material **652** along the direction parallel to axis **675**. In other embodiments, there can be a bulk flow of thermal material **652** along axis **675**, provided that a sufficient amount of heat is still able to be transferred between the first point **654** and the second point **655** during nominal operations. For example, when the heat is to be transferred against the direction of bulk flow of the thermal material **652**, the rate of heat transfer is diminished compared to a thermal material **652** which is stationary on average. This is due to the advection of the thermal material partially cancelling the conduction of heat through the thermal material in the opposite direction. In embodiments in which the thermal material is undergoing bulk flow, the force generating apparatus can also comprise an expanding or contracting cross-sectional area of the channel through which the thermal material is flowing. This can produce a force on the thermal material in a direction upstream or downstream of the bulk flow of the thermal material respectively in an example involving subsonic bulk flow. In other embodiments, therefore, the force generating apparatus can comprise a contracting or expanding duct. In yet other embodiments, the force generating apparatus can comprise a centrifugal compressor. In other embodiments the force generating apparatus can comprise coaxial, counter-rotating axial compressors.

[0233] The axial compressor shown in FIG. **19** comprises a drive shaft **670** connected to several rotor discs, each comprising several rotor blades, such as rotor blade **672** or rotor blade **671**. In order to balance the swirl of the thermal material **652**, several stator discs comprising several blades, such as stator blade **674** or stator blade **673**, are connected to the casing apparatus comprising insulating material **653**. The rotor and stator blades are rigidly attached to the shaft **670** or the casing apparatus in the depicted embodiment. In other embodiments, at least a portion of the blades is rotably connected to the drive shaft **670** or the casing apparatus, where the axis of rotation of said rotable connection is substantially perpendicular to axis **675**. This rotable connection is configured to allow the angle of attack of the stator and/or rotor blades to be controlled such that the magnitude of the force applied by the force generating apparatus on the thermal material **652** can be regulated.

[0234] The axial compressor shown in FIG. **19** is driven by a motor **669**. The motor **669** in FIG. **19** is an electric motor. In other embodiments, the motor **669** can be a piston engine, or a turboshaft engine, for example. In general, any type of power supply and any type of shaft work generating apparatus can be employed to drive the axial compressor shown in FIG. **19**. Note that the depicted embodiment consumes power during nominal operations due to frictional losses of the axial compressor moving relative to the thermal material **652**. These frictional losses increase the temperature of the thermal material **652**, which can be desirable for some applications, such as applications in which the heat transfer apparatus is employed as an artificial heat source. Due to these frictional losses of the axial compressor, the thermal material **652** will swirl, i.e. undergo bulk rotational flow about axis **675** within reservoir **651**. During steady, nominal operations, the rate of rotation of the thermal material **652** is the rate for which the torque applied by the rotating portion of the axial compressor is balanced by the torque applied by the stator, the walls, and other wetter surfaces of the reservoir **651** on the thermal material **652**.

[0235] During nominal operations, the axial compressor increases the temperature at the second point **655** compared to the first point **654**. Thus, embodiment **610** can be operated as a heat transfer apparatus in the same manner as embodiment **520** and other heat transfer apparatuses mentioned herein.

[0236] In the idealized scenario in which insulating material **653** is perfectly insulating, the compression of the thermal material at second point **655** compared to first point **654** can be modelled as an adiabatic compression. In other embodiments, the compression is not adiabatic.

[0237] FIG. **20** is a cross-sectional view of one exemplary embodiment **690** of an artificial heat source or artificial heat sink employing a heat transfer apparatus. Some features of the embodiment shown in FIG. **20** as well as some of the principles of operation of the embodiment share similarities with features and principles of operation described by the other figures, and will therefore not be described in the same detail in the context of FIG. **20**, and vice versa.

[0238] FIG. **20** shows a heat transfer apparatus comprising a reservoir **691** which in turn comprises a thermal material **692**. In this particular example, the thermal material **692** is a gas, In other embodiments, thermal material **692** can be a liquid, or a solid

[0239] A thermally insulating material **693** encompasses reservoir **691**. Reservoir **691** is cylindrical in shape in this embodiment. In other embodiments, reservoir **691** can be rectangular or annular in shape, for example. Reservoir **691** can take any shape in general.

[0240] A first heat exchanger **698** is located in the proximity of a first point **695** in reservoir **691** and comprises several fins, such as fin **702**, and pipe **699**. A second heat exchanger **703** is located in the proximity of a second point **696** in reservoir **691** and comprises several fins, such as fin **707**, and pipe **704**. These heat exchangers are configured in a similar manner as the heat exchangers shown in FIG. **16**. The pumps which pump the thermal fluid through pipe **699** and pipe **704** are not shown for simplicity.

[0241] The heat transfer apparatus can be of any suitable configuration, such as a configuration shown in FIG. **16**, FIG. **17**, FIG. **18**, or FIG. **19**, or any other configuration discussed herein or within the scope of the invention. Detailed features of the heat transfer apparatus, such as features pertaining to the force generating apparatus, are not shown for simplicity and generality.

[0242] In FIG. **20**, a first exterior reservoir, located on the portion of first heat exchanger **698** which is located outside of reservoir **691**, is shown. For example, the first exterior reservoir can be the earth's atmosphere. The temperature of the atmosphere at point **694** and the temperature at point **697** as well as the equilibrium temperature difference between first point **695** and second point **696** of the heat transfer apparatus, determine the rate of heat transfer, as well as the direction of heat transfer through the heat transfer apparatus, as discussed in the context of FIG. **16**.

[0243] A second exterior reservoir **710** comprising thermal material **711**, located on the portion of second heat exchanger **703** which is located outside of reservoir **691**, is shown. The second exterior reservoir can be the interior of a building, a vehicle, or a refrigerator, for example, Depending on the material properties of the thermal material **692**, the direction of the force applied to the thermal material **692**, as well as the temperature of the larger exterior reservoir, i.e. the temperature at point **694** in the first exterior reservoir in this case, heat can be made to flow from the first exterior reservoir to the second exterior reservoir, or vice versa. From the perspective of the second exterior reservoir, the heat transfer apparatus can thus be configured to be an artificial heat source or an artificial heat sink.

Notes and Examples

[0244] The following, non-limiting examples, detail certain aspects of the present subject matter to solve the challenges and provide the benefits discussed herein, among others.

[0245] In one aspect, a heat exchange system comprises a first reservoir having a first point and a second point; a first thermal material contained in the first reservoir; a first thermal contact thermally coupled with the first point; and a second thermal contact thermally coupled with the second point, and wherein application of a force to the first thermal material can result in a temperature difference between the first and second points.

[0246] The system may further comprise a second reservoir having a first point and a second point; and a second thermal material contained in the second reservoir, wherein at least some thermodynamic properties of the second material are different than the first material.

[0247] A distance between the first point and the second point of the first reservoir or the second reservoir may be less than 100 kilometers.

[0248] The first thermal material may comprise a gas, a liquid, or a solid material.

[0249] The force may comprise a body force or a mechanical force.

[0250] A method for facilitating heat flow may comprise employing a first reservoir having a first point and a second point; employing a first thermal material contained in the first reservoir; where the first thermal material is subjected to a force thereby forming a temperature difference between the first and second points; allowing heat flow through the first thermal material between a first thermal contact adjacent the first point and a second thermal contact adjacent the second point.

[0251] The method may further comprise employing a second reservoir having a first point and a second point; employing a second thermal material contained in the second reservoir, wherein at least some thermodynamic properties of the second material are different than the first material; and wherein the second thermal material is subjected to a force thereby forming a temperature difference between the first and second points in the second reservoir.

[0252] Applying the force may comprise applying a body force or a mechanical force to the first material.

[0253] The first material may comprise a gas, a liquid, or a solid material.

[0254] A method for facilitating heat flow may comprise employing a first reservoir containing a first thermal material, the first thermal material having a first point and a second point; employing a second reservoir containing a second thermal material, the second reservoir having a first point and a second point, wherein at least some thermodynamic properties of the second material are different than the first material; wherein the first thermal material in the first reservoir is subjected to a force, and wherein the second thermal material in the second reservoir is subjected to a force, thereby creating a temperature difference between the first point and the second point in the first reservoir, and creating a temperature difference between the first point and the second point in the second reservoir; allowing heat to flow between the first and second points in the first reservoir and between the first and second points in the second reservoir; and allowing heat to flow between the second point in the first reservoir and the second point in the second reservoir.

[0255] The method may further comprise flowing heat between a third reservoir containing a third thermal material and the first point in the first thermal material in the first reservoir.

[0256] The third material may be different than the first material.

[0257] The method may further comprise flowing heat between the first point in the second reservoir and a fourth reservoir containing a fourth thermal material.

[0258] The fourth thermal material may be the same or different than the second thermal material.

[0259] The method may further comprise at least partially thermally insulating the first reservoir or the second reservoir from each other.

[0260] Flowing heat between the second points in the first and second reservoirs or between the first and second points in either the first reservoir or second reservoir may comprise conduction, radiation, natural convection, or forced convection.

[0261] Flowing heat between the second points in the first and second reservoirs or between the first and second points in either the first reservoir or second reservoir may comprise pumping a fluid through a heat exchanger or creating a vacuum therein.

[0262] Flowing heat between the second points in the first and second reservoirs or between the first and second points in either the first reservoir or second reservoir may comprise transmitting electromagnetic waves.

[0263] The method may further comprise accelerating the first reservoir or the second reservoir.

[0264] The method may further comprise regulating a rate of heat flow through the first reservoir or the second reservoir.

[0265] Providing the force may comprise applying a constant body force in magnitude and direction over time within the first and the second reservoirs during nominal operation.

[0266] The first or the second thermal material may comprise electrical charged elements and wherein providing the force comprises producing an electrical potential difference between the first and second points in either of the first and second reservoirs.

[0267] The first or the second material may comprise electric dipoles, and wherein providing the force may comprise producing an electrical field gradient between the first or second points in either of the first and second reservoirs.

[0268] Providing the force may comprise subjecting the first and second points in either of the first and second reservoirs to a gravitational potential difference or accelerating the first or second reservoirs in inertial space.

[0269] The first or the second thermal material may comprise magnetic dipoles and wherein providing the force may comprise subjecting the first or the second materials to a magnetic field.

[0270] Applying the force may comprise a thermodynamic compressor or expander.

[0271] The thermodynamic compressor or expander may comprise an axial compressor or turbine, a centrifugal compressor or turbine, or a converging or diverging duct.

[0272] A heat exchange system may comprise a first reservoir having a first point and a second point; a first thermal material contained in the first reservoir; a second reservoir having a first point and a second point; a second thermal material contained in the second reservoir, wherein at least some thermodynamic properties of the second material are different than the first material; and a thermal contact between the second point of the first reservoir and the second point of the second reservoir so that heat can transfer from the second point in the first reservoir to the second point in the second reservoir via the thermal contact where the first reservoir is subject to a force acting to produce a temperature difference between the first point and the second point of the first reservoir, and wherein the second reservoir can be subject to a force acting to produce a temperature difference between the first point and the second point of the second reservoir

[0273] The system may further comprise a third reservoir containing a third thermal material and a second heat exchanger operably coupled to the first and third reservoirs such that heat can be exchanged from the third reservoir to the first point of the first reservoir.

[0274] The third thermal material may be the same or different than the first thermal material.

[0275] The system may further comprise a fourth reservoir containing a fourth thermal material and a thermal contract operably coupled to the second and fourth reservoirs such that heat can be exchanged from the first point of the second reservoir to the fourth reservoir.

[0276] The fourth thermal material may be the same or different than the second thermal material.

[0277] The system may further comprise thermal insulation along the path of the heat flow between the first point and the corresponding second point in either the first or second thermal material.

[0278] The thermal contact may be achieved via conduction, radiation, natural convection, or forced convection.

[0279] The first material or the second material may be configured to facilitate the transfer of heat between the first and second points in either the first reservoir or second reservoir, and wherein the transfer of heat is by conduction, radiation, natural convection, or forced convection.

[0280] The system may further comprise a motor for accelerating the first reservoir or the second reservoir.

[0281] The system may further comprise a heat flow regulator configured to regulate heat flow through the first reservoir, the second reservoir, or the heat exchanger.

[0282] The system may further comprise a force applying mechanism configured to apply the force to the first and second reservoirs.

[0283] The force applying mechanism may comprise turbomachinery or a body force generating apparatus.

[0284] A method for facilitating heat flow may comprise employing a first reservoir containing a first thermal material, the first reservoir having a first point and a second point; employing a second reservoir, transferring heat from the first reservoir to the second reservoir when the second reservoir is at a lower temperature relative to the first reservoir, or transferring heat from the second reservoir to the first reservoir when the second reservoir is at a higher temperature relative to the first reservoir; employing a force to the first thermal material thereby creating a temperature difference between the first point and the second point in the first reservoir; operably coupling or operably decoupling a second heat exchange apparatus disposed in the first reservoir with a first heat exchange apparatus disposed in the second reservoir thereby allowing heat to flow therebetween or preventing heat to flow therebetween; operably coupling or operably decoupling a third heat exchange apparatus disposed in the first reservoir with a fourth heat exchange apparatus disposed in the second reservoir thereby allowing heat to flow therebetween or preventing heat to flow therebetween; actuating a work exchange apparatus to perform work on the first material; and actuating the work exchange apparatus to allow the first material to perform work on the work exchange apparatus.

[0285] The second reservoir may have a first point and a second point and wherein the second reservoir contains a second thermal material, the second thermal material having at least some thermodynamic properties different than the first thermodynamic material.

[0286] The second heat exchange apparatus may be disposed adjacent the first point of the first reservoir, and wherein the third heat exchange apparatus is disposed adjacent the second point of the first reservoir.

[0287] The first reservoir may be a closed reservoir or an open reservoir.

[0288] The method may further comprise providing an insulating material between the first and second reservoirs.

[0289] Actuating the work exchange apparatus may comprise actuating a piston, a turbine, or a nozzle.

[0290] The method may further comprise changing a pressure in the second reservoir.

[0291] The method may further comprise controlling heat flow between the second or third heat exchange apparatus with the respective first or fourth heat exchange apparatus.

[0292] Providing the force may comprise actuating the work exchange apparatus.

[0293] Employing the force may comprise providing an inertial force, a gravitational force, or an electromagnetic force.

[0294] A heat exchange system may comprise a first reservoir containing a first thermal material having a first point and a second point; a second reservoir wherein heat is transferred from the first reservoir to the second reservoir when the second reservoir is at a lower temperature relative to the first reservoir, or wherein heat is transferred from the second reservoir to the first reservoir when the second reservoir is at a higher temperature relative to the first reservoir; a second heat exchange apparatus in the first reservoir operably couplable and decouplable with a first heat exchange apparatus in the second reservoir to allow heat to flow therebetween or to prevent heat flow therebetween; a third heat exchange apparatus in the first reservoir operably couplable and decouplable with a fourth heat exchange apparatus in the second reservoir to allow heat to flow therebetween or to prevent heat flow therebetween, wherein application of a force to the first thermal material forms a temperature difference between the first point and the second point in the first reservoir; and an actuatable work exchange apparatus, wherein actuation of the work exchange apparatus performs work on the first material, and wherein actuation of the work exchange apparatus allows the first material to perform work on the work exchange apparatus.

[0295] The second reservoir may contain a second thermal material having a first point and a second point, and wherein the at least some thermodynamic properties of the second material are different than the first material.

[0296] The first reservoir may be a closed reservoir or an open reservoir.

[0297] The system may further comprise an insulating material between the first and outside reservoirs.

[0298] The system may further comprise a force generating apparatus configured to provide the force to the first material.

[0299] The force generating apparatus may comprise an inertial force mechanism or an electromagnetic force mechanism.

[0300] The work exchange apparatus may comprise a piston, a turbine, or a nozzle.

[0301] The system may further comprise a heat flow control operably coupled to the first or the third heat exchange apparatus and a respective first or fourth heat exchange apparatus, the heat flow control configured to control heat flow therebetween.

[0302] An energy conversion system may comprise a first reservoir containing a first material; a first expander having an inflow end and an outflow end, wherein the first material is input into the inflow end and output from the outflow end; a heat transfer apparatus having a first point thermally coupled to the outflow of the first material from the first expander and configured to extract heat from or deliver heat to the first material in the output of the first expander; and a compressor configured to receive outflow of the first working material from the heat transfer apparatus, wherein the outflow from the compressor is released into the first reservoir.

[0303] The heat may be transferred between the first reservoir and the first material output from the first expander.

[0304] The first expander may comprise a piston, a centrifugal or axial turbine, a duct, or a nozzle.

[0305] The compressor may comprise a piston, a centrifugal or axial compressor, a duct or a nozzle.

[0306] Heat extracted from the first material output from the outflow end of the expander may be delivered to the first reservoir or heat is extracted from the first reservoir and exchanged with the first material output from the outflow end of the expander.

[0307] The system may further comprise a second compressor having an inflow end and an outflow end, wherein a second material is input into the second compressor inflow end and output from the outflow end; the heat transfer apparatus may have a second point thermally coupled with the outflow of the material from the second compressor and configured to deliver heat to or extract heat from the material in the outflow of the second compressor, wherein the outflow of the second material from the heat transfer apparatus is input into an input of the second expander and an outflow from the second expander is released into the first reservoir.

[0308] Heat may be transferred between the first reservoir and outflow of the first material from the first compressor.

[0309] The second material may be the same as or different than the first material.

[0310] An energy conversion system may comprise a first material contained in a first reservoir; a first compressor having an inflow end and an outflow end, wherein the first material is input into the first compressor inflow end and output from the outflow end; a heat transfer apparatus having a first point thermally coupled with the outflow of the first material from the first compressor and configured to deliver heat to or extract heat from the first material in the output of the first compressor; and a first expander, wherein outflow of the first material from the heat transfer apparatus is input into an input of the first expander and an outflow from the first expander is released into the first reservoir.

[0311] The heat extracted from the first material output from the outflow end of the compressor may be exchanged with the first reservoir or heat is extracted from the first reservoir and exchanged with the first material output from the outflow end of the first compressor.

[0312] A method of converting energy may comprise providing a first material contained in a first reservoir;

inputting the first material into an inflow end of a first expander and outputting the first material from an outflow end of the first expander; transferring heat between the first material output from the first expander and a heat transfer apparatus; inputting the first material output from the heat transfer apparatus into a first compressor; and releasing an outflow from the first compressor into the first reservoir.

[0313] The method may further comprise providing a second material contained in the first reservoir; inputting the second working material into an inflow end of a second compressor; transferring heat between the heat transfer apparatus and the second working material output from an outflow of the second compressor; and inputting outflow from the heat transfer apparatus into a second expander and outputting outflow from an output of the second expander into the first reservoir.

[0314] The second material maybe the same as or different than the first material.

[0315] An energy conversion system may comprise a first reservoir containing a first material; a first compressor having an inflow end and an outflow end, wherein the first material is input into the inflow end; an expander; a heat transfer apparatus, wherein outflow from the first compressor can exchange heat with a first point of a heat transfer apparatus, and wherein outflow from the expander can exchange heat with a second point of the heat transfer apparatus, wherein the outflow from the first compressor after exchanging heat with the heat transfer apparatus is input into the expander; and a second compressor, wherein outflow from the expander flows into the second compressor after exchanging heat with the heat exchanger, and wherein outflow from the second compressor is released into the first reservoir.

[0316] The system may further comprise a heat exchanger thermally coupled with the heat transfer apparatus and configured to exchange heat therewith.

[0317] A method of converting energy may comprise providing a first material disposed in a first reservoir inputting the first material into a first compressor; outputting the first material from the first compressor and exchanging heat with a first point in a heat transfer apparatus; inputting the first material into an expander after exchanging heat with the heat transfer apparatus; outputting the first material from the expander and exchanging heat with a second point in the heat transfer apparatus; inputting the first material into a second compressor after exchanging heat with the heat transfer apparatus; powering the second compressor; and releasing outflow from the second compressor.

[0318] The method may further comprise exchanging heat between the heat transfer apparatus and a heat exchanger.

[0319] An energy conversion system may comprise a first reservoir containing a first working material; a first expander having an inflow end and an outflow end, wherein the first working material is input into the inflow end; a first point of a heat transfer apparatus configured to exchange heat with outflow of the first working material from the outflow end of the first expander; a compressor, wherein the outflow of the first material from the first expander is input into the compressor after exchanging heat with the heat transfer apparatus; and a second point of a heat transfer apparatus for exchanging heat with the first working material output from the compressor, wherein outflow of the first working material from the compressor is input into the second expander after exchanging heat with the heat transfer apparatus, and wherein outflow from the second expander is released into the first reservoir.

[0320] The system may further comprise a heat exchanger thermally coupled with the heat transfer apparatus and configured to exchange heat therewith.

[0321] A method of converting energy may comprise providing a first working material in a first reservoir; inputting the first working material into a first expander; exchanging heat between a first point of a heat transfer apparatus and output from the first expander; inputting the first working material into a compressor after exchanging heat with the heat exchanger; powering the compressor; exchanging heat between a second point of the heat transfer apparatus and outflow from the compressor; inputting the first working material into the second expander after exchanging heat with the heat transfer apparatus; and releasing outflow from the second expander into the first reservoir.

[0322] The method may further comprise exchanging heat between the heat transfer apparatus and a heat exchanger.

[0323] An engine may comprise a duct apparatus having an inlet and an outlet with a channel extending therethrough; a first working material disposed in the channel; a first compressor, wherein the first working material passes therethrough; a first heat exchanger, wherein the first working material passes therethrough and heat is exchanged between the first working material and the first heat exchanger; a first expander, wherein the first working material passes therethrough after exiting the first compressor; a first chamber disposed within or downstream of the first compressor or within or upstream of the first expander, wherein the first heat exchanger is disposed in the first chamber; a second heat exchanger, wherein the first working material passes therethrough and heat is exchanged between the first working material and the second heat exchanger; a second compressor, wherein the first working material passes therethrough, and wherein the first working material exits the second compressor and exits the outlet of the duct apparatus; a second chamber disposed within or downstream of the first expander or within or upstream of the second compressor, wherein the second heat exchanger is disposed in the second chamber; and a heat transfer apparatus configured to transfer heat between the first heat exchanger and the second heat exchanger, wherein the heat transfer can be from the second chamber to the first chamber when net work is done by the first working material, or where a rate of the heat transfer can be from the first chamber into the second chamber when net work is done on the working material.

[0324] A method of converting energy may comprise providing a channel in a duct apparatus; inputting a first material into the channel and into a first compressor and compressing the first material; passing the first material within or after the first compressor through a first heat exchanger; passing the first material output from the first compressor through a first expander after or while being heated and expanding the first working material; cooling the first working material after or while expanding it in the first expander with a second heat exchanger; and compressing the first working material after or while cooling the first working material in the second heat exchanger.

[0325] An engine may comprise a first engine comprising a duct apparatus with a channel disposed therethrough; a first working material disposed in the channel; a first expander, wherein the first working material enters the first expander; a first heat exchanger configured to exchange heat with the first material; a first compressor, wherein the first heat exchanger is disposed within or downstream of the first expander or within or upstream of the first compressor, and wherein the first material enters the first compressor after exiting the first expander, and wherein the first material exits the first compressor.

[0326] The engine may further comprise a second engine comprising a duct apparatus with a channel disposed therein; a second working material disposed in the channel; a second compressor, wherein the second working material is input into the second compressor; a second heat exchanger configured to transfer heat with the second working material; and a second expander, wherein the second heat exchanger is disposed within the second compressor or downstream of the second compressor or upstream of the second expander or within the second expander, and wherein the second working material is input into the second expander after exiting the second compressor.

[0327] The first material may be the same as or different than the second material.

[0328] A method of converting energy may comprise providing a first engine comprising a duct apparatus with a channel disposed therethrough; passing a first working material along the channel; inputting the first working material into a first expander; passing the first working material through a first heat exchanger and exchanging heat therebetween; compressing the first working material in a first compressor wherein the first heat exchanger is disposed in a first chamber disposed within or downstream of the first expander and within or upstream of the first compressor.

[0329] The method may further comprise providing a second engine comprising an inside apparatus disposed in a duct apparatus with a channel disposed therebetween; disposing a second working material in the channel; inputting the second working material into a second compressor; passing the second working material through a second heat exchanger and exchanging heat therebetween; inputting the second working into a second expander, and wherein the second heat exchanger is disposed in a second chamber disposed within or downstream of the second compressor or within or upstream of the second expander.

[0330] The second working material may be the same as or different than the first working material.

[0331] The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments in which the invention can be practiced. These embodiments are also referred to herein as "examples." Such examples can include elements in addition to those shown or described. However, the present inventors also contemplate examples in which only those elements shown or described are provided. Moreover, the present inventors also contemplate examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

[0332] In the event of inconsistent usages between this document and any documents so incorporated by reference, the usage in this document controls.

[0333] In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, composition, formulation, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

[0334] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with each other. Other embodiments can be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is provided to comply with 37 C.F.R. § 1.72(b), to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features may be grouped together to streamline the disclosure. This should not be interpreted as intending that an unclaimed disclosed feature is essential to any claim. Rather, inventive subject matter may lie in less than all features of a particular disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description as examples or embodiments, with each claim standing on its own as a separate embodiment, and it is contemplated that such embodiments can be combined with each other in various combinations or permutations. The scope of the invention should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

1. A heat transfer system, said system comprising
a first reservoir having a first point and a second point;
a first thermal material contained in the first reservoir;
a first thermal contact thermally coupled with the first point; and
a second thermal contact thermally coupled with the second point, and
wherein application of a force to the first thermal material can result in a temperature difference between the first and second points, and
wherein heat can flow between the first and second points in the first reservoir.

2. The system of claim **1**, further comprising
a second reservoir having a first point and a second point; and
a second thermal material contained in the second reservoir, wherein at least one thermodynamic property of the second material is different than the first material, and wherein subjecting the second thermal material to a force causes a temperature difference between the first and second points in the second reservoir, and
wherein the second point in the second reservoir is in thermal contact with the second point in the first reservoir.

3. (canceled)

4. The system of claim 1, wherein a distance between the first point and the second point is less than 100 kilometers.

5. The system of claim 1, wherein the first thermal material comprises a gas, a liquid, or a solid material.

6. The system of claim 1, wherein the force comprises a body force or a mechanical force.

7. A method for facilitating heat flow, said method comprising
- employing a first reservoir having a first point and a second point;
- employing a first thermal material contained in the first reservoir,
- wherein the first thermal material is subjected to a force thereby forming a temperature difference between the first and second points; and
- allowing heat flow through the first thermal material between the first point and the second point.

8. The method of claim 7, further comprising
- employing a second reservoir having a first point and a second point;
- employing a second thermal material contained in the second reservoir, wherein at least one thermodynamic property of the second material is different than the first material; and
- wherein the second thermal material is subjected to a force thereby forming a temperature difference between the first and second points in the second reservoir, and
- providing a thermal contact between the second point in the second reservoir and the second point in the first reservoir.

9. The method of claim 7, wherein the force comprises a body force or a mechanical force in the first material.

10. The method of claim 7, wherein the first material comprises a gas, a liquid, or a solid material.

11. (canceled)

12. The method of claim 7, further comprising flowing heat between a second reservoir containing a second thermal material and the first point in the first thermal material in the first reservoir.

13. The method of claim 12, wherein the second material is different than the first material.

14. The method of claim 8, further comprising flowing heat between the first point in the second reservoir and a third reservoir containing a third thermal material.

15. The method of claim 14, wherein the third thermal material is different than the second thermal material.

16.-29. (canceled)

30. The system of claim 1, further comprising a second reservoir containing a second thermal material and a second heat exchanger operably coupled to the first and second reservoirs such that heat can be exchanged between the second reservoir and the first point of the first reservoir.

31. The system of claim 30, wherein the second thermal material is different than the first thermal material.

32. The system of claim 2, further comprising a third reservoir containing a third thermal material and a thermal contact operably coupled to the second and id reservoirs such that heat can be exchanged between the first point of the second reservoir to ad the third reservoir.

33. The system of claim 32, wherein the third thermal material is different than the second thermal material.

34. (canceled)

35. The system of claim 1, wherein the thermal contact is achieved via conduction, radiation, natural convection, or forced convection.

36. The system of claim 1, wherein the first material is configured to facilitate the transfer of heat between the first and second points in the first reservoir, and wherein the transfer of heat is by conduction, radiation, natural convection, or forced convection.

37.-87. (canceled)

88. The system of claim 1, further comprising at least partial thermal insulation disposed along a path of the heat flow between the first point and the second point in the first thermal material.

89. The system of claim 1, further comprising a heat flow regulator configured to regulate heat flow through the first reservoir, or the heat transfer system.

90. The system of claim 1, further comprising an accelerator configured to accelerate the first reservoir.

91. The system of claim 90, further comprising a motor for accelerating the first reservoir.

92. The system of claim 6, further comprising a body force generating apparatus configured to apply the body force, and wherein the body force is constant in magnitude and direction within the first reservoir during normal operation.

93. The system of claim 1, wherein the first thermal material comprises electrical charged elements and wherein at least a portion of the force is provided by an electrical potential difference between the first and second points in the first reservoir.

94. The system of claim 1, wherein the first material comprises electric dipoles, and wherein at least a portion of the force is provided by an electrical field gradient between the first and second point the first reservoir.

95. The system of claim 1, wherein at least a portion of the force is provided by a gravitational potential difference applied to the first and second points in the first reservoir, or by acceleration of the first and second points the first reservoir in inertial space.

96. The system of claim 1, wherein the first thermal material comprises magnetic dipoles and wherein at least a portion of the force is provided by a non-uniform magnetic field.

97. The system of claim 1, wherein any materials thermally connected by the first or the second thermal contact are different materials.

98. The system of claim 2, wherein heat flows between the second points in the first and second reservoirs, or heat flows between the first and second points in either the first reservoir or the second reservoir, and the heat flow comprises conduction, radiation, natural convection, or forced convection.

99. The system of claim 2, wherein the second thermal material comprises a gas, a liquid, or a solid material.

100. The system of claim 2, wherein the thermodynamic property comprises the specific heat capacity at constant pressure.

101. The system of claim 6, wherein at least a portion of the mechanical force is provided by a thermodynamic compressor or expander.

102. The system of claim 101, wherein the thermodynamic compressor or expander comprises an axial compressor or turbine, a centrifugal compressor or turbine, or a converging or diverging duct.

103. The method of claim **7**, further comprising at least partially thermally insulating the first reservoir along a path of the heat flow between the first point and the second point in the first thermal material.

104. The method of claim **7**, further comprising accelerating the first reservoir.

105. The method of claim **7**, further comprising regulating a rate of heat flow through the first reservoir.

106. The method of claim **9**, wherein the force comprises a body force constant in magnitude and direction within at least a portion of the first reservoir during nominal operation.

107. The method of claim **7**, wherein the first thermal material comprises electrical charged elements and wherein at least a portion of the force is provided by an electrical potential difference between the first and second points in the first reservoir.

108. The method of claim **7**, wherein the first material comprises electric dipoles, and wherein the at least a portion of the force is provided by producing an electrical field gradient between the first and second point the first reservoir.

109. The method of claim **7**, wherein at least a portion of the force is provided by subjecting the first and second points in the first reservoir to a gravitational potential difference or accelerating the first reservoir in inertial space.

110. The method of claim **7**, wherein the first thermal material comprises magnetic dipoles and wherein at least a portion of the force is provided by subjecting the first material to a non-uniform magnetic field.

111. The method of claim **7**, wherein allowing the heat flow through the first thermal material between the first and second points in the first reservoir, comprises transferring the heat by conduction, radiation, natural convection, or forced convection.

112. The method of claim **8**, further comprising flowing heat between the second points in the first and second reservoirs or flowing heat between the first and second points in either the first reservoir or second reservoir, and wherein the heat flow comprises conduction, radiation, natural convection, or forced convection.

113. The system of claim **8**, wherein the thermodynamic property comprises the specific heat capacity at constant pressure.

114. The system of claim **8**, wherein the second material comprises a gas, a liquid, or a solid material.

115. The method of claim **9**, wherein applying the mechanical force comprises a thermodynamic compressor or expander.

116. The method of claim **115**, wherein the thermodynamic compressor or expander comprises an axial compressor or turbine, a centrifugal compressor or turbine, or a converging or diverging duct.

117. The method of claim **9**, further comprising employing a body force generating apparatus to produce the body force.

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