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(54) **Refrigeration apparatus and method**

Verfahren und Vorrichtung zur Kühlung

Procédé et appareil de réfrigération

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Description

This invention relates to a refrigeration apparatus and refrigeration method, and in particular to refrigeration apparatus capable of operating in either a vapour compression mode or a natural cooling mode.

GB-B-2 233 080 describes a refrigeration apparatus which may be operated in a mechanical mode, or alternatively in a thermosyphon mode. In the mechanical mode the apparatus operates in a conventional manner utilising a vapour compression cycle, with refrigerant vapour being compressed before being passed through a heat exchanger (condenser) where sensible heat is rejected to the atmosphere from the compressed refrigerant, then passing the resulting condensate through a restriction, typically an expansion valve, and finally passing the expanded and cooled refrigerant to a heat exchanger (evaporator) to absorb heat from a fluid to be chilled. When ambient temperatures are sufficiently low the refrigerant path may be reconfigured to bypass the compressor and the expansion valve such that the only cooling effect experienced by the refrigerant is the natural cooling obtained when the refrigerant is passed through the condenser, the evaporator being located below the condenser such that the refrigerant may circulate without the mechanical assistance normally provided by the compressor. Clearly, operation in the thermosyphon mode is more economical than the mechanical or vapour compression mode.

In a typical refrigerating unit incorporating this feature, several refrigerating systems are arranged so that the fluid to be chilled is passed through the evaporators in series. A number of the systems may cool the fluid by vapour compression operation while other systems operating with warmer inlet fluid may contribute a share of the required cooling by thermosyphon operation. However, such units are expensive and involve high capital costs and in practice are restricted to very large units where stand-by equipment is specified. It has not yet been possible to use an individual two-mode system, as when the system changes from vapour compression refrigeration to thermosyphon refrigeration there is a period of delay while the heat rejection equipment, previously in contact with the compressed (and thus heated) refrigerant, cools to a temperature below that of the fluid being chilled.

US-A-5 211 029 discloses air-conditioning apparatus which includes a conventional condensing unit including a compressor and condenser, and a negative energy storage system including an insulated tank for containing negative heat energy storage material and through which refrigerant may be circulated. Both the condensing unit and the negative energy storage system may be connected to an evaporating unit to provide cooling to an associated air-conditioned space. In a first mode, the apparatus does not provide an air-conditioning effect, refrigerant cooled by the action of the condensing unit and an expansion device being passed through the negative energy storage system to cool the material therein. In a second mode, an air-conditioning effect is provided by circulating refrigerant through the evaporating unit and the negative energy storage system. In a third mode, an air-conditioning effect is provided by circulating refrigerant through the evaporating unit and the condensing unit. In a fourth mode, the negative energy storage system and the condensing unit combine to provide cooling of the refrigerant from the evaporating unit.

According to the present invention there is provided refrigeration apparatus capable of operating in i) vapour compression cooling mode or ii) natural cooling mode, the apparatus defining a refrigerant path comprising:

compression means for compressing a refrigerant;
heat rejection means for cooling the compressed refrigerant;
restriction means for expanding the refrigerant;
chilling means for permitting the absorption of heat by the refrigerant from a fluid to be chilled;
valve means configurable for selectively directing refrigerant i) to pass through the compression means and restriction means or ii) to bypass the compression means and restriction means; and
thermal storage means for i) being cooled while the apparatus operates in the vapour compression cooling mode and ii) providing a chilling effect to the fluid during changeover to natural cooling mode.

According to a further aspect of the present invention there is provided a refrigeration method including i) a vapour compression cooling mode or ii) a natural cooling mode, the method including the steps of:

providing a heat rejecting means and utilising said means to reject heat from a refrigerant;
chilling a fluid with the refrigerant; and

i) when operating in vapour compression cooling mode the method further including the steps of:

a) compressing the refrigerant;
b) expanding the refrigerant; and
c) cooling a thermal storage means; and

ii) when operating in natural cooling mode the method further including the step of:

a) providing a chilling effect to said fluid using the thermal storage means, at least during initial changeover from vapour compression mode to natural cooling mode.

The chilled fluid may be the fluid contained within a space to be cooled, for example a refrigerated compartment, but will usually be a liquid, such as water, to be utilised as a cooling medium for a region to be cooled, such as an air conditioned space, which may be remote from the refrigeration apparatus.

Preferably, the thermal storage means i) is cooled by the chilled fluid while the apparatus operates in the vapour compression cooling mode and ii) chills the fluid on changeover to natural cooling mode.

Preferably also, operation in natural cooling mode is achieved without any mechanical circulation of the refrigerant, which, in the vapour compression cooling mode, is typically provided by the compression means. In this case the chilling means will be positioned below the heat rejection means. Alternatively, if some other arrangement is desired, refrigerant circulation means may be provided for use in the natural cooling mode.

Thus, the present invention allows changeover from compression mode to natural cooling mode without the period of delay that occurs in conventional two-mode systems as the heat rejection means cools to a temperature below that of the fluid being chilled; during this changeover period the present invention provides for chilling of the fluid by the thermal storage means.

In a preferred embodiment, with selection of appropriate thermal storage means, the invention may operate at full capacity in the vapour compression cooling mode irrespective of cooling load, any excess capacity being utilised to cool the thermal storage means. On the thermal storage means reaching a condition where it cannot be cooled further, the fluid temperature will drop sharply, allowing a thermostatic switch to reconfigure the valve means to provide the natural cooling mode. The thermal storage means then begins to chill the fluid, preventing an immediate rise in temperature of the fluid and allowing time for the apparatus to adjust to natural cooling mode.

Preferably also, the thermal storage means contains a phase change material which will absorb or reject heat at a substantially constant temperature. Substances suitable for use in such means include acetic acid and lactic acid.

These and other aspects of the present invention will now be described, by way of example, with reference to the accompanying drawing, which illustrates, in schematic form, refrigeration apparatus in accordance with a preferred embodiment of the present invention.

The apparatus includes ducting 10 which partially defines a refrigerant path around which refrigerant is cycled in either i) a mechanical or vapour compression cooling mode or ii) a thermosyphon or natural cooling mode. In vapour compression mode the refrigerant is first subject to compression by a positive displacement compressor 12, from which the high pressure refrigerant passes to heat rejection means in the form of a condenser 14, which is exposed to ambient air. Following condensing and cooling in the condenser 14, the refrigerant passes to restriction means in the form of an expansion valve 16, which causes a sufficient portion of the refrigerant to vaporise to reduce the temperature of the remaining liquid to that consistent with the lower pressure. The expanded and cooled refrigerant is then passed to a heat exchanger in the form of a chiller 18 where the refrigerant absorbs heat from fluid to be cooled. On exit from the chiller 18, the refrigerant, now in the form of low pressure vapour, returns to the compressor 12.

The chiller 18 forms part of a secondary cooling circuit around which a fluid, such as water, is circulated. Following chilling, the water passes through a thermal store 20 which contains a phase change material. The water then passes through a region to be cooled 22, before returning to the chiller 18, circulation of the fluid around the cooling circuit being achieved by means of a fluid pump 24.

The refrigeration circuit includes a three-way valve 26 and a two-way ball valve 28, and for operation in the vapour compression mode the valves 26, 28 are configured such that refrigerant is passed through the compressor 12 and the expansion valve 16. However, when the ambient temperature is particularly low (that is lower than the temperature of the water to be chilled), the valves 26, 28 may be configured to bypass the compressor 12 and valve 16, such that the refrigerant is cooled solely by ambient air as it passes through the condenser 14. Also, the chiller 18 is positioned below the condenser 14 and the ducting 10 is arranged such that the refrigerant will circulate in this thermosyphon mode without mechanical assistance, thus minimising the energy consumption of the apparatus.

While operating in vapour compression mode, the compressor 12 may operate at full capacity, irrespective of the cooling load, any excess cooling of the water being absorbed by the thermal store 20, in which the excess cooling capacity is utilised to solidify a liquid, at constant temperature. When the phase change material has completely solidified there will be a sharp decrease in the temperature of the water, which may be detected by a thermostat 30 which operates to switch the apparatus from vapour compression mode to thermosyphon mode, that is by shutting down the compressor 12 and reconfiguring the valves 26, 28 to bypass the compressor 12 and the expansion valve 16. Initially, on switching from vapour compression mode to thermosyphon mode, the refrigerant in the ducting 10 downstream of the compressor 12 and upstream of the expansion valve 16 will be at a higher temperature than the water and it takes some time for the refrigerant and the condenser hardware and ducting to be cooled to a level where its temperature is lower than that of the water. Also, in order for circulation of refrigerant to take place without mechanical assistance, the temperature of the refrigerant in the condenser 14 must fall below the temperature at the outlet from the chiller 18, the reverse of the situation in the vapour compression mode. During this transition period the water is chilled by the thermal store 20, as the phase change material in the store is melted by the circulating water.

From the above description it will be seem that this embodiment of the invention provides an arrangement in which refrigeration apparatus capable of operating in a thermosyphon mode may be utilised on an individual basis, and not necessarily as part of a larger system. Further, the provision of the thermal store 20 allows the system to be operated at full capacity in vapour compression mode, which is of course more efficient than operating at part capacity.

The present invention may be utilised in a wide variety of applications, but is particularly useful where the cooling load is to be maintained at a relatively high temperature, such as in air conditioning systems for building which chill the ceilings of rooms and corridors. Such air conditioning is particularly suitable for thermosyphon cooling techniques as the chilled ceilings must be kept at a temperature higher than the dew point of the room air. These relatively high temperatures allows the associated refrigeration apparatus to operate in thermosyphon mode for a significant number of hours per year.

Claims

1. Refrigeration apparatus capable of operating in i) vapour compression cooling mode or ii) natural cooling mode, the apparatus defining a refrigerant path comprising:

compression means (12) for compressing a refrigerant;
heat rejection means (14) for cooling the compressed refrigerant;
restriction means (16) for expanding the refrigerant;
chilling means (18) for permitting the absorption of heat by the refrigerant from a fluid to be chilled;
valve means (26, 28) configurable for selectively directing refrigerant i) to pass through the compression means (12) and restriction means (16) or ii) to bypass the compression means (12) and restriction means (16); and
thermal storage means (20) for i) being cooled while the apparatus operates in the vapour compression cooling mode and ii) providing a chilling effect to the fluid during changeover to natural cooling mode.

2. The apparatus of claim 1 in which the chilled fluid is a cooling medium for a region (22) to be cooled.

3. The apparatus of claim 1 or claim 2 in which the thermal storage means (20) is i) arranged to be cooled by the chilled fluid while the apparatus operates in the vapour compression cooling mode and ii) arranged to chill the fluid during changeover to natural cooling mode.

4. The apparatus of claims 1, 2 or 3 in which the chilling means (18) is positioned below the heat rejection means (14) to allow operation in natural cooling mode without any mechanical circulation.

5. The apparatus of claims 1, 2 or 3 wherein refrigerant circulation means is provided for use in the natural cooling mode.

6. The apparatus of any one of the preceding claims wherein the thermal storage means (20) is arranged such that the apparatus is operable at full capacity in the vapour compression cooling mode irrespective of cooling load, any excess capacity being utilised to cool the thermal storage means (20).

7. The apparatus of claim 6 further comprising a thermostatic switch (30) to reconfigure the valve means (26, 28) from the vapour compression mode to the natural cooling mode on the thermal storage means (20) reaching a condition where it cannot be cooled further.

8. The apparatus of any one of the preceding claims wherein the thermal storage means (20) contains a phase change material which will absorb or reject heat at a substantially constant temperature.

9. The apparatus of claim 8 wherein the phase change material is one of acetic acid or lactic acid.

10. A refrigeration method including i) a vapour compression cooling mode or ii) a natural cooling mode, the method including the steps of:

providing heat rejecting means and utilising said means to reject heat from a refrigerant;
chilling a fluid with the refrigerant; and

i) when operating in vapour compression cooling mode the method further including the steps of:

a) compressing the refrigerant;
b) expanding the refrigerant; and
c) cooling a thermal storage means; and

ii) when operating in natural cooling mode the method further including the step of:

a) providing a chilling effect to said fluid using the thermal storage means, at least during initial changeover from vapour compression cooling mode to natural cooling mode.

11. The method of claim 10 wherein the chilled fluid provides a cooling medium for a region to be cooled.

12. The method of claim 10 or claim 11 wherein the thermal storage means is i) cooled by the chilled fluid in vapour compression cooling mode and ii) chills the fluid during changeover to natural cooling mode.

13. The method of claim 10, 11 or 12 in which, in the natural cooling mode, the refrigerant circulates without any mechanical circulation.

14. The method of any one of claims 10 to 13 wherein operation in vapour compression cooling mode is at full capacity irrespective of cooling load, any excess capacity being utilised to cool the thermal storage means.

15. The method of claim 14 wherein the mode of operation changes from i) vapour compression cooling mode to ii) natural cooling mode on the thermal storage means reaching a condition where it cannot be cooled further.

16. The method of any one of claims 10 to 15 wherein the thermal storage means absorbs or rejects heat at substantially constant temperature.

Patentansprüche

1. Kühlvorrichtung, die in der Lage ist, i) im Kühlmodus mit Dampfkompression oder ii) im Modus mit natürlicher Kühlung zu arbeiten, wobei die Vorrichtung eine Kältemittelbahn bildet, die folgende Komponenten umfaßt:

   Kompressionsmittel (12) zum Verdichten eines Kältemittels;
   Wärmeabfuhrmittel (14) zum Kühlen des verdichteten Kältemittels;
   Restriktionsmittel (16) zum Ausdehnen des Kältemittels;
   Abkühlmittel (18), um die Absorption von Wärme aus einem abzukühlenden Fluid durch das Kältemittel zu ermöglichen;
   Ventilmittel (26, 28), die konfiguriert werden können, um das Kältemittel selektiv so zu leiten, daß es i) durch das Kompressionsmittel (12) und das Restriktionsmittel (16) strömt oder ii) daß es das Kompressionsmittel (12) und das Restriktionsmittel (16) umgeht; und
   Wärmespeichermittel (20), um i) gekühlt zu werden, während die Vorrichtung im Kühlmodus mit Dampfkompression arbeitet, und ii) bei der Umschaltung auf den Modus mit natürlicher Kühlung eine abkühlende Wirkung auf das Fluid auszuüben.

2. Vorrichtung nach Anspruch 1, bei der das abgekühlte Fluid ein Kühlmittel für einen zu kühlenden Bereich (22) ist.

3. Vorrichtung nach Anspruch 1 oder Anspruch 2, bei der das Wärmespeichermittel (20) i) so angeordnet ist, daß es durch das abgekühlte Fluid gekühlt wird, während die Vorrichtung im Kühlmodus mit Dampfkompression arbeitet, und ii) so angeordnet ist, daß es das Fluid bei der Umschaltung auf den Modus mit natürlicher Kühlung abkühlt.

4. Vorrichtung nach Anspruch 1, 2 oder 3, bei der das Abkühlmittel (18) unter dem Wärmeabfuhrmittel (14) angeordnet ist, um ohne jede mechanische Umwälzung den Betrieb im Modus mit natürlicher Kühlung zu ermöglichen.

5. Vorrichtung nach Anspruch 1, 2 oder 3, bei der für die Nutzung im Modus mit natürlicher Kühlung ein Kältemittel-Umwälzmittel vorgesehen ist.

6. Vorrichtung nach einem der vorhergehenden Ansprüche, bei der das Wärmespeichermittel (20) so angeordnet ist, daß die Vorrichtung im Kühlmodus mit Dampfkompression ungeachtet der Kühllast bei voller Kapazität betrieben werden kann, wobei jedwede überschüssige Kapazität dazu genutzt wird, das Wärmespeichermittel (20) zu kühlen.

7. Vorrichtung nach Anspruch 6, die außerdem einen Wärmeschalter (30) umfaßt, um das Ventilmittel (26, 28) vom Modus mit Dampfkompression auf den Modus mit natürlicher Kühlung umstellen zu können, wenn das Wärmespeichermittel (20) einen Zustand erreicht, in dem es nicht weiter gekühlt werden kann.

8. Vorrichtung nach einem der vorhergehenden Ansprüche, bei der das Wärmespeichermittel (20) ein Material für Phasenumwandlung enthält, das bei einer im wesentlichen konstanten Temperatur Wärme absorbiert oder abführt.

9. Vorrichtung nach Anspruch 8, bei der das Material für Phasenumwandlung entweder Essigsäure oder Milchsäure ist.

10. Kühlverfahren, das i) einen Kühlmodus mit Dampfkompression oder ii) einen Modus mit natürlicher Kühlung einschließt, wobei das Verfahren die folgenden Schritte einschließt:

   Bereitstellen eines Wärmeabfuhrmittels und Nutzen des Mittels, um Wärme von einem Kältemittel abzuführen;
   Abkühlen eines Fluids mit dem Kältemittel; und

i) bei der Arbeit im Kühlmodus mit Dampfkompression schließt das Verfahren außerdem die folgenden Schritte ein:

a) Verdichten des Kältemittels;
b) Ausdehnen des Kältemittels; und
c) Kühlen eines Wärmespeichermittels; und

ii) bei der Arbeit im Modus mit natürlicher Kühlung schließt das Verfahren außerdem den folgenden Schritt ein:

a) Ausüben einer abkühlenden Wirkung auf das Fluid unter Nutzung des Wärmespeichermittels, zumindest während der anfänglichen Umschaltung vom Kühl modus mit Dampfkompression auf den Modus mit natürlicher Kühlung.

11. Verfahren nach Anspruch 10, bei dem das abgekühlte Fluid ein Kühlmittel für einen zu kühlenden Bereich darstellt.

12. Verfahren nach Anspruch 10 oder Anspruch 11, bei dem das Wärmespeichermittel i) im Kühlmodus mit Dampfkompression durch das abgekühlte Fluid gekühlt wird und ii) das Fluid während der Umschaltung auf den Modus mit natürlicher Kühlung abkühlt.

13. Verfahren nach Anspruch 10, 11 oder 12, bei dem das Kältemittel im Modus mit natürlicher Kühlung ohne jede mechanische Umwälzung zirkuliert.

14. Verfahren nach einem der Ansprüche 10 bis 13, bei dem der Betrieb im Kühlmodus mit Dampfkompression ungeachtet der Kühllast bei voller Kapazität erfolgt, wobei jedwede überschüssige Kapazität dazu genutzt wird, das Wärmespeichermittel zu kühlen.

15. Verfahren nach Anspruch 14, bei dem der Betriebsmodus vom i) Kühlmodus mit Dampfkompression auf den ii) Modus mit natürlicher Kühlung übergeht, wenn das Wärmespeichermittel einen Zustand erreicht, in dem es nicht weiter gekühlt werden kann.

16. Verfahren nach einem der Ansprüche 10 bis 15, bei dem das Wärmespeichermittel bei einer im wesentlichen konstanten Temperatur Wärme absorbiert oder abführt.

Revendications

1. Appareil de réfrigération capable de fonctionner i) en mode de refroidissement par compression de vapeur ou ii) en mode de refroidissement naturel, l'appareil définissant un circuit réfrigérant, comprenant:

un moyen de compression (12) pour comprimer un réfrigérant;
un moyen de rejet de chaleur (14) pour refroidir le réfrigérant comprimé;
un moyen de restriction (16) pour assurer l'expansion du réfrigérant;
un moyen de réfrigération (18) pour permettre l'absorption de chaleur par le réfrigérant à partir d'un fluide devant être réfrigéré;
un moyen de soupape (26, 28) pouvant être configuré pour diriger sélectivement le réfrigérant de sorte à i) traverser le moyen de compression (12) et le moyen de restriction (16) ou ii) à contourner le moyen de compression (12) et le moyen de restriction (16); et
un moyen de stockage thermique (20) destiné i) à être refroidi pendant que l'appareil fonctionne dans le mode de refroidissement par compression de vapeur et ii) à assurer un effet de réfrigération du fluide au cours du passage au mode de refroidissement naturel.

2. Appareil selon la revendication 1, dans lequel le fluide réfrigéré est un agent de refroidissement pour une région (22) devant être refroidie.

3. Appareil selon les revendications 1 ou 2, dans lequel le moyen de stockage thermique (20) est i) agencé de sorte à être refroidi par le fluide réfrigéré pendant que l'appareil fonctionne dans le mode de refroidissement par compression de vapeur et ii) agencé de sorte à assurer la réfrigération du fluide au cours du passage au mode de refroidissement naturel.

4. Appareil selon les revendications 1, 2 ou 3, dans lequel le moyen de réfrigération (18) est agencé audessous du moyen de rejet de chaleur (14) pour permettre le fonctionnement dans le mode de refroidissement naturel sans aucune circulation mécanique.

5. Appareil selon les revendications 1, 2 ou 3, dans lequel le moyen de circulation du réfrigérant est destiné à être utilisé dans le mode de refroidissement naturel.

6. Appareil selon l'une quelconque des revendications précédentes, dans lequel le moyen de stockage thermique (20) est agencé de sorte que l'appareil peut fonctionner à pleine capacité dans le mode de refroidissement par compression de vapeur, indépendamment de la charge de refroidissement, une quelconque capacité excédentaire étant utilisée pour refroidir le moyen de stockage thermique (20).

7. Appareil selon la revendication 6, comprenant en outre un commutateur thermostatique (30) pour reconfigurer le moyen de soupape (26, 28), en vue du passage du mode de refroidissement par compression de vapeur au mode de refroidissement naturel, le moyen de stockage thermique (20) ayant atteint un état dans lequel un refroidissement ultérieur est impossible.

8. Appareil selon l'une quelconque des revendications précédentes, dans lequel le moyen de stockage thermique (20) contient un matériau de changement de phase, absorbant ou rejetant la chaleur à une température pratiquement constante.

9. Appareil selon la revendication 8, dans lequel le matériau de changement de phase est ou bien de l'acide acétique ou bien de l'acide lactique.

10. Procédé de réfrigération englobant i) un mode de refroidissement par compression de vapeur ou ii) un mode de refroidissement naturel, le procédé englobant les étapes ci-dessous:

fourniture d'un moyen de rejet de chaleur et utilisation dudit moyen pour rejeter la chaleur d'un réfrigérant;
réfrigération d'un fluide avec le réfrigérant; et

i) le procédé englobant en outre les étapes ci-dessous en cas de fonctionnement dans le mode de refroidissement par compression de vapeur:

a) compression du réfrigérant;
b) expansion du réfrigérant; et
c) refroidissement d'un moyen de stockage thermique; et

ii) le procédé englobant en outre l'étape ci-dessous en cas de fonctionnement dans le mode de refroidissement naturel:

a) établissement d'un effet de réfrigération dudit fluide par l'intermédiaire du moyen de stockage thermique, au moins au cours du passage initial du mode de refroidissement par compression de vapeur au mode de refroidissement naturel.

11. Procédé selon la revendication 10, dans lequel le fluide réfrigéré fournit un moyen de refroidissement pour une région devant être refroidie.

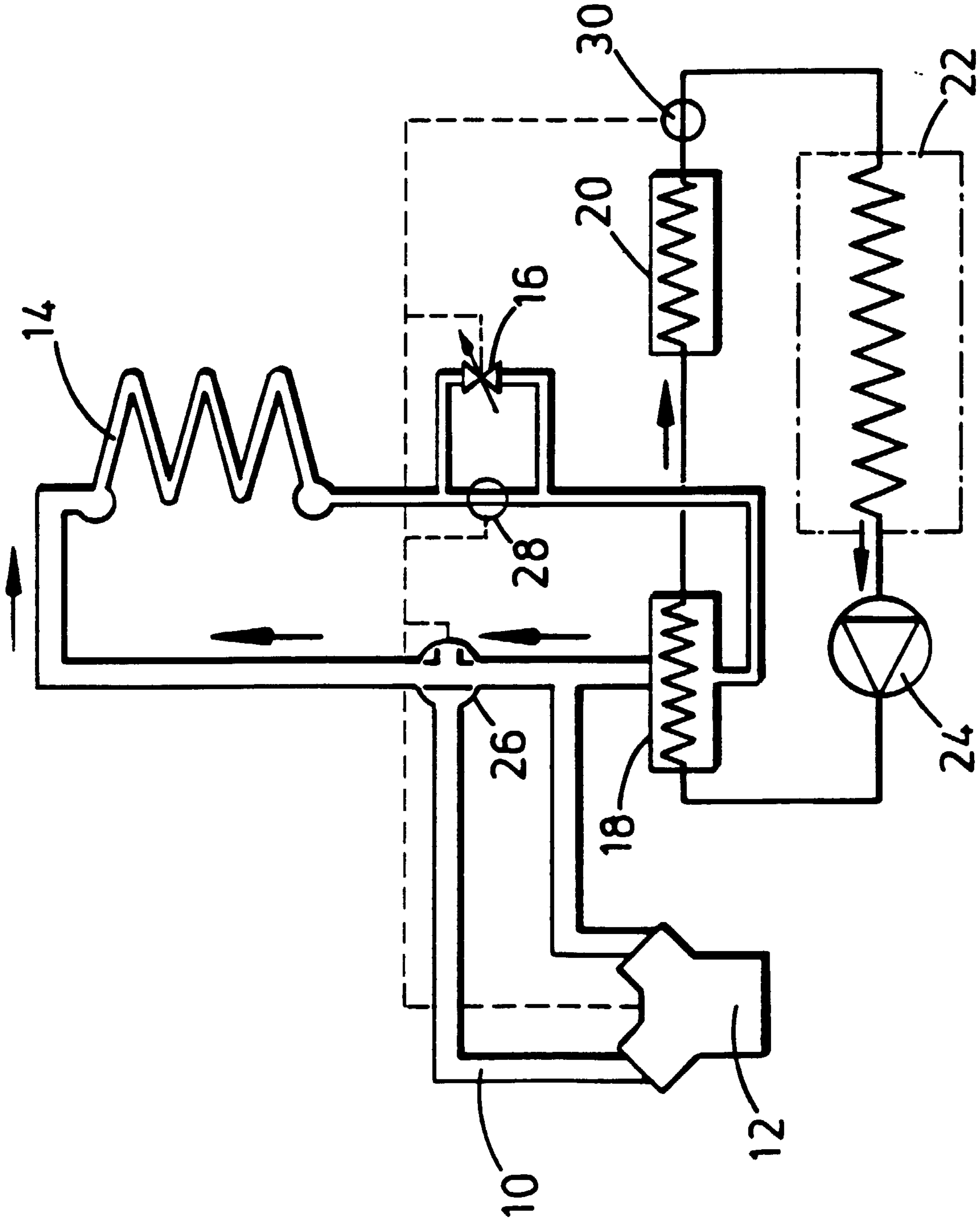
12. Procédé selon les revendications 10 ou 11, dans lequel le moyen de stockage thermique est i) refroidi par le fluide réfrigéré dans le mode de refroidissement par compression de vapeur et ii) assure le réfrigération du fluide au cours du passage au mode de refroidissement naturel.

13. Procédé selon les revendications 10, 11 ou 12, dans lequel, dans le mode de refroidissement naturel, le réfrigérant circule sans aucune circulation mécanique.

14. Procédé selon l'une quelconque des revendications 10 à 13, dans lequel le fonctionnement dans le mode de refroidissement par compression de vapeur se fait à pleine capacité, indépendamment de la charge de refroidissement, une quelconque capacité excédentaire étant utilisée pour refroidir le moyen de stockage thermique.

15. Procédé selon la revendication 14, dans lequel le mode de fonctionnement passe i) du mode de refroidissement par compression de vapeur au ii) mode de refroidissement naturel, le moyen de stockage thermique ayant atteint un état dans lequel un refroidissement ultérieur est impossible.

16. Procédé selon l'une quelconque des revendications 10 à 15, dans lequel le moyen de stockage thermique absorbe ou rejette la chaleur à une température pratiquement constante.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