

**DEVICE FOR GENERATING A THERMAL FLUX WITH A
MAGNETO-CALORIC MATERIAL**

Technical field:

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The present invention concerns a device for generating a thermal flux with a magneto-caloric material, comprising at least one thermal flux generation unit provided with at least two thermal bodies each containing at least one magneto-caloric element, magnetic means arranged to emit at least one magnetic field, displacement means coupled to the magnetic
10 means in order to move them relative to the magneto-caloric elements so as to subject the latter to a magnetic field variation or annulment in such manner as to change their temperature, and means for recovering the positive and/or negative calories emitted by the magneto-caloric elements.

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Prior art:

Conventional refrigeration devices usually comprise a compressor for compressing a cooling fluid in order to raise its temperature and expansion means to decompress this cooling fluid
20 in order to cool it adiabatically. These conventional devices have a number of disadvantages. In effect, gases such as the CFCs (chlorofluorocarbons) currently used as the cooling fluid are serious pollutants and their use entails great risks of atmospheric pollution and destruction of the ozone layer. Consequently, those gases do not satisfy present-day requirements, nor the environmental standards of many countries. Furthermore, such
25 conventional equipment, which operates under pressure, has to be installed and maintained by trained and certified personnel who must follow constraining procedures whose implementation demands lengthy and repeated intervention times. Finally, such equipment is noisy, produces numerous vibrations, is bulky and complex, and consumes a lot of electrical energy. So conventional devices are not satisfactory.

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Research efforts have identified magneto-caloric materials that can be used in tempering and/or cooling installations. The magneto-caloric effect is the property that certain materials possess, of becoming warmer under the action of a magnetic field and then cooling to a temperature lower than their initial temperature once the magnetic field has disappeared or
5 when the magnetic field is varied.

A first technology, based on the use of large, superconducting magnetic assemblies, is used in laboratories and in the field of nuclear research to get down to temperatures close to absolute zero.

10 In particular the patent US-A-4.674.288 is known, which describes equipment for the liquefaction of helium, comprising a magnetizable substance that is moved within a magnetic field generated by a superconducting coil and a reservoir containing helium in thermally conductive contact with the said superconducting coil. The translatory movement
15 of the magnetizable substance produces cold, which is transmitted to the helium by conducting elements. The use of superconducting equipment necessitates installations for cooling with liquid nitrogen, which are bulky, costly, and which require delicate maintenance operations. Such devices are complex and can only be used for limited applications. Accordingly, that solution is not satisfactory.

20 The object of the publication FR-A-2 525 748 is a magnetic refrigeration device comprising a magnetizable material, a system for generating a variable magnetic field and means for transferring heat and cold that comprise a space filled with a saturated liquid coolant. In a first position the magnetizable material generates cold and the means for cold transfer extract
25 it from the magnetizable material by condensation of a coolant. In a second position the magnetizable material generates heat and the means for heat transfer extract the heat from the magnetizable material by the boiling or heating of another coolant. The overall efficacy of such systems is extremely low and they cannot match the current refrigeration systems in terms of efficiency. Thus, this solution is not economically satisfactory.

Studies carried out in the United States have led to the development of a new heat flow production process using a magneto-caloric material. On passing across the magnetic field the magnetic moments of the magneto-caloric material become aligned and this gives rise to a rearrangement of its atoms which causes the magneto-caloric material to heat up. Outside
5 the magnetic field the process is reversed and the magneto-caloric material cools down to a temperature lower than its initial temperature. A first material based on gadolinium has been developed. This material, which is effective at ambient temperature, has the disadvantage of being costly and difficult to obtain for this application. Less expensive alloys which are easier to obtain are currently being studied.

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A team of American researchers has developed and implemented a prototype that enables the theoretical results of research on gadolinium to be validated. This prototype comprises a disc formed by sectors containing a gadolinium alloy. The disk is guided in continuous rotation around its axis so that its sectors pass through a magnetic field created by a permanent
15 magnet. The permanent magnet straddles the sectors of the disk. Opposite the permanent magnet, the disk passes into a heat transfer block comprizing a heat transfer fluid circuit designed to transport the calories and/or frigories produced by the gadolinium subjected in alternation to the presence and absence of the magnetic field. The heat transfer block can be designed in two ways. In a first embodiment the heat transfer block is said to be “blind” and
20 the circuit passes through it without direct contact between the heat transfer fluid and the disk. In this first case the heat transfer efficiency is very low and the device is not viable in energy terms. In a second embodiment the heat transfer block has inlet and outlet orifices which open onto the rotating disk and allow the heat transfer fluid to make direct contact with the disk. In this second case even if rotary joints are used it is very difficult to prevent
25 leakage between the disk and the heat transfer block without adverse effect on the overall efficiency of the device. Thus, this solution is not satisfactory.

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Publication WO-A-03/050456 also describes a magnetic refrigeration apparatus with a similar magneto-caloric material which uses two permanent magnets. The device comprizes
a monoblock annular container which delimits twelve magnetocaloric compartments separated by joints, each compartment containing gadolinium in porous form. Each

compartment has a minimum of four orifices, including an inlet orifice and an outlet orifice connected to a hot circuit and an inlet orifice and an outlet orifice connected to a cold circuit. The two permanent magnets are set into continuous rotation movement so as to sweep in succession across the fixed magneto-caloric compartments and subject them successively to a different magnetic field. The calories and/or frigories produced by the gadolinium in the various compartments are transported to heat exchangers by hot and cold heat transfer fluid circuits to which they are successively connected by rotary joints whose rotation is coupled by one or more belts to the axle which drives the two magnets in continuous rotation. Thus the flow of heat transfer fluid passing through the fixed magneto-caloric compartments is successively connected to the hot and cold circuits by rotating joints. This device, which therefore simulates the operation of a liquid ring, necessitates continuous and precisely synchronized rotation of the various rotary joints and the permanent magnets, and is consequently technically difficult and costly to produce. Its principle of continuous operation severely restricts its potential for technical evolution. Moreover, the design of the apparatus precludes the use of a larger number of magneto-caloric compartments without making it economically unviable and technically unreliable. Finally, the use of rotary joints makes it impossible to guarantee that there will be no leaks, and reduces the life of the device.

Publication FR-A-2 601 440 describes a magnetic refrigeration apparatus and process which use a magneto-caloric substance in the form of a magneto-caloric disk that rotates relative to a fixed magnetic ring which generates the magnetic field. Since the magneto-caloric disk is rotating, it is difficult to ensure that no leakage will take place between the ducts carrying the heat transfer fluid and the external hot and cold circuits, which are fixed.

Publication XP 002047554, which bears the title "Rotary recuperative magnetic heat pump", describes a heat pump comprising a fixed magnetic rotor and moving magneto-caloric disks of small thickness comprising a magneto-caloric material such as gadolinium. The magnetic field variation is obtained by continuous or reciprocating rotation of the magneto-caloric disks. In this case the operation is similar to the preceding one and has the same drawbacks.

Explanation of the invention:

The present invention is intended to overcome the above disadvantages by providing a device
5 for heat flow production which is non-polluting, effective, reliable, simply designed while
being able to incorporate a large number of thermal bodies, evolutive, flexible, modular,
relatively inexpensive, whose installation and maintenance operations can be carried out by
personnel without specific training, which consumes relatively little electrical energy, whose
volume is optimized, whose efficiency is high, which requires only a limited amount of
10 magneto-caloric material, and which is suitable for use both in large-scale industrial
installations and in domestic applications.

In this aim the invention concerns a device for heat flow production with a magneto-caloric
material of the type indicated in the preamble, characterized in that the displacement means
15 move in reciprocation and are arranged so as to displace the magnetic means relative to the
magneto-caloric elements in a reciprocating movement chosen from the group that includes
at least a pivoting motion, pivoting combined with translation such as a helicoidal motion,
rectilinear translation, circular motion, sinusoidal motion, or movement along any other
suitable trajectory.

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In a preferred embodiment the recuperation means comprise at least one heat transfer fluid
circuit, means for circulating the said heat transfer fluid in the circuit(s) and means for
extracting the calories and/or frigories recuperated by the heat transfer fluid(s), said circuit
comprising at least two transfer zones each located in the immediate vicinity of one of the
25 magneto-caloric elements and arranged so that the heat transfer fluid recuperates at least in
part the calories and/or frigories emitted by the corresponding magneto-caloric element.

The recuperation means can comprise means for reversing the circulation direction of the
heat transfer fluid in the heat transfer fluid circuit.

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The recuperation means preferably comprize at least two heat transfer fluid circuits, of which at least one is a “hot circuit” for the calories and at least one is a “cold circuit” for the frigories, as well as commutation means arranged so as to connect each transfer zone to one or other of the said heat transfer fluid circuits.

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Advantageously, the device has synchronization means designed to synchronize the reciprocating displacement means with the commutation means in such manner that, in accordance with the magnetic field to which each magneto-caloric element is subjected, the corresponding transfer zone is connected to one or other of the heat transfer fluid circuits.

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Advantageously, the magneto-caloric element comprizes at least one magneto-caloric material chosen from the group that includes at least gadolinium (Gd) or a gadolinium alloy comprizing at least material chosen from the group that includes at least silicon (Si), germanium (Ge), iron (Fe), magnesium (Mg), phosphorus (P) and arsenic (As), the magneto-caloric material being in one of the forms chosen from the group that includes a block, a pastille, powder, or an agglomerate of pieces. The use of magneto-caloric materials having different active temperature levels makes it possible to obtain a very wide range of powers and temperatures.

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Advantageously, each thermal body is made at least partially of a conductive material selected for its good thermal conductivity and chosen from the group that includes at least copper, copper alloys, aluminum, aluminum alloys, steels, steel alloys, stainless metals and alloys thereof.

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Preferably, at least one of the thermal bodies comprizes at least one through-channel provided with at least one inlet orifice and at least one outlet orifice connected to the heat transfer fluid circuit, this through-channel constituting the corresponding transfer zone.

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Particularly advantageously, at least one of the thermal bodies comprizes a single through-channel provided with a single inlet orifice and a single outlet orifice connected to the circuit, the through-channel constituting the corresponding transfer zone.

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Preferably, the magnetic means comprise at least one magnetic element provided with at least one permanent magnet.

- 5 This magnetic element can comprise at least one magnetizable material arranged so as to concentrate and direct the field lines of the permanent magnet, said magnetizable material being chosen from the group that includes at least iron (Fe), cobalt (Co), soft iron, vanadium (V), or a combination of those materials.
- 10 The magnetic element is preferably U-shaped or C-shaped, arranged so as to receive the magneto-caloric element between its arms in a reciprocating movement. As a function of the magnetic field to be generated, the shape of the magnetic element can be different and can be optimized.
- 15 Advantageously, the thermal bodies are independent and are separated by at least one thermally insulating element chosen from the group that includes at least a space or an insulating material. The device can also comprise several magnetic elements carried by a support coupled to the reciprocating displacement means.
- 20 In a first embodiment the support is essentially circular, forming at least one ring mounted to pivot in reciprocation about its axis, said ring carrying the magnetic means radially and the thermal bodies defining circular sectors arranged essentially in a circle one after another so that they can be freely straddled by the magnetic means.
- 25 In this configuration the magnetic means can be orientated so that the gaps of the U or C shapes are substantially parallel or perpendicular to the pivoting axis of the ring, and the thermal bodies can be orientated, respectively, substantially parallel or perpendicular to the pivoting axis of the support.
- 30 In a second embodiment the support is essentially rectilinear, forming at least one bar, which travels in reciprocating rectilinear motion, the bar carrying the magnetic means and the

thermal bodies being carried by at least one frame surrounding the bar and being arranged essentially in line so that they can be straddled freely by the magnetic means.

In this configuration the magnetic means can be positioned in a staggered arrangement on either side of the bar in two rows, and the frame can have two series of thermal bodies each of which corresponds to the magnetic means of one of the rows.

Part of the thermal bodies is advantageously carried by at least one plate comprising at least communication orifices that allow the heat transfer fluid to pass into its circuit.

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Advantageously, the circulation means are chosen from the group that includes at least a pump, a circulator, or thermosiphonic circulation.

The extraction means preferably comprise at least two exchangers, at least one exchanger for calories connected to the "hot circuit" and at least one exchanger for frigories connected to the "cold circuit".

The reciprocating drive means can be chosen from the group that includes at least a motor, a jack, a spring mechanism, an aerogenerator, an electromagnet or a hydrogenerator.

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Advantageously, the device comprises several thermal flux generation units connected in series, in parallel, or in a series-parallel combination.

25 Brief description of the drawings:

The present invention and its advantages will be more easily understood from the description below, of several embodiments, given as non-limiting examples and referring to the attached drawings in which:

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- Fig. 1 shows an exploded perspective view of a first embodiment of a device according to the invention
- Fig. 2 shows a sectional side view of a thermal body for the heat transfer fluid of the device in Fig. 1
- Figs. 3A-B are perspective views of the device in Fig. 1, shown respectively from below and from above
- Figs. 4A-C are, respectively, exploded perspective views from above and below, of a second embodiment of a device according to the invention
- Figs. 5A-C are, respectively, exploded and non-exploded perspective views of a third embodiment of a device according to the invention at two stages of operation, and
- Figs. 6A-B are simplified schematic illustrations of the way in which a device according to the invention operates

Optimum manner of implementing the invention:

Referring to Figs. 1, 2 and 3A-B and according to a first embodiment of the invention, the device 1 for thermal flux generation with a magneto-caloric material, called “the device” in the remainder of this description, comprises a thermal flux generation unit 10 provided with twelve thermal bodies 11 each defining a circular sector. Each thermal body 11 forms an independent mechanical element which can be adapted according to need. These thermal bodies 11 are arranged in sequence essentially in a circle, and are mutually separated by one or more thermally insulating elements such as a space J, an insulating material, or any other equivalent means.

The thermal bodies 11 contain a magneto-caloric element 12 made of a magneto-caloric material such as gadolinium (Gd), a gadolinium alloy containing for example silicon (Si), germanium (Ge), iron (Fe), magnesium (Mg), phosphorus (P), arsenic (As), or any other equivalent magnetizable material or alloy. The choice between magneto-caloric materials is made having regard to the heating and cooling powers sought and the temperature ranges needed. Similarly, the quantity of magneto-caloric material used in the thermal body 11 depends on the heating and cooling powers installed, the range of operating temperatures, the installed power of the magnetic field and the nature of the magneto-caloric material itself. For information, it is for example possible to obtain 160 Watts of cooling power with 1 kg of gadolinium, a magnetic field of 1.5 Tesla, a temperature range of 33°C and a cycle of 4 seconds, said cycle comprising successive phases of exposure and non-exposure to the magnetic field.

In this example the magneto-caloric element 12 is in the form of a circular sector and each thermal body 11 comprises a heat-conducting element 13 which extends the magneto-caloric element 12 laterally. The heat-conducting element 13 is made of a conductive material chosen for its good thermal conductivity, such as copper or its alloys, aluminum or its alloys, steel or steel alloys, stainless metals or their alloys, or any other equivalent material. Thus, when the magneto-caloric element 12 warms up or cools under the effect of the magnetic field variation, it transfers part of its calories or frigories to the heat-conducting element 13 which warms up or cools rapidly, increasing the thermal absorption capacity of the thermal body 11 to the same extent. The geometry of the thermal bodies 11 thus favors a large contact area with the magnetic elements 103 described later. In general, the magneto-caloric material can be a block, a pastille, powder, an agglomerate of pieces, or any other suitable form. The magneto-caloric element 12 can comprise several magneto-caloric materials, for example several plates arranged side by side.

Each thermal body 11 comprises a transfer zone 14 through which passes the heat transfer fluid to be heated or cooled. This transfer zone, illustrated in Fig. 2A, is formed of a through-channel which opens, on the same side in this example, into an essentially flat wall 15 of the thermal body 11 at an inlet orifice 16 and an outlet orifice 17. Of course it is

possible to provide that for all or some of the thermal bodies 11, the inlet 16 and outlet 17 orifices are distributed on two or even a larger number of walls 15, said walls 15 all being flat or not.

5 The thermal bodies 11 are fixed, resting on their wall 15 comprizing the inlet 16 and outlet 17 orifices, on a plate 18 made of a mechanically rigid material. On the side facing the plate 18 the thermal bodies 11 are provided with shoulders 11' which increase their area in order to facilitate their mounting on the plate 18 and to improve heat exchange with the heat transfer fluid. The plate 18 and the thermal bodies 11 are separated by a thermal joint 19. This
10 thermal joint 19 and the plate 18 comprize communication orifices 100 which allow passage of the heat transfer fluid. The communication orifices 100 are provided with connectors (not shown) for connecting the inlet 16 and outlet 17 orifices of the transfer zones 14 of the various thermal bodies 11 to one or more external circuits provided with heat exchangers (not shown in these figures). These external circuits are for example formed of rigid or flexible
15 pipes each filled with an identical or different heat transfer fluid. The external circuit(s) and the transfer zones 14 define the heat transfer fluid circuit(s).

Each heat transfer fluid circuit has means (not shown in these figures) for the forced or free circulation of the heat transfer fluid, such as a pump or any other equivalent means. The
20 chemical composition of the heat transfer fluid is adapted to the temperature range desired and is chosen to obtain maximum heat exchange. For example, pure water is used for positive temperatures and water containing antifreeze, for example a glycolated product, for negative temperatures. Thus, this device 1 makes it possible to avoid using any fluid that is corrosive or harmful to man and/or his environment. Each heat transfer fluid circuit is also
25 provided with extraction means (not shown in these figures), such as exchangers or any other equivalent means to allow the dispersion of the calories and frigories.

The magnetic means 102 of the device 1 comprize magnetic elements 103 each provided with one or more solid, sintered or laminated permanent magnets which concentrate and
30 direct the magnetic field lines of the permanent magnet. The magnetizable materials can contain iron (Fe), cobalt (Co), vanadium (V), soft iron, a combination of these materials, or

any equivalent material. Besides, it is understood that any other type of equivalent magnet such as an electromagnet or a superconductor can be used. Nevertheless, permanent magnets have certain advantages in terms of size, simplicity of use, low consumption of electrical energy, and low cost.

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The magnetic elements 103 are carried by a mobile support 104. In this example the device 1 has six magnetic elements 103 arranged in sequence essentially in a circle and spaced an interval I apart. The magnetic elements 103 are U- or C-shaped with their arms far enough apart to allow free passage of the thermal bodies 11. The magnetic elements 103 are fixed
 10 radially on an essentially circular support in the shape of a ring 104. This ring 104 is mounted to pivot about its axis between two positions and is coupled to means (not shown) for driving it in reciprocation, which move the ring 104 reciprocally from one position to the other. The reciprocating driving means are for example a motor, a jack, a spring mechanism, an aerogenerator, an electromagnet, a hydrogenerator or any other equivalent means.
 15 Compared with continuous or step by step movements, the reciprocating pivoting movement has the advantage of being obtainable by simple and inexpensive reciprocating drive means. Moreover, this reciprocating movement only requires two positions and this simplifies operation over a limited and easily controllable displacement path.

20 The magnetic elements 103 fit over part of the thermal bodies 11 so that the latter are straddled and surrounded on each side by the arms of the magnetic elements 103. Since there are twice as many thermal bodies 11 as magnetic elements 103, as the magnetic elements 103 pivot in reciprocation relative to the thermal bodies 11 the latter are, in succession, face to a magnetic element 103 or not so.

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In this example the thermal bodies 11 are orientated essentially parallel to the pivoting axis of the ring 104 and the magnetic elements 103 are orientated with their gap essentially parallel to the said pivoting axis.

30 As described later with reference to Figs. 6A-B, the device 1 comprizes commutation and synchronization means. Thus, in a first stage the heat transfer fluid heated by a thermal body

11 subjected to a magnetic field circulates in a “hot circuit” towards a calorie exchanger. In a second stage the heat transfer fluid cooled by the thermal body 11 in the absence of a magnetic field or when subjected to a different magnetic field, circulates in a “cold circuit” towards a frigorific exchanger.

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This thermal flux generation unit 10 can be coupled with other units, whether similar or not, with which it can be connected in series and/or in parallel and/or in a series/parallel combination.

10 The device 2 according to a second embodiment and illustrated in Figs. 4A-C is substantially similar to the previous one. The difference is that the thermal bodies 21 are orientated essentially perpendicularly to the pivoting axis of the ring 204 and the magnetic means 203 are orientated with their gap essentially perpendicular to the said pivoting axis.

15 In a third embodiment illustrated in Figs. 5A-C, the device 3 comprises two thermal flux generation units 30 arranged side by side, each provided with twelve thermal bodies 31 and six magnetic elements 303. This device is shown in Figs. 5B and C in two different positions corresponding to two distinct stages of operation.

20 The thermal bodies 31 are rectilinear and are arranged essentially in line along two superimposed rows. Their structure is essentially similar to that of the previous ones. They are separated by intervals J. Each row of thermal bodies 31 is carried by an essentially rectilinear frame 306, the said rows being positioned on either side of this frame on a crossmember 305. The frame 306 is made of a thermally insulating and mechanically rigid material. The frames 306 are fixed to one another, for example by screwing, riveting, clipping, welding or in any other equivalent way. They can be separated from one another and/or relative to the thermal bodies by a thermal joint (not shown). The lines of thermal bodies 31 are respectively covered at the top and bottom by connection plates essentially similar to the previous ones and not shown.

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The magnetic elements 303 are essentially similar to the previous ones and are also U- or C-shaped. They are positioned in a staggered arrangement on either side of two essentially rectilinear bars 304 each provided between the two crossmembers 305 of the corresponding frame 306. Thus, the magnetic elements 303 form two rows of Us or Cs each straddling part
 5 of the thermal bodies 31. The bars 304 are mounted to move in reciprocating rectilinear motion on the frame 306 and are coupled to reciprocating drive means (not shown). For that purpose the bars 304 have at their ends guiding fingers 307 which slide in reciprocation within guide flanges 308 provided in the frames 306.

10 As with the previous embodiments, these thermal flux generation units 30 can be coupled to other units, whether similar or not, with which they can be connected in series and/or in parallel and/or in a series/parallel combination. Differentiated temperature stages can be realized in this way.

15 In other variant embodiments, not illustrated, the reciprocal movement produced by the reciprocating displacement means which move the magnetic means can be a pivoting combined with a translation, such as a helicoidal motion, a circular translation, a sinusoidal translation or a translation along any other suitable path.

20 The operation of the above devices 1–3 is described with reference to Figs. 6A-B, which illustrate schematically three stages of the operating cycle. Referring to these figures, the device 4 comprises two thermal bodies 41a, 41b, a magnetic element 403 and two heat transfer fluid circuits 410a, 410b one of which is a “hot circuit” 410a coupled to a calorie exchanger 413a while the other is a “cold circuit” 410b coupled to a frigorie exchanger 413b.

25 The heat transfer fluid is circulated by pumps 411a, 411b, for example a dual pump with multiple chambers or several stages. The commutation means 412 enable each thermal body 41a, 41b to be connected to one or other of the heat transfer fluid circuits 410a, 410b and comprise for example vanes or slide valves controlled by electric, pneumatic, hydraulic or any other suitable means.

In the example described, the operation of the device 4 can be decomposed into three stages, to change between which the commutation means 412 are actuated and the magnetic field is modified. In another variant embodiment (not illustrated) the heat transfer fluid is circulated by a circulator, by thermosiphonic action or by any other suitable means.

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During the first stage when the cycle begins (see Fig. 6A in part) the thermal body 41a is connected to the "hot circuit" 410a by the commutation means 412. It is subjected to the magnetic field of the magnetic element 403, warms up, and transfers its calories to the heat transfer fluid passing through the "hot circuit" 410a. The calories are transported by the "hot circuit" 410a and extracted by the calorie exchanger 413a.

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To pass from the first to the second stage, the commutation means 412 are switched so that the thermal bodies 41a, 41b are respectively connected to the "cold circuit" 410b and to the "hot circuit" 410a. Moreover, the magnetic element 403 is moved so that the thermal body 41a is no longer subjected to its magnetic field, while the thermal body 41b is.

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During the second stage of the cycle (see Fig. 6B) the thermal body 41a which is no longer subjected to the magnetic field of the magnetic element 403 cools down to a temperature lower than its initial temperature and transmits its frigories to the heat transfer fluid passing through the "cold circuit" 410b. The frigories are transported by the "cold circuit" 410b and extracted by the frigorie exchanger 413b, which can be located in a cold compartment 414. Besides, the thermal body 41b is subjected to the magnetic field of the magnetic element 403, warms up, and transmits its calories to the heat transfer fluid passing through the "hot circuit" 410a. The calories are transported by the "hot circuit" 410a and extracted by the calorie exchanger 413a.

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To change from the second to the third stage, the commutation means 412 are switched so that the thermal bodies 41a, 41b are respectively connected to the "hot circuit" 410a and to the "cold circuit" 410b. Moreover, the magnetic element 403 is moved so that the thermal body 41b is no longer subjected to its magnetic field while the thermal body 41a is subjected to the field.

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During the third stage of the cycle (see Fig. 6A) the thermal body 41a is thus connected to the “hot circuit” 410a and the thermal body 41b to the “cold circuit” 410b by the commutation means 412. The thermal body 41a is subjected to the magnetic field of the magnetic element 403, it warms up, and transmits its calories to the “hot circuit” 410a passing through it. The calories are transported by the “hot circuit” 410a and extracted by the calorie exchanger 413a. The thermal body 41b, which is no longer subjected to the magnetic field of the magnetic element 403, cools down to a temperature lower than its initial temperature and transmits its frigories to the “cold circuit” 410b passing through it. The frigories are transported by the “cold circuit” 410b and extracted by the frigorie exchanger 413b, which can be located in a cold compartment 414.

The commutation means 412 then switch and restore the device 4 to the configuration of the second stage. The heating/cooling cycle can therefore be repeated without limit. At each cycle the magneto-caloric material of the thermal bodies 41a, 41b is successively subjected to magnetic fields and then removed from the said magnetic fields. The frequency of the cycle depends on the means used and the thermal results to be obtained.

The switching of the thermal bodies 41a, 41b and of the “cold” 410b and “hot” 410a circuits can be synchronized with the reciprocating displacement of the magnetic field, for example by pivoting through a constant angle or linear displacement through a constant interval. The operating cycle can be controlled by a temperature sensor fitted in the cold compartment 414 or, for example, close to the products to be cooled.

In a variant embodiment (not illustrated) the device 4 does not have commutation means and passage from one stage to the other is effected by reversing the circulation direction of the heat transfer fluid in a single heat transfer fluid circuit. This variant overcomes all problems of ensuring no leaks by dispensing with valves.

Industrial application possibilities:

Thus, the device 4 makes it possible to heat, cool or temper a space, an agroalimentary tunnel or the inside of a refrigerator, and can also be used as a heat pump or for any other similar application, in industry or in the domestic context. Finally, the device 4 can be used to regulate the temperature of preservation or drying cabinets or for the climatization of spaces.

In general, according to the invention the reciprocating displacement means are coupled to the magnetic means 103, 203, 303, 403 in order to move them in reciprocation relative to the thermal body 11, 21, 31, 41a, 41b. Accordingly, the system of heat transfer fluid circuits is fixed and the magnetic field variation is obtained by reciprocating displacement of the magnetic means 103, 203, 303, 403 themselves. This particular structure thus overcomes the many leakage problems that arise when part of the heat transfer fluid circuits 410a, 410b is mobile relative to the rest of the said circuits 410a, 410b.

The above description shows clearly that while reducing energy consumption, the device 1-4 according to the invention enables the pollution-free generation of large thermal flux that can be used for any type of application. This simple device can be installed and maintained by personnel without specific training. Moreover, it operates very quietly.

Besides, the device 1-4 has the advantage of only needing two operating positions, which simplifies its design, operation and control. It is therefore less expensive to produce and use than are traditional devices.

The reciprocating displacements also make it possible to obtain structures of the device 1-4 which allow the number of thermal bodies 11, 21, 31, 41a, 41b and/or magnetic means 103, 203, 303, 403 and/or thermal flux generation units 10, 30 to be increased easily and economically. By combining several thermal flux generation units that operate with reciprocating displacements, the thermal capacities of the device 1-4 can also be reliably increased at moderate cost and without excessive complication of the operation or structure of the device 1-4.

The present invention is not limited to the example embodiments described, but extends to any modification and variant evident to those with knowledge of the field while remaining within the scope of the protection defined in the attached claims.

Claims

1. Device for generating a thermal flux with magneto-caloric material (1-4), comprising at least one thermal flux generation unit (10, 30) provided with at least two thermal bodies (11, 21, 31, 41a, 41b) each containing at least one magneto-caloric element (12, 22, 32), magnetic means (103, 203, 303, 403) arranged to emit at least one magnetic field, displacement means coupled to the said magnetic means (103, 203, 303, 403) to move them relative to the said magneto-caloric elements (12, 22, 32) so as to subject the latter to a magnetic field variation in such manner as to vary their temperature, and means for the recuperation of the calories and/or frigories emitted by the said magneto-caloric elements (12, 22, 32), **characterized in that** the said displacement means reciprocate and are arranged to move the said magnetic means (103, 203, 303, 403) relative to the said magneto-caloric elements (12, 22, 32) in a reciprocating motion.
2. Device (1-4) according to Claim 1, **characterized in that** the said reciprocating movement is chosen from the group that includes at least pivoting, pivoting combined with translation, and translation.
3. Device (1-4) according to Claim 1, **characterized in that** the said recuperation means comprise at least one heat transfer fluid circuit (410a, 410b), means (411a, 411b) for circulating said heat transfer fluid in said circuit (410a, 410b) and means (413a, 413b) for extracting said calories and/or frigories recovered by said heat transfer fluid, the said circuit (410a, 410b) comprising at least two transfer zones (14) each located immediately adjacent to one of said magneto-caloric elements (12, 22, 32) and arranged so that said heat transfer fluid recovers, at least in part, said calories and/or frigories emitted by the said corresponding magneto-caloric element (12, 22, 32).
4. Device (1-4) according to Claim 3, **characterized in that** the said recuperation means comprise means for reversing the circulation direction of said heat transfer fluid in said heat transfer fluid circuit (410a, 410b).

5. Device (1-4) according to Claim 3, **characterized in that** the said recuperation means comprise at least two circuits (410a, 410b), at least one being a “hot circuit” (410a) for the calories and at least one being a “cold circuit” (410b) for the frigories, and commutation means (412) arranged so as to connect each transfer zone (14) in alternation to one or other of said circuits (410a, 410b).

6. Device (1-4) according to Claim 5, **characterized in that** it comprises synchronization means arranged to synchronize the said reciprocating displacement means with said commutation means (412) in such manner that, depending on the magnetic field to which each magneto-caloric element (12, 22, 32) is subjected, said corresponding transfer zone (14) is connected to one or other of said circuits (410a, 410b).

7. Device (1-4) according to Claim 1, **characterized in that** the said magneto-caloric element (12, 22, 32) comprises at least one magneto-caloric material chosen from the group that includes at least gadolinium (Gd), a gadolinium alloy containing at least one material chosen from the group that includes silicon (Si), germanium (Ge), iron (Fe), magnesium (Mg), phosphorus (P) and arsenic (As), said magneto-caloric material being in one of the forms chosen from the group that includes a block, a pastille, powder or an agglomerate of pieces.

8. Device (1-4) according to Claim 1, **characterized in that** each thermal body (11, 21, 31, 41a, 41b) is made at least in part from a conductive material selected for its good thermal conductivity and chosen from the group that includes at least copper and its alloys, aluminum and its alloys, steels and steel alloys, stainless metals and alloys thereof.

9. Device (1-4) according to Claim 1, **characterized in that** said thermal body (11, 21, 31, 41a, 41b) comprises at least one through-channel provided with at least one inlet orifice (16) and at least one outlet orifice (17) connected to said circuit (410a, 410b), said through-channel constituting the said corresponding transfer zone (14).

10. Device (1-4) according to Claim 1, **characterized in that** the said thermal body (11, 21, 31, 41a, 41b) comprises a single through-channel provided with a single inlet orifice (16) and a single outlet orifice (17) connected to said circuit (410a, 410b), said through-channel constituting the said corresponding transfer zone (14).

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11. Device (1-4) according to Claim 1, **characterized in that** said magnetic means comprise at least one magnetic element (103, 203, 303, 403) provided with at least one permanent magnet or an electromagnet or a superconductor.

10 12. Device (1-4) according to Claim 11, **characterized in that** the said magnetic element (103, 203, 303, 404) comprises at least one magnetizable material arranged to concentrate and direct the field lines of said permanent magnet, and chosen from the group that includes iron (Fe), cobalt (Co), vanadium (V), soft iron, or a combination of those materials.

15 13. Device (1-4) according to Claim 11, **characterized in that** the said magnetic element (103, 203, 303, 403) has the shape of a U or C arranged to receive said magneto-caloric element (12, 22, 32) between its arms and in alternation.

14. Device (1-4) according to Claim 11, **characterized in that** the said thermal bodies
20 (11, 21, 31, 41a, 41b) are independent and are separated by at least one thermally insulating element chosen from the group that includes at least a space or an insulating material.

15. Device (1-4) according to Claim 1, **characterized in that** it comprises a plurality of magnetic elements (103, 203, 303, 403) carried by at least one support (104, 304) coupled to
25 said reciprocating displacement means.

16. Device (1, 2) according to Claim 15, **characterized in that** said support is essentially circular and constitutes at least one ring (104) mounted to pivot in reciprocation about its axis, said ring carrying the magnetic means (103, 203) radially, **and in that** the said thermal
30 bodies (11, 21) define circular sectors arranged in sequence essentially in a circle to be able to be straddled freely by said magnetic means (103, 203).

17. Device (1) according to Claim 16, **characterized in that** the said magnetic means (103) are orientated so that the gaps of the said U or C shapes are essentially parallel to said ring (104), **and in that** the said thermal bodies (11) are orientated essentially parallel to the pivoting axis of said ring (104).

18. Device (2) according to Claim 16, **characterized in that** the said magnetic means (203) are orientated so that the gaps of the said U or C shapes are essentially perpendicular to the pivoting axis of said ring (204), **and in that** the said thermal bodies (21) are orientated essentially perpendicularly to the pivoting axis of said ring (204).

19. Device (3) according to Claim 15, **characterized in that** the said support is essentially rectilinear and defines at least one bar (304) that moves in reciprocating rectilinear translation, said bar (304) carrying said magnetic means (303), **and in that** the said thermal bodies (31) are carried by at least one frame (306) positioned around the said bar (304) and are arranged essentially in line so that they can be straddled freely by said magnetic means (303).

20. Device (3) according to Claim 19, **characterized in that** the said magnetic means (303) are positioned in a staggered arrangement on either side of said bar (304) forming two rows, **and in that** the said frame (306) comprizes two series of thermal bodies (31) each of which corresponds to the magnetic means (303) of one of the said rows.

21. Device (1-4) according to Claim 1, **characterized in that** at least part of the said thermal bodies (11, 21, 31, 41a, 41b) is carried by at least one plate (18, 28), which comprizes communication orifices (100) to allow passage of said heat transfer fluid to said circuit (410a, 410b).

22. Device (1-4) according to Claim 3, **characterized in that** the said circulation means are chosen from the group that includes at least a pump (411a, 411b), a circulator or a thermosiphon.

23. Device (1-4) according to Claim 4, **characterized in that** the said extraction means
comprize at least two exchangers, of which at least one is a calorie exchanger (413a)
connected to the “hot circuit” (410a) and at least one is a frigorie exchanger (413b) connected
5 to the “cold circuit” (410b).

24. Device (1-4) according to Claim 1, **characterized in that** the said reciprocating drive
means are chosen from the group that includes at least a motor, a jack, a spring mechanism,
an aerogenerator, an electromagnet or a hydrogenerator.

25. Device (1-4) according to Claim 1, **characterized in that** it comprizes a plurality of
thermal flux generation units connected in series, in parallel or in a series-parallel
combination.