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(54) COOLING ELEMENT FOR REFRIGERATOR

KÜHLELEMENT FÜR EINEN KÜHLSCHRANK

ÉLÉMENT DE REFROIDISSEMENT POUR RÉFRIGÉRATEUR

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(73) Proprietor: **LG Electronics Inc.**
Yeongdeungpo-gu
Seoul 150-721 (KR)

(72) Inventors:
- **JAIN NAVEEN, Kumar**
  Greater Noida 201 301
  U.P. (IN)
- **SHARMA BRIJESH, Kumar**
  Greater Noida 201 301
  U.P. (IN)
- **GAMBHIR, Amit**
  Greater Noida 201 301
  U.P. (IN)
- **GUPTA, Gaurav**
  Greater Noida 201308
  U.P. (IN)

(74) Representative: **Morrall, Jonathan Ian McLachlan et al**
Kilburn & Strode LLP
Lacon London
84 Theobalds Road
London WC1X 8NL (GB)

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a direct cool refrigeration system having a cooling element containing phase change material.

BACKGROUND OF THE INVENTION

[0002] The basic principle of an AC powered refrigerator is that it consists of a thermally insulated compartment and a compressor(mechanical, electronic, or chemical) which transfers heat from inside of the refrigerator to its external environment so that the inside of the refrigerator is cooled to a temperature below the ambient temperature of the room. Cooling is a popular food storage technique worldwide and works by decreasing the reproduction rate of bacteria. Bacteria are majorly responsible for food spoilage, so the refrigerator helps reduce the rate of spoilage of foodstuffs.

[0003] The problem of power failure is very common in developing countries and irregular power supply leads to significant reduction in the cooling efficiency of refrigerators. This has an adverse effect on the quality of perishable items stored in the refrigerator cabinet because of poor cooling retention. If the power failure lasts for several hours, then the food in the freezer section also gets adversely affected. In case of high electricity consumption or low voltage in a household, the refrigerator can't provide sufficient cooling for the stored items. Thus, it is important to find a way of maintaining cooling inside the refrigerator compartments during high electricity consumption, low voltage, power failure, etc.

[0004] One of the methods to overcome this problem is to use phase change materials (PCM) in the freezer compartment of the refrigerator. PCMs have been used for many years for latent heat storage (LHS) through solid-solid, solid-liquid, solid-gas and liquid-gas phase change. However, the only phase change used for PCMs is the solid-liquid phase change. Liquid-gas phase changes do have higher heat of transformation than solid-liquid phase changes but are not practical due to the high pressures involved. Several types of phase change materials can be used like eutectic mixtures, organic PCMs, inorganic PCMs, etc.

[0005] In case of refrigerators employing the latent heat storage of PCMs, the cooling of the evaporator is used to freeze the phase change material when the power supply is available. In the event of power failure, the refrigeration cycle stops and the evaporator plate does not have any source of cooling. Thus, the temperature inside the refrigerator begins to rise. However, due to the presence of frozen/partially-frozen phase change material, the rate of temperature rise is greatly reduced. Thus, the cooling potential of the PCM is used to cool the air inside the refrigerator and keep the stored items at a sufficiently low temperature. A generally acceptable temperature is 0°C for freezer section and 10°C for refrigerator section. If the temperature rises above these temperatures for long periods of time, the stored items may get spoiled.

[0006] However, the existing methods suffer from one or more problems. For instance, if the freezing point of the PCM is too low, it can't be completely frozen. If the freezing point of the PCM is too high, the PCM gets completely frozen but has very low cooling potential in terms of latent heat. Thus, it is imperative to use PCM with freezing point in the correct range of temperature, depending upon the average plate temperature of the evaporator.

[0007] Another problem in the existing methods is that the PCM is provided in a rigid plastic casing/housing. Thus, the thermal resistance between the PCM and the evaporator plate is high. Also, the contact area between the PCM casing and evaporator plate is poor leading to slow freezing of the PCM and/or high energy consumption during availability of power. Likewise, in case of power failure the cooling provided by the PCM is very slow. Thus, it is important to provide high contact area and low thermal resistance between the PCM casing and the evaporator plate. European Patent Number 152155 discloses a plurality of cold storage elements for a chest freezer, each element comprising a casing of plastic material, for example, polyethylene, containing a eutectic solution. In particular, the storage elements can be used in such a manner that the eutectic solution becomes frozen by practically continuous operation of the compressor during those (night) hours in which the mains electricity is sold at reduced tariff. The thermal energy stored by these elements is, then utilized during those (day) hours in which the mains electricity is sold at full tariff, so avoiding operation of the freezer compressor during these hours. However, due to inadequate area of contact, the compressor has to be run continuously to freeze the PCM. Moreover, since the cold storage elements have to be fitted into each other by inosculation, the casing has to be thick and rigid leading to high thermal resistance.

[0008] A prior art direct cool refrigeration system is known from US 4 748 823 A, comprising a refrigerator compartment and a freezer compartment. The freezer compartment comprises an evaporator plate in contact with a plurality of cooling coils. The freezer compartment further comprises a plurality of cooling elements provided inside the evaporator plate and a supporter case disposed inside the evaporator plate and arranged to support the plurality of cooling elements. The cooling elements are in contact with the evaporator plate and comprise flexible bags containing a phase change material.

[0009] It is an object of the invention to avoid or mitigate the disadvantages set out above. The present invention provides a direct cool refrigeration system having a cooling element containing PCM having freezing point within a desired range of temperatures, to ensure complete freezing of the PCM during normal operation. Moreover, the cooling element is designed such that there is high contact area and low thermal resistance between the PCM and the evaporator plate. This cooling element containing a suitable PCM allows for maximum heat transfer between evaporator and cooling retention media through use of a flexible PCM case. Thus, sufficiently low temperatures are maintained for extended periods of time within the compartments of the refrigerator in the event of power failure or high power consumption or low voltage. The cooling element may also reduce the amount of PCM required. The operating cost of the refrigerator can also be reduced because of efficient utilization of the cooling supplied by the refrigerator during normal operation.

SUMMARY OF THE INVENTION

[0010] In accordance with the invention, a direct cool refrigeration system according to claim 1 is provided, comprising a refrigerator compartment and a freezer compartment; the freezer compartment comprising an evaporator plate in contact with a plurality of coils or tubes with refrigerant circulating therewithin; characterized in that, a plurality of cooling elements are provided inside the refrigerator, at least one of the cooling elements being in contact with the evaporator plate, the cooling element comprising a phase change material (PCM) having freezing point lower than 0°C and higher than the average evaporator plate temperature, enclosed in a flexible case.

[0011] In accordance with another embodiment of the invention, the flexible case comprises at least a pair of thin, flexible and spaced apart walls joined together to form a closed surface.

[0012] In accordance with yet another embodiment of the invention, the flexible walls are adapted to match the shape of the evaporator plate such that there is an enhancement in the area of the flexible case in contact with the evaporator plate. In accordance with yet another embodiment of the invention is provided a direct cool refrigeration system, wherein the flexible walls are thin.

[0013] In accordance with yet another embodiment of the invention, the direct cool refrigeration system further comprises a tray fresh room or TFR with another cooling element placed therewithin; the cooling element comprising a phase change material having freezing point higher than the minimum attainable temperature inside the TFR, enclosed in a rigid, semi-rigid or flexible case.

[0014] In accordance with yet another embodiment of the invention, the rigid case comprises at least a pair of rigid and spaced apart walls joined together to form a closed surface.

[0015] In accordance with the invention, the direct cool refrigeration system comprises a supporter case disposed inside the evaporator plate and in contact with at least one wall of the flexible case. In accordance with the invention, the cooling elements are divided into three compartments.

[0016] In accordance with yet another embodiment of the invention, the evaporator plate is a metallic sheet. In accordance with yet another embodiment of the invention, the supporter case has three (U-shaped), four (O-shaped) or more faces placed in proximity with and spaced apart from the sides/faces of the evaporator plate.

[0017] In accordance with yet another embodiment of the invention, the supporter case has three faces (U-shaped) and the cooling element is in contact with one or more faces of the supporter case.

[0018] In accordance with yet another embodiment of the invention, the phase change material(s) in the cooling element(s) gets partially or completely frozen during normal operation of the refrigeration system, and provides cooling during power failure/outage.

[0019] In accordance with yet another embodiment of the invention, the phase change material is any organic or inorganic PCM or eutectics having freezing point in the given range of temperatures.

[0020] In accordance with yet another embodiment of the invention, the flexible case is composed of plastic materials like Poly Vinyl Chloride (PVC), Polypropylene, Polyethylene, Polystyrene, Acrylonitrile Butadiene Styrene (ABS), Nylon and the like.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

Fig. 1(a) is a front view of a direct cool refrigeration system in accordance with an embodiment of the invention.

Fig. 1(b) is a perspective view of the freezer compartment and tray fresh room (TFR) in accordance with an embodiment of the invention.

Fig. 2(a) is a perspective view showing the attachment of the flexible plastic case over the supporter case.

Fig. 2(b) is a view of the flexible plastic case in accordance with an embodiment of the invention.

Fig. 2(c) is an exploded view of the TFR of Fig. 1(b) with the rigid plastic case placed therewithin.

Fig. 3 is a temperature vs. time graph for freezing of two PCMs having freezing points of -12°C and - 5°C.

Fig. 4 is a temperature vs. time graph for freezing a PCM having freezing point of -12°C by cycling operation in a refrigerator.

Fig. 5(a) is a perspective view showing a rigid plastic case containing PCM placed in contact with the evaporator plate of the freezer compartment.

Fig. 5(b) is a view of a section along the line AA' of Fig. 5(a) showing a part of the evaporator plate, rigid plastic case, PCM and the freezer compartment.

Fig. 5(c) is a magnified view showing the encircled portion of Fig. 5(b).

Fig. 6(a) is a magnified sectional view showing a part of the evaporator plate, rigid plastic case and PCM.

Fig. 6(b) is a schematic diagram showing the thermal resistances offered by the components of Fig. 6(a).

Fig. 6(c) is a schematic diagram showing the relationship between the thermal resistances of Fig. 6(b).

Fig. 7 is a diagram showing the response of $(UA)_2$ to changes in some parameters.

Fig. 8(a) is a schematic diagram showing a rigid plastic case in contact with the evaporator plate.

Fig. 8(b) is a schematic diagram showing a flexible plastic case in contact with the evaporator plate.

Fig. 9 is a temperature vs. time graph for freezing of the same PCM in a flexible plastic case and a rigid plastic case.

[0022] It is to be noted that the above mentioned figures are with reference to a direct cool refrigerator. However, the teachings of the invention can be readily applied to other types of refrigerators also with or without some minor modifications.

DETAILED DESCRIPTION

[0023] Discussed below are some representative embodiments of the current invention. The invention in its broader aspects is not limited to the specific details, representative devices and methods, and illustrative examples shown and described in this section in connection with the embodiments and methods. The invention according to its various aspects is particularly pointed out and distinctly claimed in the attached claims read in view of this specification, and appropriate equivalents.

[0024] It is to be noted that, as used in the specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Throughout the description, the term "x°C PCM" means "a Phase Change Material (PCM) having a freezing/melting point of x°C", where "x" is a real number.

[0025] A large number of PCMs are available having freezing points in the temperature range of -5°C to 190°C. The PCMs useful for domestic refrigerators generally have freezing points below 0°C. The effectiveness of PCMs can be judged on the basis of the thermodynamic, kinetic, economic and chemical properties. An important prerequisite is that the melting temperature should lie within the operating range of the refrigerator. Two important factors to judge the effectiveness of the PCM in refrigerators are time taken to completely freeze the PCM and the amount of sensible and latent heat stored during phase transformation.

[0026] Fig. 1(a) is a front view of a domestic natural convection or single door or direct cool refrigeration system (100) in accordance with an embodiment of the invention. The freezer compartment (102) is located at the top of the refrigerator. The temperature inside this compartment is maintained at a few degrees below the freezing point of water so as to form ice and provide cold storage for other items. The tray fresh room or TFR (103) is disposed just below the freezer compartment. The temperature in this compartment is usually close to the freezing point of water. Thus, items that need to be chilled/cooled to a low temperature but preferably not frozen are stored in this section. The main refrigerator compartment (101) is provided with a number of trays for placement of food and other items. The temperature in this section is kept a few degrees lower than the ambient temperature. The bottom part of the refrigerator may have a crisper tray (105) for storing and maintaining the freshness of fruits and vegetables.

[0027] Fig. 1(b) is a perspective view of the freezer compartment (102) and TFR (103) shown in Fig. 1(a). The freezer contains the evaporator plate (106) which supplies cooling throughout the refrigerator and the frame of the evaporator (107) which holds the thermostat, bulb and the freezer door. The supporter case (108) for holding the flexible plastic case is disposed inside the freezer compartment (102). The PCM is stored in the flexible plastic case disposed in the space between the evaporator plate and the supporter case. The supporter case (108) therefore prevents the flexible plastic case containing PCM from accidental damage. It also prevents sagging or bulging of the flexible plastic case under its own weight, which could happen when a large amount of PCM is stored therewithin. A different PCM or the same PCM is placed inside the TFR (103). The PCM placed inside TFR may be stored in a flexible plastic case or a rigid plastic case.

[0028] Fig. 2(a) is a perspective view illustrating the attachment of the flexible plastic case (110) over the supporter case (108). The PCM is stored inside the flexible plastic case. In the present embodiment, the supporter case has three faces bent into a U-shape. Two of the faces are parallel to each other and perpendicular to the third face. In order to prevent bending of the supporter case, a strip (117) is provided between the two parallel faces. Thus, the items to be kept inside the freezer are enclosed by the supporter case. The supporter case (108) has attachment means in the form of a plurality of projections (111) mounted on it or molded into it to enable the flexible plastic case to be press-fitted or attached onto it.

[0029] Fig. 2(b) is a view of the flexible plastic case (110) having three compartments for storing the PCM in accordance with an embodiment of the invention. The compartments have a small gap between them to accommodate the edges of the supporter case (108) when placed thereupon. These three faces compliment the corresponding surfaces of the supporter case (108) on which they are placed. A plurality of through holes (112) are also present to allow the projections (111) of the supporter case to tightly fit or attach with them.

[0030] Fig. 2(c) is an exploded view of the TFR (103) of Fig. 1(b). The PCM can be stored in a rigid, semi-rigid or flexible case inside the TFR. It is stored in a rigid plastic case (109) in the present embodiment. The case is divided into a plurality of compartments so as to promote faster freezing of the PCM. The rigid plastic case (109) is placed inside the TFR (103) and may be detached or removed whenever required. This serves as an additional source of cooling during power failure, and also helps arrest the rise in temperature of the refrigerator compartment (101).

[0031] Fig. 3 is a temperature vs. time graph for freezing of two PCMs having freezing points of -12°C and - 5°C. The liquid PCMs at ambient temperature (roughly 30°C) are attached to the evaporator plate and the compressor is run continuously. Due to continuous operation of the compressor, the evaporator plate temperature goes to lower than -30°C. The PCMs get frozen at different times and are further cooled in solid phase to roughly -30°C. The graph clearly indicates that the PCM having the lower freezing point shows the longer completion time for phase change. Thus, the -12°C PCM looses more heat before getting frozen than the -5°C PCM. In case of power failure, it is expected that the -12°C PCM would perform better because it can absorb more heat before melting than the -5°C PCM. One may conclude that the PCM having the larger completion time for phase change shall have more cooling potential or latent heat storage (neglecting sensible heat). Fig. 4 is a temperature vs. time graph for freezing a PCM having freezing point of -12°C by cycling operation in a direct cool refrigerator. Cycling is the common mode of operating direct cool refrigerators, wherein the compressor is cycled on and off such that the evaporator plate temperature keeps increasing and decreasing between certain preset temperatures. The same is illustrated by the notches in the evaporator plate temperature graph. When the PCM is attached at the evaporator of direct cooling type refrigerator, PCM is frozen by giving up heat to the evaporator plate. The evaporator plate on the other hand is cooled by releasing heat to the refrigerant flowing through a plurality of tubes or coils attached to the evaporator plate. The refrigerant enters the tubes at a lower temperature but exits at a higher temperature because it takes up heat from the evaporator plate. Thus, there is a minor variation in the temperature at various sections of the evaporator plate. Consequently, there is variation in the temperature profiles of the PCM placed in contact with different sections of the evaporator plate. When the notch was at normal position, the average temperature of evaporator plate is -13°C. The graph showing the temperature of the PCM shows that the temperature varies within a narrow range of temperatures. It is observed that the PCM having freezing point of -12°C cannot be completely frozen when the evaporator plate average temperature is -13°C. Therefore the melting point of PCM attached to the evaporator should be ≥ -12°C. In case of normal notch cycling of direct cool type refrigerator, the average temperature of TFR is -1.5°C. Therefore the melting point of PCM placed in TFR should be ≥ -1°C. Thus, the PCMs having melting points between -12°C to 0°C are effective in the freezer compartment and PCMs having freezing point higher than -1°C are particularly effective in the TFR of this particular direct cool refrigerator.

[0032] Fig. 5(a) is a perspective view of an evaporator plate (106). The evaporator plate is essentially a metallic sheet bent into a suitable shape having a plurality of tubes or coils (113) attached to its surface. In the given example, it has a network of tubes on four faces. The refrigerant enters the tubes at one end and exits from another end, picking up heat in the process. A rigid plastic case (116) is placed in contact with one of the faces of the evaporator plate (106)

[0033] Fig. 5(b) is a view of a section along the line AA' of Fig. 5(a) showing a part of the evaporator plate, rigid plastic case, PCM and the freezer compartment. The evaporator plate section (115) has a few of the tubes (113) passing through it. The refrigerant flows through these tubes and picks up heat from the evaporator plate, thereby lowering its temperature. The cooled evaporator plate acts as the source of cooling inside the freezer. Thus, the air inside the freezer loses heat to or gets cooled by the evaporator plate. The rigid plastic case (116) containing PCM placed adjacent to the evaporator plate section (115) can be seen as a pair of parallel walls (104 and 114) with a PCM (120) placed therewithin. The wall (104) is adjacent to the evaporator plate section (115) and has several air gaps due to the wall being inflexible. The second wall (114) may be in contact with the supporter case or in direct contact with the air inside the freezer.

[0034] Fig. 5(c) is a magnified view showing the encircled portion of Fig. 5(b). The arrows in the given figure show the direction of flow of heat. Q_1 represents the flow of heat from the interior of the freezer to the PCM (120). Q_2 represents the flow of heat from the PCM (120) to the evaporator plate section (115). Thus, the flow of heat is from the interior of the freezer towards the evaporator plate.

[0035] To theoretically determine the suitable freezing point of the PCM, we need to do an energy balance for the freezer compartment. An energy balance is provided for the embodiment shown in Fig. 5(a), (b), (c) for the duration of the phase change operation of the PCM. We have assumed that the amount of latent heat consumed or liberated during phase change is much higher than the sensible heat consumed or liberated when the temperature of the PCM changes in solid state or liquid state. For instance, during freezing of the PCM, we assume that the heat liberated in cooling it from a liquid at ambient temperature to a liquid at its freezing point is negligible in comparison to the heat liberated during phase change from liquid at its freezing point to solid at its freezing point. Likewise, it is assumed that the sensible heat liberated in cooling the solid PCM further below its freezing point is also negligible in comparison to the heat liberated during phase change.

[0036] The thermal resistance to heat transfer offered by the supporter case has also not been considered because it may or may not be provided. Minor positional variations in the temperature of the evaporator plate may also be neglected. The term "Cabinet" used hereinafter refers to the interior of the freezer. We assume the cabinet to be empty, i.e. no food or other articles are placed therewithin.

[0037] The rate of freezing of the PCM stored in a rigid plastic case placed in contact with the evaporator in direct cool refrigerator is determined according to the Energy Balance equation:

$$\delta Q = Q_2 - Q_1 = mh_{sf}/t \qquad \text{..........(1)}$$

where,

Q_1: Rate of absorption of heat by the PCM from cabinet
Q_2: Rate of dissipation of heat from the PCM to evaporator
m : mass of PCM
h_{sf}: latent heat of PCM
t: time to change phase

<u>Heat absorbed from cabinet (Q_1):</u>

[0038]

$$Q_1 = (UA)_1 \Delta T_1 = (UA)_1 (T_F - T_{PCM}) \qquad \text{..........(2)}$$

$$(UA)_1 = \frac{1}{R_{1,th}} = \frac{1}{\dfrac{1}{h_i A_o} + \dfrac{t_{rp}}{k_{rp} A_o}}$$

where,

$(UA)_1$: Product of overall heat transfer coefficient and heat transfer area for heat absorption by the PCM from cabinet
A_o : Area of rigid plastic case in contact with the freezer cabinet
T_F : Average temperature of the cabinet
T_{PCM} : Freezing point of the PCM
h_i : Convective heat transfer coefficient
k_{rp} : Thermal conductivity of the rigid plastic case

t_{rp} : Thickness of the rigid plastic case
$R_{1,th}$: Equivalent thermal resistance to heat absorption from cabinet

[0039] Here we have assumed that the cabinet temperature remains constant throughout the duration of the phase transformation of the PCM. The temperature of the PCM is assumed to be its freezing point because there are very minor variations in temperature during phase transformation, as seen from Fig. 3.

[0040] Also, it has been assumed that there aren't any significant positional variations in the temperature of the PCM or cabinet temperature. Thus, T_F and T_{PCM} represent average temperatures inside the freezer and the PCM respectively.

Dissipated heat to Evaporator (Q_2):

[0041] Fig. 6(a) is a magnified sectional view showing a part of the evaporator plate (115), rigid plastic case (116) and the PCM (120). Q_2 represents the flow of heat from the PCM to the evaporator plate. The thicknesses and thermal conductivities of the evaporator plate, air, rigid plastic case and PCM have been labeled in the figure. Several thermal resistances are encountered during transfer of heat from the PCM to the evaporator plate. The expression for Q_2 is derived as follows:

$$Q_2 = (UA)_2 \Delta T_2 = (UA)_2 (T_{PCM} - T_{Eva}) \qquad \text{..........(3)}$$

$$(UA)_2 = \frac{1}{R_{2,th}}, \quad R_{2,th} = \frac{R_1 R_2}{R_1 + R_2} + R_3$$

and,

$$R_1 = \frac{t_{eva}}{k_{eva} A_1} + \frac{t_{air}}{k_{air} A_1} + \frac{t_{rp}}{k_{rp} A_1}$$

$$R_2 = \frac{t_{eva}}{k_{eva} A_2} + \frac{t_{rp}}{k_{rp} A_2} + R_C, \; R_3 = \frac{t_{PCM}}{k_{PCM} A_i}$$

$A_i = A_1 + A_2$, $r = A_2/A_i$ (Area ratio)
R_C: Thermal contact resistance

where,

$(UA)_2$: Product of overall heat transfer coefficient and heat transfer area for dissipation of heat from the PCM to evaporator
A_i: Total available area of the evaporator plate
A_1: Area of evaporator plate not in contact with the rigid plastic case
A_2: Area of evaporator plate in contact with the rigid plastic case
T_{Eva}: Average temperature of the evaporator plate
k_{rp}, k_{air}, k_{Eva}, k_{PCM} : Thermal conductivity of the rigid plastic case, air, evaporator plate material, PCM
t_{rp}, t_{air}, t_{Eva}, t_{PCM}: Thickness of the rigid plastic case, air, evaporator plate material, PCM
$R_{2,th}$: Equivalent thermal resistance for dissipation of heat from the PCM to evaporator

[0042] Fig. 6(b) is a schematic diagram showing the thermal resistances offered by the components of Fig. 6(a). The resistance term R_1 represents the total thermal resistance to heat transfer through the area A_1 not in contact with the rigid plastic case. It includes the thermal resistance of the area A_1 of the evaporator plate, the thermal resistance of the air between the evaporator plate and rigid plastic case, and the thermal resistance offered by the corresponding area of the rigid plastic case which is not in contact with the area A_1 of evaporator.

[0043] The resistance term R_2 represents the total thermal resistance to heat transfer through the area A_2 of the evaporator plate in contact with the rigid plastic case. It includes the thermal resistance of the area A_2 of the evaporator plate, the thermal resistance offered by an area A_2 of the rigid plastic case which is in contact with the evaporator and the thermal contact resistance between the evaporator plate and the rigid plastic case. The thermal contact resistance R_C is much smaller in comparison to the other two terms involved in calculating R_2. Hence, it has been neglected in further calculations. The resistance term R_3 represents the thermal resistance to heat transfer through the PCM based on the width of the PCM enclosed inside the layers of rigid plastic.

[0044] The overall thermal resistance $R_{2,th}$ has been calculated based on the combination of resistances shown in Fig. 6(c). Fig. 6(c) is a schematic diagram showing the relationship between the thermal resistances of Fig. 6(b). The resistances R_1 and R_2 are in parallel with each other and their combination is in series with R_3. It is clear from the expression obtained that the thermal resistance will increase with increasing width of the PCM. For a given heat transfer area, reducing the amount of PCM used will reduce the width of the PCM enclosed in the layers of rigid plastic, thereby reducing the thermal resistance to heat transfer.

[0045] **Example 1:** An experiment was conducted for a direct cool refrigerator having a steel evaporator plate. A PCM having a thermal conductivity of 0.5W/mK was used. A_o has been assumed to be equal to A_i, but in actual practice it should be slightly higher. Fig. 8(a) is a schematic diagram showing a rigid plastic case in (116) contact with the evaporator plate. The areas of the evaporator plate in contact with the rigid plastic case are labeled as A_2. For a rigid plastic case, it would be reasonable to assume an area ratio (A_2/A_i) of 0.5, which means only half of the area of the rigid plastic case will be in direct physical contact with the evaporator plate. In practice, the area ratio is lower than 0.5 for a rigid plastic case because of the tubes or coils being spaced apart.

[0046] The values for the various variables used in the calculations for $(UA)_1$ and $(UA)_2$ were found to be as follows:

$$h_i = 8W/m^2k \qquad k_{steel} = 70W/mK$$
$$t_{rp} = 2.5mm \qquad k_{air} = 0.026W/mK$$
$$k_{rp} = 0.1W/mk \qquad k_{rp} = 0.1W/mK$$
$$A_o = 0.037m^2 \qquad k_{PCM} = 0.5W/mK$$

$$t_{steel} = 0.55mm$$
$$t_{air} = 1.4mm$$
$$t_{rp} = 2.5mm$$
$$t_{PCM} = 17mm$$
$$A_1 = 0.0185m^2$$
$$A_2 = 0.0185m^2$$
$$A_i = 0.037m^2$$
$$r = 0.5$$

[0047] Substituting these values we get,

$$(UA)_1 = 0.247\ W/K$$

and,

$$(UA)_2 = 0.514\ W/K$$

[0048] The parameters related with Q_1 (absorption of heat from cabinet) affect both Latent heat Storage (LHS) and the blackout performance, i.e. the performance during power failure. Since the evaporator doesn't have any source of cooling during power failure, it only exchanges a small amount of heat with the surroundings upon power failure. This is much less in comparison with the latent heat taken up by the PCM before melting and can be neglected. Thus, during power failure, the heat transfer from the freezer cabinet to the PCM plays a major role and hence the rate of absorption of heat from inside the freezer (Q_1) is the major contributor to blackout performance of the refrigerator. The parameters related to Q_1 are h_i, t_{rp}, k_{rp}, and A_o. For a given value of A_0, the thickness of the plastic case is a very important property which the designer can control. Use of a rigid plastic limits the reduction in thickness of the case. However, if a flexible plastic like PVC is used, the thickness can be reduced to a great extent.

[0049] The parameters related with Q_2 (dissipation of heat to evaporator) are important only during latent heat storage, i.e. when the PCM is being frozen. A sensitivity analysis was done for the various factors affecting $(UA)_2$ in the expression obtained in equation (3). The results are represented graphically in Fig. 7. The rigid plastic case of Example 1 is taken as the base case, where $(UA)_2$ = 0.514 W/K. As expected, a direct relationship with the heat transfer area or area of evaporator plate A_i is observed. A 10% increase in the evaporator plate area would increase $(UA)_2$ by 10%. For a given evaporator plate area, contact area of the PCM case and thickness of the PCM are important response factors to sensitivity analysis.

[0050] In order to extend the contact area between the evaporator and the PCM case and decrease the thickness of PCM, it is possible by using a flexible plastic case. The thickness of the flexible plastic case is almost 90% less than the rigid plastic case and its flexibility increases the contact area.

[0051] **Example 2:** The rigid plastic case in Example 1 was replaced with a flexible plastic case. The conductivity of the rigid and flexible plastic can be assumed to be the same. The thickness of the case is reduced by 90% by virtue of using flexible plastic. Due to reduced thickness and increased flexibility of the case the area of contact between the evaporator plate and said case increases. Fig. 8(b) is a schematic diagram showing a flexible plastic case (110) in contact with the evaporator plate. As seen from the figure, the flexible plastic is able to closely follow the shape of the evaporator plate and a large portion of the case is in direct contact with the evaporator plate. Only small parts of the evaporator plate labeled as A_1 are not in contact with the rigid plastic case. Thus, it is reasonable to assume area ratio, r = 0.8.

[0052] Substituting in equation (3),

$$t_{fp} = 0.25mm$$

$$r = 0.8$$

$$A_1 = 0.0074m^2,\ A_2 = 0.0296m^2,\ A_i = 0.037m^2$$

where,

t_{fp}: Thickness of flexible plastic case

[0053] Assuming the energy balance to be the same (in practice there will be some minor changes in some of the individual thermal resistances), we get, $(UA)_2'$ = 0.997 W/K which is a 94% increase over the value $(UA)_2$ = 0.514 W/K obtained in Example 1. Thus, there is almost a two-fold increase in the heat dissipation from PCM to the evaporator plate by using the flexible plastic case of Example 2.

[0054] Fig. 9 is a temperature vs. time graph for freezing of the same PCM in a flexible plastic case and a rigid plastic case. It can be seen that the freezing point is reached much faster in the flexible plastic case. The completion time for phase change is also much less in case of the flexible plastic case. At every time instance, the temperature in the flexible plastic case is lower than the rigid plastic case, owing to the better heat transfer. Thus, for the same amount of PCM, freezing time is reduced by almost two-thirds by using the flexible plastic case.

[0055] It is clear that the designer has to choose between better blackout performance and faster freezing of the PCM. If the PCM has very high latent heat storage, then it will provide cooling for a long time during power failure and the blackout performance will be better. However, it will take a lot of time and energy to completely freeze such a PCM, which may not be possible in case of frequent power cuts. On the contrary, if the PCM has lower latent heat storage, then it will provide cooling for a limited period of time after power failure and the blackout performance won't be very good. However, this PCM would get completely frozen much faster. In the present methods of using PCMs in refrigerators, it often happens that the latent heat storage is low and at the same time, complete freezing is not possible due to low contact area and high thermal resistance of the PCM casing and/or very high amount of PCM to be frozen and/or improper freezing point of the PCM.

[0056] Thus, the present invention provides a direct cool refrigerator with one or more cooling elements comprising Phase Change Materials of a particularly suitable freezing point, enclosed in a flexible or rigid plastic case provided at one or more locations inside the refrigerator. The refrigerator provides good blackout performance and at the same time ensures fast freezing of the PCM housed therewithin.

[0057] Several variations are possible within the scope of the invention. For instance, the PCM in the TFR may also be provided inside a flexible plastic case. The flexible and rigid plastic cases may have any suitable number of compartments. PCM may additionally be provided in other locations inside the refrigerator if required. The supporter case may or may not be present. Please note that the terms "flexible plastic" and "rigid plastic" are not limited to plastics but any material possessing properties similar to flexible and rigid plastics. Some suitable flexible plastics include Poly Vinyl Chloride (PVC), Polypropylene, Polyethylene, Polystyrene, Acrylonitrile Butadiene Styrene (ABS), Nylon etc.

[0058] The shapes of the various components may also be modified as required. For instance, if the evaporator plate is L-shaped instead of a hollow cuboid, then the PCM case should also be provided in a similar shape proximate to one or more faces where the evaporator plate is present. This is because if the PCM was disposed at other faces inside the freezer where the evaporator plate doesn't come in direct contact with the PCM, it would make it difficult to completely freeze the PCM. Similarly, the configuration of the supporter case is also decided on the basis of the shape of the evaporator plate and/or PCM case. For instance, if the evaporator plate is U-shaped i.e. any one of the faces from the evaporator plate (106) of Fig. 5(a) is removed, the supporter case may also have three similar faces and the PCM can be provided in contact with one or more faces of the evaporator plate. One can use any suitable means to attach the PCM case onto the supporter case.

[0059] The invention is not limited to the embodiments which have been described and illustrated by way of example and numerous modifications and variations can be proposed without departing from the scope of the appended claims. The teachings of the invention may be applied to other types of refrigerators, freezers and refrigerated shelves, etc. with or without some minor modifications.

REFERENCE NUMERALS

[0060]

100. Direct cool refrigeration system
101. Refrigerator compartment
102. Freezer compartment
103. Tray fresh room (TFR)
104 and 114. Walls of rigid plastic case
105. Crisper Tray
106. Evaporator Plate
107. Frame of the evaporator
108. Supporter Case
109. Rigid plastic case for TFR
110. Flexible plastic case
111. Projections on supporter case
112. Through holes in flexible plastic case
113. Tubes or Coils
115. Evaporator plate section
116. Rigid plastic case for freezer
117. Supporter case strip
120. Phase Change material (PCM)

Claims

1. A direct cool refrigeration system (100) comprising
a refrigerator compartment (101) and a freezer compartment (102); the freezer compartment (102) comprising an evaporator plate (106) in contact with a plurality of coils or tubes (113) with refrigerant circulating therewithin;
wherein, the freezer compartment (102) further comprises
a plurality of cooling elements provided inside the evaporator plate (106), wherein at least one of the cooling elements is in contact with the evaporator plate (106), the plurality of cooling elements comprising a phase change material (PCM) having freezing point lower than 0°C and higher than the average evaporator plate temperature, enclosed in a flexible plastic case (110), and
a supporter case (108) disposed inside the evaporator plate (106) and arranged to support the plurality of cooling elements;
wherein the supporter case (108) is in contact with at least one wall of the flexible case (110) and comprises means for engagement with the flexible case (110),
characterized in that
the flexible case (110) has three compartments arranged to be bent into a U-shape such that two compartments are parallel to each other and perpendicular to the third compartment, the compartments having a gap between them to accommodate edges of the supporter case (108),
wherein the means for engagement with the flexible case (110) comprises a plurality of projections (111) on the supporter case (108), and a plurality of through holes (112) in the third compartment of the flexible case (110) to allow the plurality of projections (111) of the supporter case (108) to tightly fit or attach with the plurality of through holes (112).

2. The direct cool refrigeration system as claimed in claim 1, wherein the flexible plastic case (110) comprises at least a pair of thin, flexible and spaced apart walls joined together to form a closed surface.

3. The direct cool refrigeration system as claimed in claim 2, the flexible walls being adapted to match the shape of the evaporator plate (106) such that there is an enhancement in the area of the flexible case (110) in contact with the evaporator plate (106).

4. The direct cool refrigeration system as claimed in claim 3, the flexible walls being thin.

5. The direct cool refrigeration system as claimed in any of the preceding claims, further comprising a tray fresh room or TFR (103) with another cooling element placed therewithin;
the cooling element comprising a phase change material having freezing point higher than the minimum attainable temperature inside the TFR, enclosed in a rigid, semi-rigid or flexible case.

6. The direct cool refrigeration system as claimed in claim 5, wherein the rigid case comprises at least a pair of rigid and spaced apart walls joined together to form a closed surface.

7. The direct cool refrigeration system as claimed in any of the preceding claims, wherein the evaporator plate is a metallic sheet.

8. The direct cool refrigeration system as claimed in claims 1 or 7, wherein the supporter case has three (U-shaped), four (O-shaped) or more faces placed in proximity with and spaced apart from the sides/faces of the evaporator plate.

9. The direct cool refrigeration system as claimed in claim 8, wherein the supporter case has three faces (U-shaped) and the cooling element is in contact with one or more faces of the supporter case.

10. The direct cool refrigeration system as claimed in any of the preceding claims, wherein the phase change material(s) in the cooling element(s) gets partially or completely frozen during normal operation of the refrigeration system, and provides cooling during power failure/outage.

11. The direct cool refrigeration system as claimed in any of the preceding claims, wherein the phase change material is any organic or inorganic PCM or eutectics having freezing point in the given range of temperatures.

12. The direct cool refrigeration system as claimed in any of the preceding claims, wherein the flexible case is composed of plastic materials like Poly Vinyl Chloride (PVC), Polypropylene, Polyethylene, Polystyrene, Acrylonitrile Butadiene Styrene (ABS), Nylon and the like.

Patentansprüche

1. Direktes Kühlsystem (100) mit
einem Kühlfach (101) und einem Gefrierfach (102), wobei das Gefrierfach (102) eine Verdampferplatte (106) umfasst, die mit einer Vielzahl von Spulen oder Rohren (113) in Kontakt steht, in denen Kältemittel zirkuliert;
wobei das Gefrierfach (102) ferner umfasst
eine Vielzahl von Kühlelementen, die innerhalb der Verdampferplatte (106) vorgesehen sind, wobei mindestens eines der Kühlelemente in Kontakt mit der Verdampferplatte (106) ist, wobei die Vielzahl von Kühlelementen ein Phasenwechselmaterial (PCM) mit einem Gefrierpunkt unter 0°C und über der durchschnittlichen Verdampferplattentemperatur umfasst, das in einem flexiblen Kunststoffgehäuse (110) eingeschlossen ist, und
ein Trägergehäuse (108), das innerhalb der Verdampferplatte (106) und so angeordnet ist, dass es die Vielzahl von Kühlelementen trägt;
wobei das Trägergehäuse (108) mit mindestens einer Wand des flexiblen Gehäuses (110) in Kontakt ist und Mittel zum Eingriff mit dem flexiblen Gehäuse (110) aufweist,
dadurch gekennzeichnet, dass das flexible Gehäuse (110) drei Fächer aufweist, die so angeordnet sind, dass sie zu einer U-Form gebogen werden, sodass zwei Fächer parallel zueinander und senkrecht zum dritten Fach sind, wobei die Fächer einen Spalt zwischen ihnen aufweisen, um Kanten des Trägergehäuses (108) aufzunehmen, wobei das Mittel zum Eingriff mit dem flexiblen Gehäuse (110) eine Vielzahl von Vorsprüngen (111) am Trägergehäuse (108) und eine Vielzahl von Durchgangslöchern (112) im dritten Fach des flexiblen Gehäuses (110) aufweist, um der Vielzahl von Vorsprüngen (111) des Trägergehäuses (108) einen festen Sitz mit der Vielzahl von Durch-

gangslöchern (112) oder eine Befestigung mit der Vielzahl von Durchgangslöchern (112) zu ermöglichen.

2. Direktes Kühlsystem nach Anspruch 1, wobei das flexible Kunststoffgehäuse (110) mindestens ein Paar von dünnen, flexiblen und beabstandeten Wänden aufweist, die miteinander verbunden sind, um eine geschlossene Oberfläche zu bilden.

3. Direktes Kühlsystem nach Anspruch 2, wobei die flexiblen Wände an die Form der Verdampferplatte (106) angepasst sind, sodass eine Verstärkung im Bereich des flexiblen Gehäuses (110) in Kontakt mit der Verdampferplatte (106) vorhanden ist.

4. Direktes Kühlsystem nach Anspruch 3, wobei die flexiblen Wände dünn sind.

5. Direktes Kühlsystem nach einem der vorhergehenden Ansprüche, ferner umfassend ein Frischraumschubfach (Tray Fresh Room oder TFR) (103) mit einem anderen Kühlelement, das darin angeordnet ist;
wobei das Kühlelement ein Phasenwechselmaterial mit einem Gefrierpunkt umfasst, der höher als die minimal erreichbare Temperatur innerhalb des TFR ist und in einem starren, halbstarren oder flexiblen Gehäuse eingeschlossen ist.

6. Direktes Kühlsystem nach Anspruch 5, wobei das starre Gehäuse mindestens ein Paar von starren und beabstandeten Wänden aufweist, die miteinander verbunden sind, um eine geschlossene Oberfläche zu bilden.

7. Direktes Kühlsystem nach einem der vorhergehenden Ansprüche, wobei die Verdampferplatte ein Metallblech ist.

8. Direktes Kühlsystem nach Anspruch 1 oder 7, wobei das Trägergehäuse drei (U-förmige), vier (O-förmige) oder mehr Flächen aufweist, die in der Nähe der und beabstandet von den Seiten/Flächen der Verdampferplatte angeordnet sind.

9. Direktes Kühlsystem nach Anspruch 8, wobei das Trägergehäuse drei Seiten (U-förmig) aufweist und das Kühlelement mit einer oder mehreren Seiten des Trägergehäuses in Kontakt steht.

10. Direktes Kühlsystem nach einem der vorhergehenden Ansprüche, wobei das/die Phasenwechselmaterial(ien) in dem/den Kühlelement(en) während des normalen Betriebs des Kühlsystems teilweise oder vollständig eingefroren wird/werden und bei Stromausfall für Kühlung sorgt/sorgen.

11. Direktes Kühlsystem nach einem der vorhergehenden Ansprüche, wobei das Phasenwechselmaterial ein beliebiges organisches oder anorganisches PCM oder Eutektikum mit einem Gefrierpunkt im vorgegebenen Temperaturbereich ist.

12. Direktes Kühlsystem nach einem der vorhergehenden Ansprüche, wobei das flexible Gehäuse aus Kunststoffmaterialien wie Polyvinylchlorid (PVC), Polypropylen, Polyethylen, Polystyrol, AcrylnitrilButadien-Styrol (ABS), Nylon und dergleichen besteht.

Revendications

1. Système de réfrigération (100) à refroidissement direct comprenant
un compartiment réfrigérateur (101) et un compartiment congélateur (102); le compartiment congélateur (102) comprenant une plaque d'évaporation (106) en contact avec une pluralité de serpentins ou de tubes (113) dans lesquels circule un fluide frigorigène;
dans lequel le compartiment congélateur (102) comprend en outre
une pluralité d'éléments de refroidissement prévus à l'intérieur de la plaque d'évaporation (106), dans laquelle au moins l'un des éléments de refroidissement est en contact avec la plaque d'évaporation (106), la pluralité d'éléments de refroidissement comprenant un matériau à changement de phase (PCM) ayant un point de congélation inférieur à 0°C et supérieur à la température moyenne de la plaque d'évaporation, contenu dans un boîtier souple (110), et un boîtier de support (108) disposé à l'intérieur de la plaque d'évaporation (106) et agencé pour supporter la pluralité d'éléments de refroidissement;
le boîtier de support (108) étant en contact avec au moins une paroi du boîtier souple (110) et comprend des moyens d'engagement avec le boîtier souple (110),

caractérisé en ce que
le boîtier souple (110) comporte trois compartiments agencés pour être pliés en forme de U de telle sorte que deux compartiments sont parallèles l'un à l'autre et perpendiculaires au troisième compartiment, les compartiments ayant un espace entre eux pour recevoir les bords du boîtier de support (108),
le moyen d'engagement avec le boîtier souple (110) comprenant une pluralité de saillies (111) sur le boîtier de support (108), et une pluralité de trous traversants (112) dans le troisième compartiment du boîtier souple (110) pour permettre à la pluralité de saillies (111) du boîtier de support (108) de s'ajuster étroitement ou de s'attacher à la pluralité de trous traversants (112).

2. Système de réfrigération à refroidissement direct selon la revendication 1, dans lequel le boîtier souple (110) en plastique comprend au moins une paire de parois minces, souples et espacées les unes des autres, réunies ensemble pour former une surface fermée.

3. Système de réfrigération à refroidissement direct selon la revendication 2, les parois souples étant adaptées à la forme de la plaque d'évaporation (106) de telle sorte qu'il y ait une amélioration dans la zone du boîtier souple (110) en contact avec la plaque d'évaporation (106).

4. Système de réfrigération à refroidissement direct selon la revendication 3, les parois souples étant minces.

5. Système de réfrigération à refroidissement direct selon l'une quelconque des revendications précédentes, comprenant en outre une pièce fraîche à plaquette ou TFR (103) avec un autre élément de refroidissement placé dans celle-ci; l'élément de refroidissement comprenant un matériau à changement de phase ayant un point de congélation supérieur à la température minimale pouvant être atteinte à l'intérieur de la TFR, enfermé dans un boîtier rigide, semi-rigide ou souple.

6. Système de réfrigération à refroidissement direct selon la revendication 5, dans lequel le boîtier rigide comprend au moins une paire de parois rigides et espacées les unes des autres pour former une surface fermée.

7. Système de réfrigération à refroidissement direct tel que revendiqué dans l'une quelconque des revendications précédentes, dans lequel la plaque d'évaporation est une feuille métallique.

8. Système de réfrigération à refroidissement direct selon la revendication 1 ou 7, dans lequel le boîtier de support comporte trois faces (en forme de U), quatre faces (en forme de O) ou plus de faces placées à proximité et espacées des faces latérales/faces de la plaque d'évaporation.

9. Système de réfrigération à refroidissement direct selon la revendication 8, dans lequel le boîtier de support a trois faces (en forme de U) et l'élément de refroidissement est en contact avec une ou plusieurs faces du boîtier de support.

10. Système de réfrigération à refroidissement direct tel que revendiqué dans l'une quelconque des revendications précédentes, dans lequel le ou les matériaux à changement de phase dans le ou les éléments de refroidissement sont partiellement ou complètement gelés pendant le fonctionnement normal du système de réfrigération, et qui assure le refroidissement pendant une panne ou défaillance de courant.

11. Système de réfrigération à refroidissement direct tel que revendiqué dans l'une quelconque des revendications précédentes, dans lequel le matériau à changement de phase est n'importe quel PCM organique ou inorganique ou eutectique ayant un point de congélation dans la plage de températures donnée.

12. Système de réfrigération à refroidissement direct tel que revendiqué dans l'une quelconque des revendications précédentes, dans lequel le boîtier souple est composé de matériaux plastiques tels que le polychlorure de vinyle (PVC), le polypropylène, le polyéthylène, le polystyrène, l'acrylonitrile, le butadiène-styrène (ABS), le nylon et similaires.

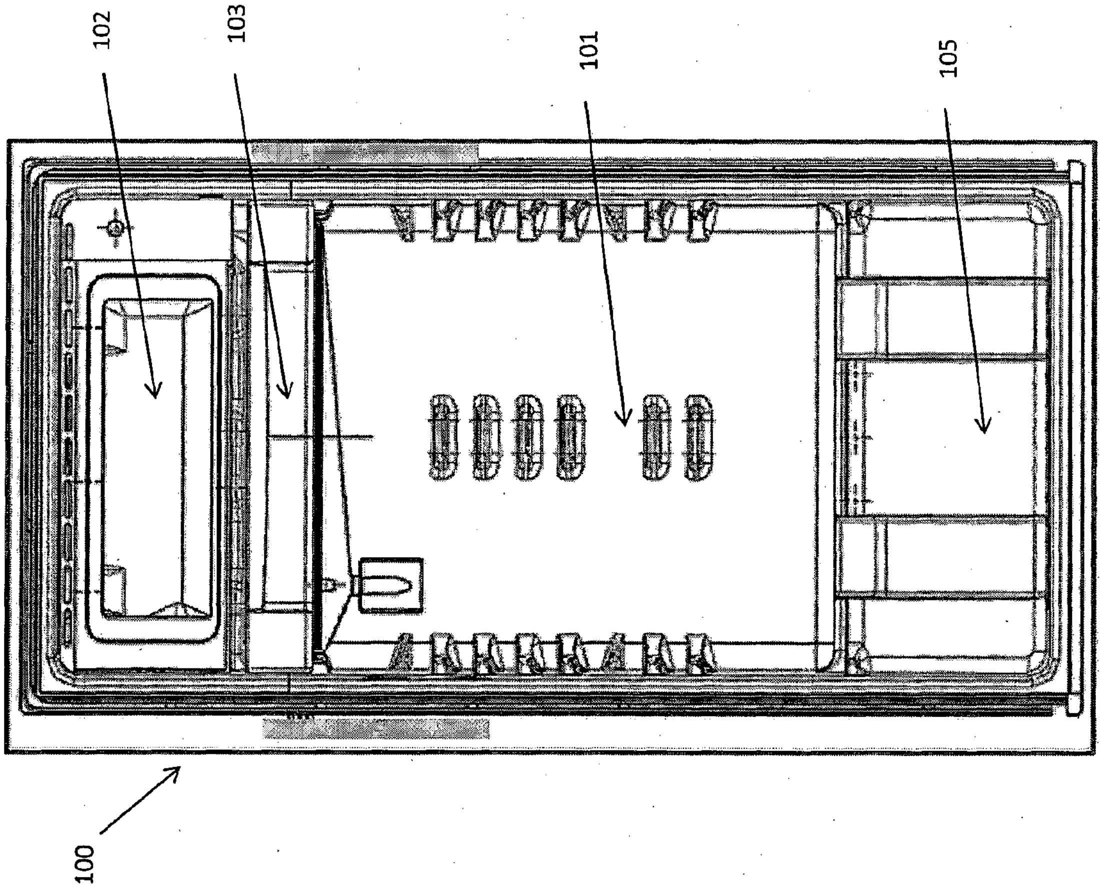


Fig. 1(a)

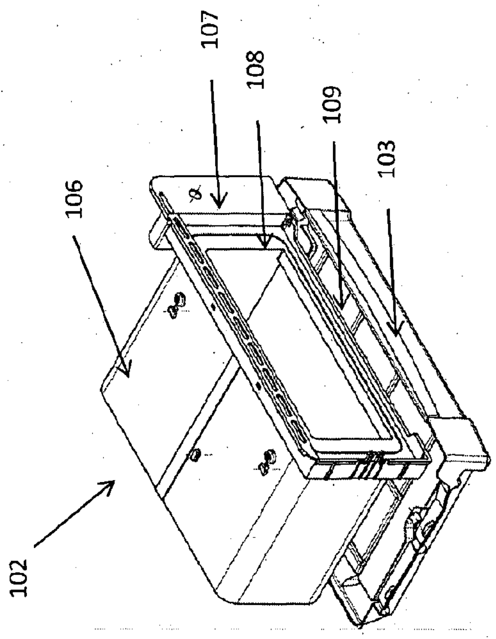


Fig. 1(b)

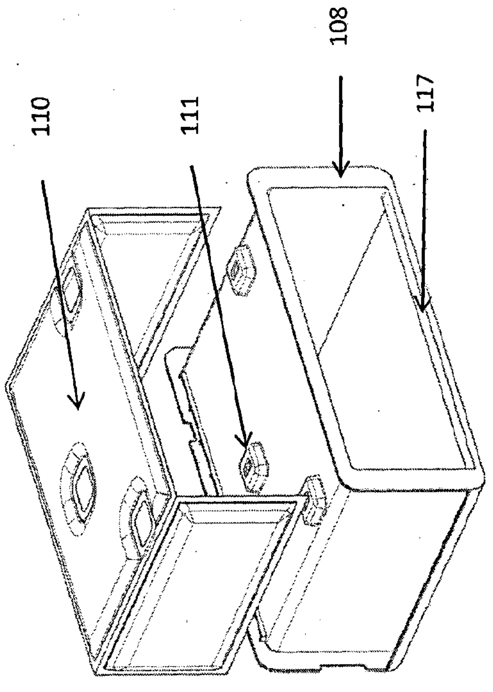


Fig. 2(a)

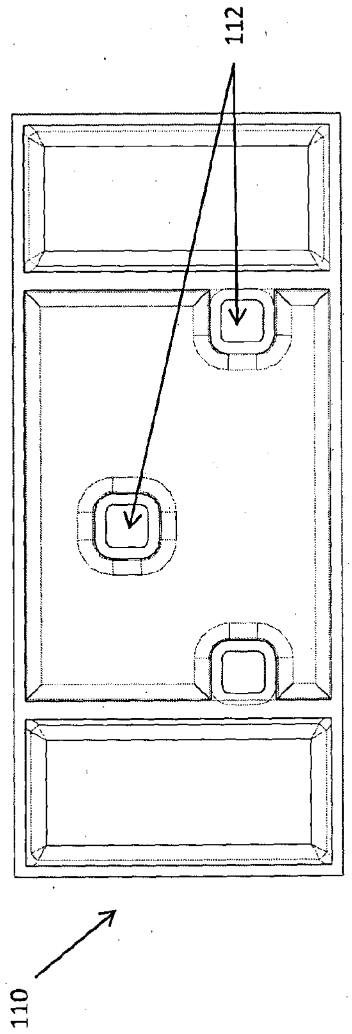


Fig. 2(b)

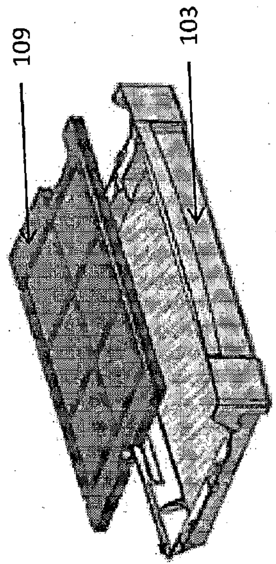


Fig. 2(c)

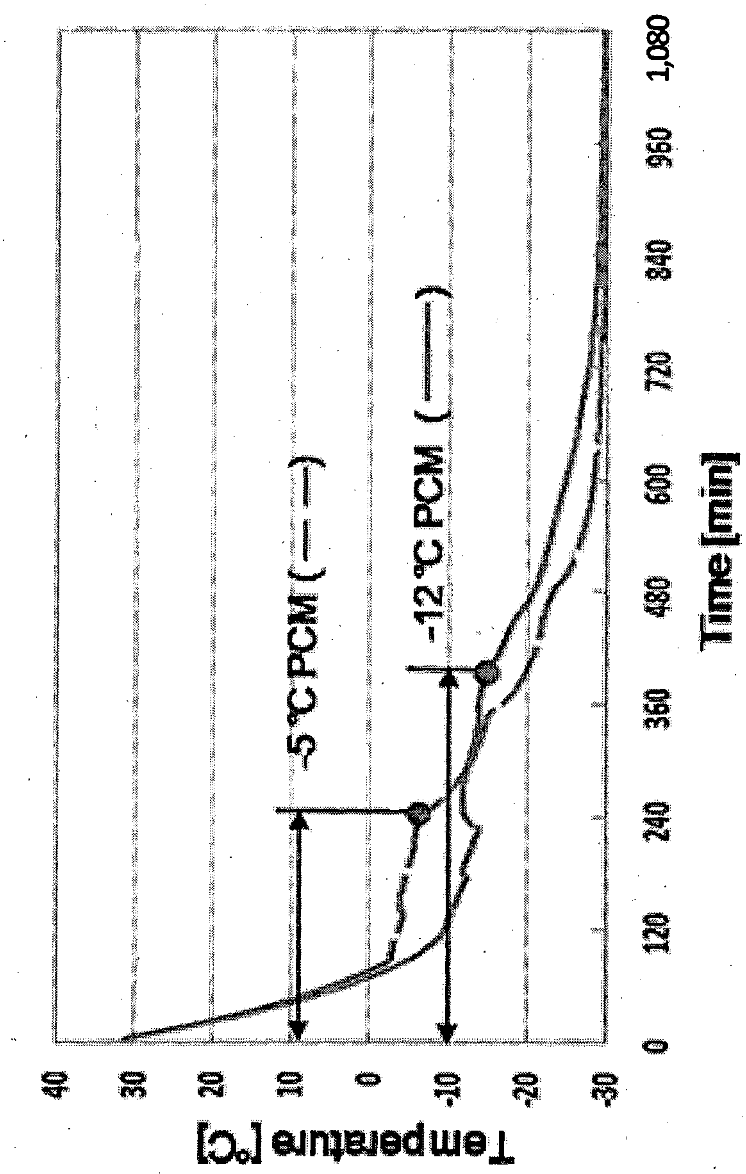

Temperature [°C]
40
30
20
10
0
-10
-20
-30
0
120
240
360
480
600
720
840
960
1,080
Time [min]
-5 °C PCM (— —)
-12 °C PCM (——)

Fig. 3

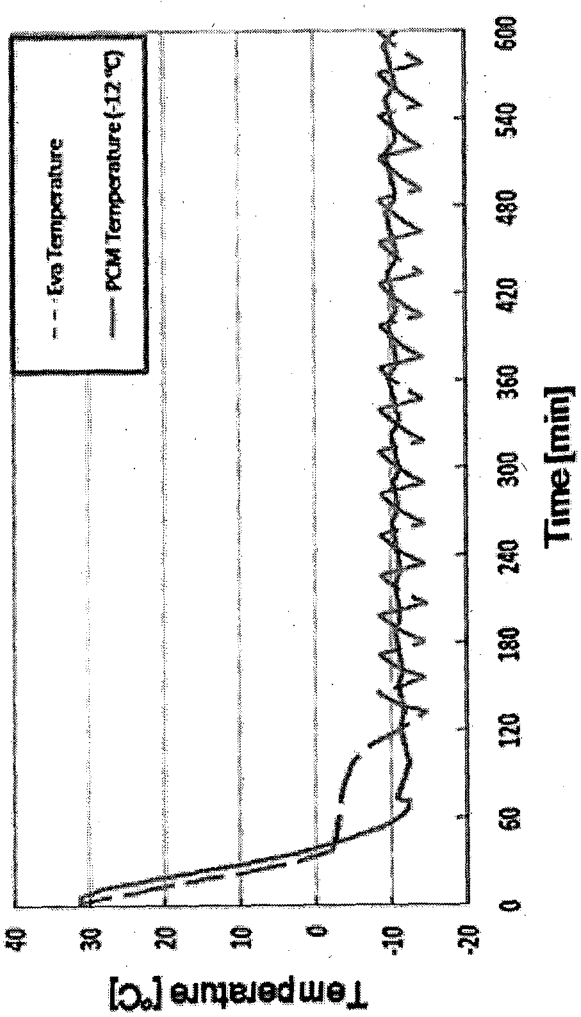

Eva Temperature
PCM Temperature (-12 °C)
Temperature [°C]
Time [min]
40
30
20
10
0
-10
-20
0
60
120
180
240
300
360
420
480
540
600

Fig. 4

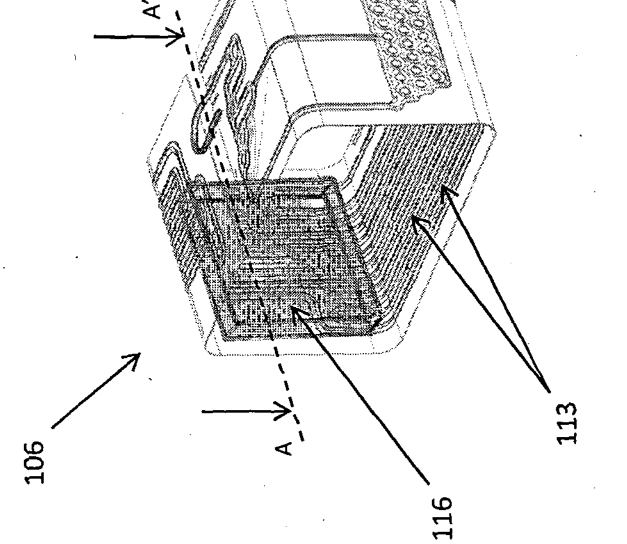


Fig. 5(a)

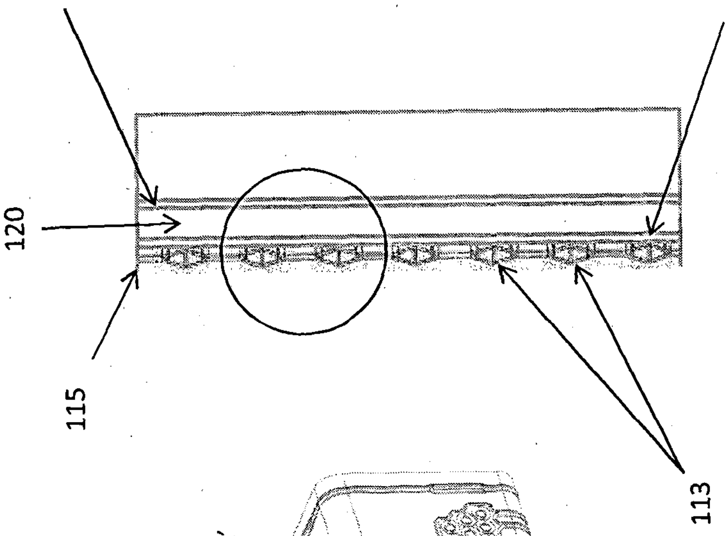


Fig. 5(b)

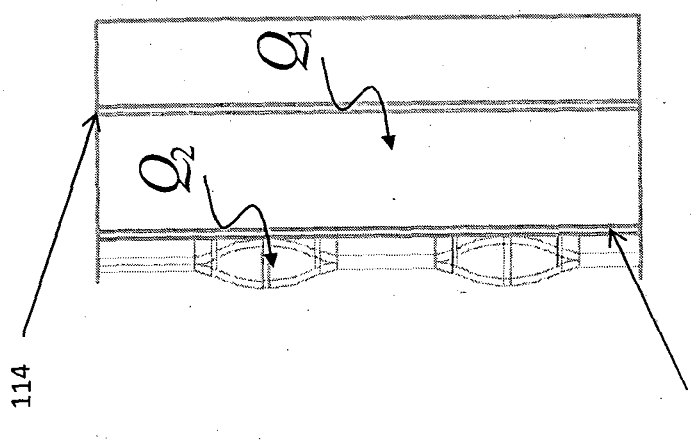


Fig. 5(c)

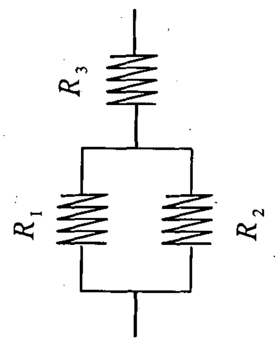


Fig. 6(c)

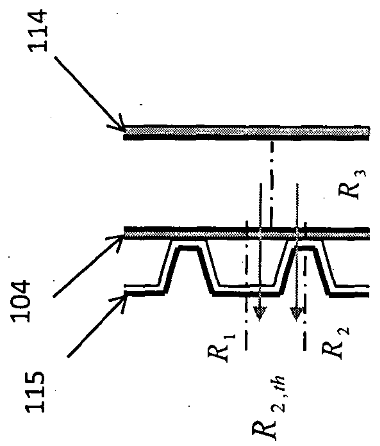


Fig. 6(b)

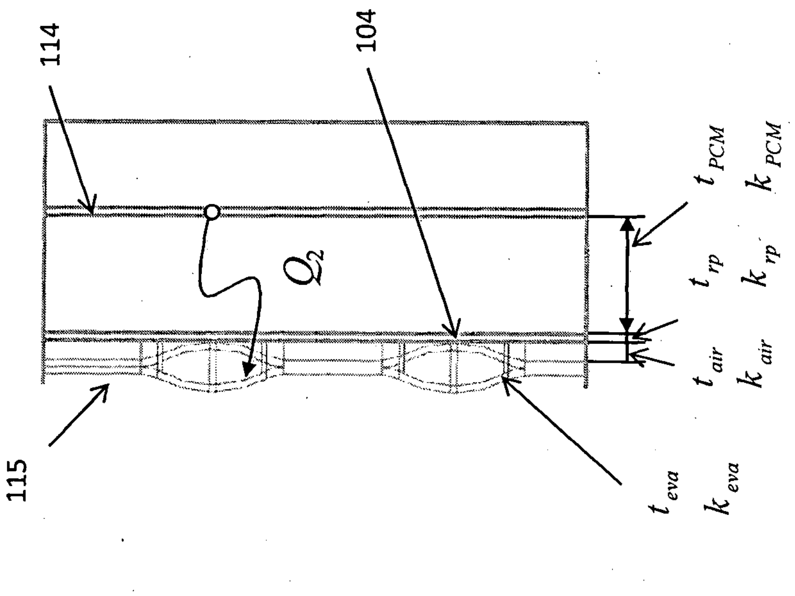
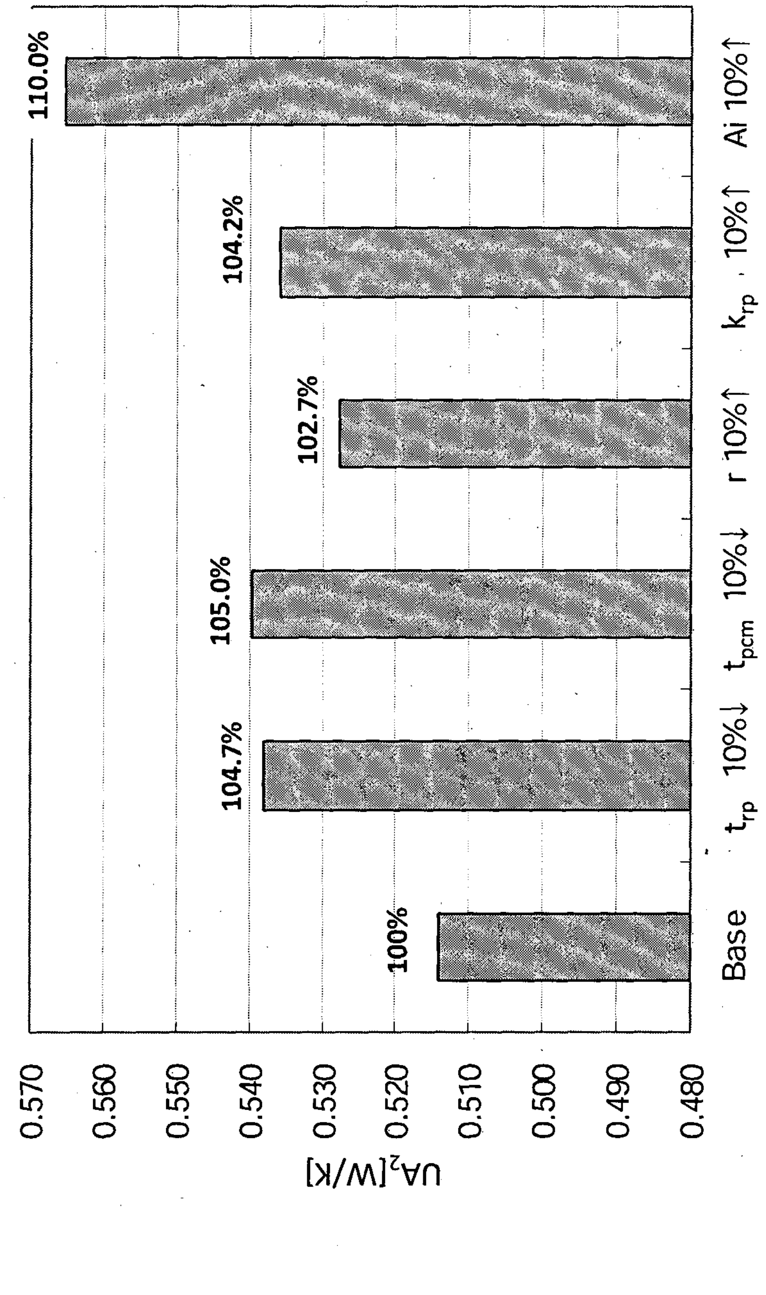


Fig. 6(a)



UA2[W/K]
0.570
0.560
0.550
0.540
0.530
0.520
0.510
0.500
0.490
0.480
100%
104.7%
105.0%
102.7%
104.2%
110.0%
Base
t_{rp} 10%↓
t_{pcm} 10%↓
r 10%↑
k_{rp} 10%↑
Ai 10%↑

Fig. 7

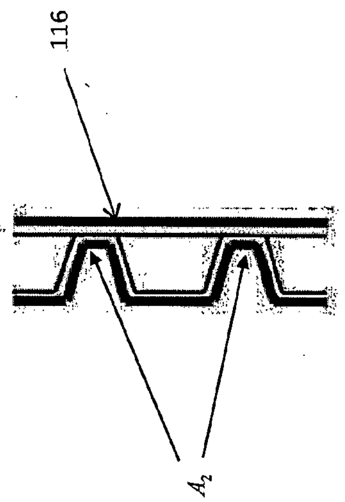


Fig. 8(a)

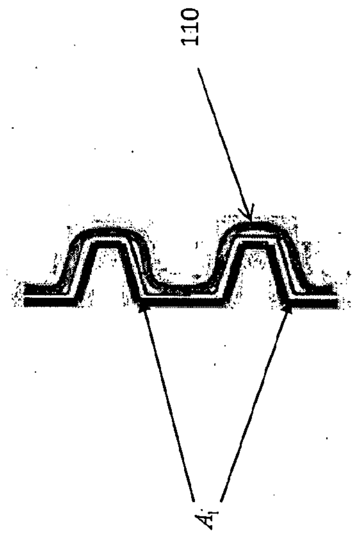


Fig. 8(b)

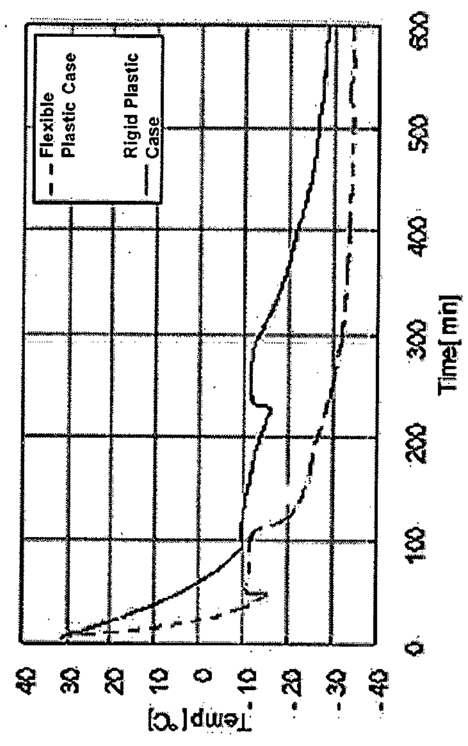


Fig. 9

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 152155 A **[0007]**
- US 4748823 A **[0008]**