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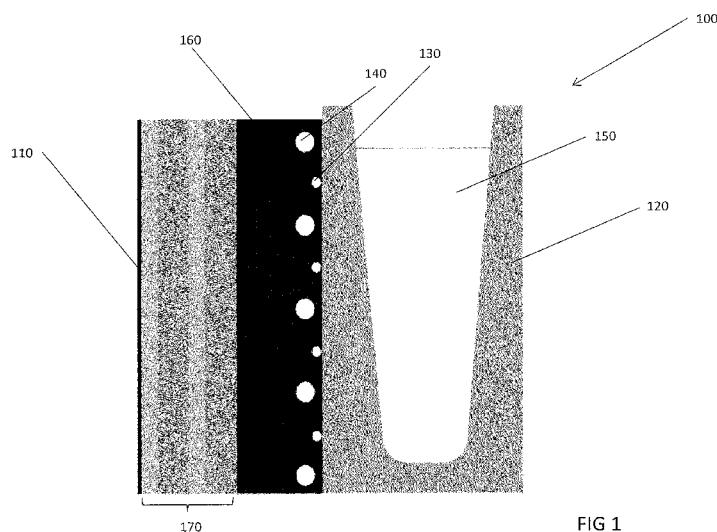


FIG 1

(57) Abstract: An energy storage apparatus comprising: a casing; at least one crucible (150); at least one heating element adjacent the crucible (130); at least one heat conduit, having an inlet and outlet, adjacent the crucible (140); and a phase change material located within the at least one crucible, the phase change material selected from the group consisting of aluminium-silicon alloys, aluminium, magnesium chloride, sodium chloride and potassium chloride.

THERMAL CELL

FIELD OF THE INVENTION

[0001] The present invention relates to the field of energy storage. More
5 particularly, the invention relates to an apparatus and method for storing energy.
Most particularly, the invention relates to an energy storage apparatus.

BACKGROUND TO THE INVENTION

[0002] Any reference to background art herein is not to be construed as an
10 admission that such art constitutes common general knowledge in Australia or
elsewhere.

[0003] Today's population relies heavily on electricity and its use, and
therefore demand on a network can vary considerably according to the season
and even to different times of the day. Energy storage systems can be used to
15 improve the performance of energy systems by levelling out the supply of
electricity and increasing the reliability of the system at peak times. For example,
energy storage systems can improve the performance of a power generating
plant by load levelling. Load levelling is a method for reducing energy
fluctuations in customer demand by storing energy when there is little demand
20 for electricity, and releasing this stored energy when there is a spike in demand.
Further to this, load levelling also improves the cost effectiveness of a power
generating plant.

[0004] The sun provides an abundance of clean and safe energy. However,
the supply of solar energy is periodic following yearly and diurnal cycles, and can
25 be unpredictable. The energy demand of the population is also unsteady, and
follows a yearly and diurnal cycle for both industrial and residential needs. The
use of energy storage systems can help alleviate the problem of this
unpredictability by storing energy when there is an abundance of solar energy,
and releasing it when there is a drop in supply. Further to this, energy storage is

also useful when there is a break in the supply of electricity, such as in a blackout.

[0005] Typically batteries are used to store energy but their cost and replacement become an overriding factor when energy demand is 5kW or greater. One important characteristic of an energy storage system is the length of time which energy can be stored with acceptable losses. One disadvantage of storing energy in the form of thermal energy is that it can only be stored for short timeframes due to the loss of thermal energy through radiation, convection and conduction. It would be desirable to have an energy storage system that alleviates the problems associated with thermal energy loss.

[0006] Another important characteristic of an energy storage system is its volumetric energy capacity, or the amount of energy stored per unit volume. If the energy required to be stored is large then the energy storage system will also be large. A large energy storage unit is undesirable due to transport and storage issues. As such, it is desirable to have an energy storage apparatus that is more compact.

[0007] Heat storage at power generating plants is typically in the form of steam or hot water and can only be stored for short periods of time. Recently, other materials such as oils, that have a high boiling point, have been suggested as heat storage substances. However, these heat storage substances lose thermal energy to the surroundings quickly. Another problem with the prior art thermal energy storage systems is the design of the heat exchangers which result in a substantial amount of heat, and hence energy, being lost to the surroundings.

[0008] It should be apparent to those skilled in the art that there is need for an energy storage apparatus that is able to store large amounts of energy without losing a substantial amount of energy, and is relatively compact.

SUMMARY OF THE INVENTION

[0009] In a first aspect, although it need not be the only or indeed the broadest form, the invention resides in an energy storage apparatus comprising:

a casing;

5 at least one crucible;

at least one heating element adjacent the crucible;

at least one heat conduit, having an inlet and outlet, adjacent the crucible;

and

10 a phase change material located within the at least one crucible, the phase change material selected from the group consisting of aluminium-silicon alloys, aluminium, magnesium chloride, sodium chloride and potassium chloride.

[0010] In one embodiment, the phase change material is an aluminium-silicon alloy.

15 [0011] In another embodiment, the aluminium-silicon alloy comprises between about 1% and 30% by weight of aluminium.

[0012] In an embodiment, the phase change material is AlSi_{12} .

[0013] In another embodiment, the phase change material is AlSi_{20} .

20 [0014] In one embodiment, the crucible is formed from a material selected from silicon carbide, graphite, reinforced polymer, clay, porcelain, ceramics, carbon nanotubes, aluminium nitride, aluminium oxide, boron nitride, silicon nitride or a combination thereof.

[0015] In another embodiment, the energy storage apparatus further comprises a thermal interface between the casing and the crucible.

25 [0016] In a further embodiment, the thermal interface is selected from the group consisting of graphite, graphene and carbon nanotubes.

[0017] In an embodiment, the energy storage apparatus further comprises insulation.

[0018] In a second aspect, the invention resides in a method of storing and retrieving energy comprising the steps of:

30 a. providing an energy storage apparatus comprising:

a casing
at least one crucible;
at least one heating element adjacent the crucible;
at least one heat conduit, having an inlet and outlet, adjacent the crucible;

5 and

a phase change material located within the at least one crucible, the phase change material selected from the group consisting of aluminium-silicon alloys, aluminium, magnesium chloride, sodium chloride and potassium chloride;

- 10 b. heating the at least one heating element to cause a phase change in the phase change material, to thereby store energy;
- c. introducing a liquid to the at least one heat conduit; and
- d. converting the liquid to a gas through absorption of thermal energy stored in the phase change material;
- 15 to thereby retrieve stored energy.

[0019] The various features and embodiments of the present invention referred to in the individual sections above apply, as appropriate, to other sections, *mutatis mutandis*. Consequently features specified in one section may be combined with features specified in other sections as appropriate.

20 [0020] Further features and advantages of the present invention will become apparent from the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

25 [0021] To assist in understanding the invention and to enable a person skilled in the art to put the invention into practical effect, preferred embodiments of the invention will be described by way of example only with reference to the accompanying drawings, in which:

FIG 1 shows a sectional view of an embodiment of the energy storage apparatus;

30 FIG 1a shows a section view of another embodiment of the energy storage apparatus;

FIG 2 shows a perspective sectional view of the energy storage apparatus;

FIG 2a shows a perspective view of another embodiment of the energy storage apparatus;

5 FIG 2b shows a view of the thermal interface of FIG 2a where the crucible is partially removed; and

FIG 3 shows a graphical representation of the storage capacity per unit mass of AlSi_{12} vs temperature.

DETAILED DESCRIPTION OF THE INVENTION

10 [0022] Embodiments of the present invention reside primarily in an energy storage apparatus. Accordingly, the method steps and apparatus have been illustrated in concise schematic form in the drawings, showing only those specific details that are necessary for understanding the embodiments of the present invention, but so as not to obscure the disclosure with excessive detail that will
15 be readily apparent to those of ordinary skill in the art having the benefit of the present description.

[0023] In this specification, adjectives such as first, second, adjacent and the like may be used solely to distinguish one element or action from another element or action without necessarily requiring or implying any actual such
20 relationship or order. Words such as “comprises” or “includes” are intended to define a non-exclusive inclusion, such that a method or apparatus that comprises a list of elements do not include only those elements but may include other elements not expressly listed, including elements that are inherent to such a process, method, article, or apparatus.

25 [0024] As used herein, the term ‘about’ means the amount is nominally the number following the term ‘about’ but the actual amount may vary from this precise number to an unimportant degree.

[0025] In a first aspect, although it need not be the only or indeed the broadest form, the invention resides in an energy storage apparatus comprising:

30 a casing;
at least one crucible;

at least one heating element adjacent the crucible;

at least one heat conduit, having an inlet and outlet, adjacent the crucible;

and

a phase change material located within the at least one crucible, the
5 phase change material selected from the group consisting of aluminium-silicon
alloys, aluminium, magnesium chloride, sodium chloride and potassium chloride.

[0026] Referring to FIG 1 there is shown an energy storage apparatus 100.
The energy storage apparatus 100 comprises a casing 110, a crucible 120, a
heating element 130, a heat conduit 140, a phase change material 150, a
10 thermal interface 160 and insulation 170.

[0027] The crucible 120, the heating element 130, the heat conduit 140, the
phase change material 150, the thermal interface 160 and insulation 170 are
encased within the casing 110. The phase change material 150 is located within
the crucible 120 such that when the crucible 120 is heated, the thermal energy is
15 transferred to the phase change material 150. The phase change material 150 is
heated to high temperatures so it will be appreciated that the crucible 120 has
high mechanical properties, high thermal conductivity and is stable at high
temperatures. This allows the crucible 120 to facilitate thermal energy transfer
whilst containing the phase change material 150. Suitable materials for the
20 crucible 120 include but are not limited to silicon carbide, graphite, reinforced
polymer, clay, porcelain, ceramics, carbon nanotubes, aluminium nitride,
aluminium oxide, boron nitride, silicon nitride, steel, copper, mullite, zirconium
oxide, ductile iron, cast iron, stainless steel, brass, alloys of columbian, tantalum,
molybdenum, tungsten and combinations thereof. It will be appreciated by the
25 person skilled in the art that the above lists of materials are not an exhaustive list
but merely exemplify types of materials that can be used. In another
embodiment, the crucible 120 may be a sealed canister. In this regard, the
sealed canister has pillow of argon, nitrogen or any other non-oxidising gas or
vacuum. It will be appreciated that any inert atmosphere may be used.

30 [0028] In one embodiment, the crucible 120 is formed of silicon carbide.
Silicon carbide is composed of a crystal lattice of carbon and silicon atoms, and
is able to provide structural integrity to the crucible 120. Silicon carbide is

relatively inert in that it does not react with acids, alkali materials, or molten salts at temperatures up to 800°C. Further to this, silicon carbide forms a silicon oxide coating at 1200°C which is able to withstand temperatures up to 1600°C. The crucible material therefore includes silicon oxide in one embodiment. Silicon carbide also has high thermal conductivity, low thermal expansion characteristics and high mechanical strength, and this provides the crucible 120 with exceptional thermal shock resistant qualities. It should be apparent that a crucible 120 made of silicon carbide is resistant to chemical reactions, is suitably strong, and has good thermal conductivity which assists in heating the phase change material 150.

[0029] The density of the silicon carbide is suitably between about 1 g/cm³ and about 4 g/cm³, more suitably between about 1.5 g/cm³ and about 3.5 g/cm³, preferably between about 2.5 g/cm³ and about 3.5 g/cm³, and preferably about 3.1 g/cm³.

[0030] The crucible 120 is not particularly limited by shape or size. The crucible 120 is an open ended container. In one embodiment, the crucible 120 has a smaller diameter at the base and a larger diameter at the top. The crucible 120 can have a cylindrical shape, a prism shape, a cone shape, a pyramid shape, a trapezium shape, a pentagon shape, an oval shape, a trapezoid, a diamond shape or a triangular shape. In one embodiment, the crucible 120 has a cylindrical shape. It will be appreciated by the person skilled in the art that the list provided merely exemplifies the types of shapes that the crucible 120 can be formed into and this shape is not limited to the list provided. The smaller diameter at the base and the larger diameter at the top allow the phase change material 150 to expand in a vertical direction rather than in a horizontal direction and against the sides of the crucible 120. In another embodiment, the energy storage apparatus 100 comprises multiple crucibles 120. In one embodiment, the energy storage apparatus suitably comprises 1 to 9 crucibles, more suitably comprises 3 to 9 crucibles, most preferably 3, 4 or 9 crucibles.

[0031] The heating element 130 is adjacent the crucible 120. The heating element 130 generates heat so that thermal energy is transferred to the crucible 120 and thus the phase change material 150. This is discussed in more detail

hereinafter. The heating element 130 is formed of material that has a high thermal conductivity value to facilitate thermal energy transfer. As such, suitable materials for the heating element 130 include but are not limited to molybdenum, nichrome, kanthal, curpronickel, aluminium oxide, boron nitride, mullite, silicon nitride, silicon carbide, zirconium oxide and combinations thereof. In one embodiment, the heating element 130 is formed of silicon carbide.

[0032] The heating element 130 converts electrical energy to thermal energy so that the phase change material 150 can store said thermal energy. The heating element 130 sources the energy required for heating from any source of electricity, such as wind generated electricity, hydro powered electricity, fossil fuel powered generators, photovoltaic devices, geothermal power, grid distributed power, heat engines, nuclear fusion, hydrogen fuel cells, thermocouples, thermopiles, thermionic converters, natural gas, coal and combinations thereof.

[0033] The voltage of the heating element 130 is suitably between about 10V and about 1000V, more suitably between about 20V and about 600V, preferably between about 20V and 500V, and most preferably between about 24V and about 415V.

[0034] It will also be appreciated that the heating element 130 can be located anywhere within the energy storage apparatus 100 as long as the thermal energy from the heating element 130 is transferred to the phase change material 150. However, it is more efficient to have the heating element 130 located close to the crucible 120. It will also be appreciated that the energy storage apparatus 100 may comprise multiple heating elements 130 to ensure that there is sufficient thermal energy transfer to the phase change material 150.

[0035] One of the problems associated with thermal energy storage is that the temperature typically increases with the amount of energy stored within a material. One method of addressing this problem is to utilize a greater mass of material, however, as previously mentioned, there are disadvantages associated with using a greater amount of phase change material, such as storage issues and difficulty in transport. In order to address this problem the material is heated to higher temperatures to store greater amounts of energy. However, a material

which is much hotter than the surrounding environment will lose thermal energy to the surrounding environment much faster compared to a material at a lower temperature. As such, these high temperatures result in an unacceptable loss of energy.

5 [0036] Phase change material 150 can be used to store larger amounts of thermal energy without a proportionate increase in temperature, and therefore alleviates the problem associated with the loss of thermal energy to the surroundings. This is known as latent heat storage.

10 [0037] The principle of latent heat storage is that when heat is applied to a phase change material 150 it changes phase from a solid to a liquid, or a liquid to a gas, by storing the heat as latent heat of fusion or vapourization. When the stored thermal energy is retrieved from the phase change material 150 then it reverts from a liquid to a solid, or a vapour to a liquid. Heat storage through phase change has the advantage of compactness because the latent heat of
15 fusion is generally larger than the enthalpy change for a change in temperature. For example, the ratio of latent heat to specific heat of water is about 80 which means that the energy required to melt 1 kg of ice is about 80 times the magnitude of the energy required to increase the temperature of 1 kg of water by 1°C. It should be clear that there is a significant increase in energy stored within
20 the phase change material 150 when the material changes phases and this is not accompanied by a proportionate increase in temperature. This alleviates the problem of loss of thermal energy through convection, conduction and radiation. Further to this, many of the phase change materials known in the art are corrosive, expensive and have poor thermal conductivity requiring large heat
25 exchange areas.

[0038] In order to address the disadvantages associated with using prior art phase change materials, the phase change material 150 should have a high heat storage density for a small temperature variation during the charge and discharge process. Further to this, the phase change material 150 should also
30 have high thermal conductivity and no phase segregation.

[0039] The phase change material 150 has a phase change temperature suitably greater than about 100°C, more suitably between about 200°C and

about 800°C, preferably between about 400°C and about 600°C, more preferably between about 500°C and about 600°C, and most preferably about 576°C.

[0040] The phase change material 150 has a specific heat for the liquid state suitably greater than about 1.1kJ/KgK, more suitably between about 1.1kJ/KgK and about 8kJ/KgK, preferably between about 1.2 kJ/KgK and about 4 kJ/KgK, more preferably between about 1.5 kJ/KgK and about 2 kJ/KgK and most preferably about 1.741 kJ/KgK.

[0041] The phase change material 150 has a specific heat for the solid state suitably greater than about 1 kJ/KgK, more suitably between about 1 kJ/KgK and about 8kJ/KgK, preferably between about 1 kJ/KgK and about 4 kJ/KgK, more preferably between about 1 kJ/KgK and about 2 kJ/KgK and most preferably about 1.038 kJ/KgK.

[0042] The phase change material 150 has a heat of fusion suitably greater than 100 kJ/kg, more suitably between about 100 kJ/kg and about 1000 kJ/kg, preferably between about 300 kJ/kg and 700 kJ/kg, more preferably between about 450 kJ/kg and about 600 kJ/kg, and most preferably about 560 kJ/kg.

[0043] In one embodiment, the phase change material 150 is selected from aluminium-silicon alloys, aluminium, magnesium chloride, sodium chloride and potassium chloride. More suitably, the phase change material 150 is selected from the group consisting of aluminium-silicon alloys and aluminium. Preferably, the phase change material is an aluminium-silicon alloy. It will be appreciated that the list of phase change materials 150 is not an exhaustive list and merely exemplify certain examples of the phase change material 150. The person skilled in the art will appreciate that the phase change material 150 may be other materials not expressly listed.

[0044] The aluminium-silicon alloy comprises suitably between about 1% and about 50% by weight of aluminium, more suitably between about 5% and about 25% by weight of aluminium, preferably between about 10% and about 20% by weight of aluminium, and most preferably about 12% by weight of aluminium with the rest of the aluminium-silicon alloy being made up of silicon.

[0045] An aluminium-silicon alloy comprising about 20% by weight of

aluminium is known as AlSi_{20} , and an aluminium-silicon alloy comprising about 12% by weight of aluminium is known as AlSi_{12} . It will be appreciated that the major constituents of the aluminium-silicon alloys are aluminium and silicon, however, additional elements such as iron, copper, manganese, magnesium, lead, nickel, zinc titanium, tin, strontium, chromium and the like may be present as impurities. In one embodiment, the phase change material 150 is AlSi_{20} . In another embodiment, the phase change material 150 is AlSi_{12} .

[0046] AlSi_{12} has a melting temperature of about 576°C and a heat of fusion of about 560 kJ/kg, and AlSi_{20} has a melting temperature of about 585°C and a heat of fusion of about 460 kJ/kg. Table 1 shows the physical properties of AlSi_{12} , and it should be clear that the heat of fusion of AlSi_{12} is many magnitudes greater than the specific heat capacity of AlSi_{12} .

Properties of AlSi_{12}	
Specific heat for solid state, kJ/kgK	1.038
Specific heat for liquid state, kJ/kgK	1.741
Phase change temperature, $^{\circ}\text{C}$	576
Heat of fusion, kJ/kg	560
Density, kg/m^3	2700
Thermal conductivity, W/M $^{\circ}\text{C}$	160

Table 1 – Thermal Physical Properties of AlSi_{12}

[0047] FIG 3 shows a graphical representation of the storage capacity per unit mass of AlSi_{12} versus temperature. The graphical representation shows that there is a significant increase in the heat storage capacity of AlSi_{12} at about 576°C and this correlates to the phase change temperature.

[0048] It is advantageous if the phase change material 150 changes from a solid to a liquid as there is no significant expansion in the volume of the phase change material 150. Although phase change materials 150 that change from a liquid to gas are capable to storing thermal energy, this phase change results in an increase in volume and pressure. In a preferred embodiment, the phase change in the phase change material 150 is from a solid to a liquid when heated.

[0049] The heating element 130 generates thermal energy which is transferred through the adjacent crucible 120 to the phase change material 150

to store this energy. It should be apparent to the person skilled in the art that the heating element 130 needs to be placed sufficiently close to the crucible 120 so that thermal energy can be transferred to the crucible 120. Additionally, a thermal interface 160 can be utilized in the volume between the casing 110 and the crucible 120 to facilitate thermal energy transfer.

[0050] The thermal interface 160 facilitates the transfer of thermal energy from the heating elements 130 to the crucible 120, and also the transfer of thermal energy from the crucible 120 to the heat conduit 140. It will be appreciated that the thermal interface 160 is preferably between the heating elements 130 and the crucible 120. It was also be appreciated that the thermal interface 160 is preferably between the heat conduits 140 and crucible 120. The thermal interface 160 has high thermal conductivity properties whilst also creating a barrier between the casing 110 and the crucible 120. This barrier assists in alleviating the problem of corrosion between the phase change material 150 and the casing 110.

[0051] The thermal interface 160 surrounds the crucible 120, the heating element 130, and the heat conduit 140 so that thermal energy can be absorbed by the crucible 120 and recollected by the heat conduit 140.

[0052] In one embodiment, the thermal interface 160 is selected from the group consisting of graphite, graphene and carbon nanotubes. In a preferred embodiment, the thermal interface 160 is graphite. Graphite is an excellent medium to achieve high thermal conductivity between the crucible 120, the heating elements 130 and the heat conduit 140. Graphite can be found in many forms such as crystalline graphite, amorphous graphite, lump or vein graphite, and pyrolytic graphite. Further to this, graphite has a melting point above 3000°C, which makes it compatible with the energy storage apparatus 100.

[0053] The volume between the casing 110 and the crucible 120 may be filled with granular or flakes of graphite, or may be a solid block. The graphite block can have the heat conduit 140 and heating element 130 embedded at the time of casting the energy storage apparatus 100. The graphite can be coated with a carbon nanotube solution. Carbon nanotubes are extremely strong, robust and are very good thermal conductors making them suitable as the thermal

interface 160 either alone or in conjunction with another material.

[0054] To alleviate the problem of thermal energy loss to the surroundings, the energy storage apparatus 100 may further comprise insulation 170. The insulation 170 can suitably be located between the thermal interface 160 and the casing 110 to minimize the amount of thermal energy lost to the surroundings. Further to this, the insulation 170 ensures that the casing 110 does not get hot and alleviates the problem of an operator burning themselves if they accidentally come into contact with the casing 110. As such, it will be appreciated that the insulation 170 will generally be located next to casing 110. It will be appreciated that there can be multiple layers of insulation 170 using different materials. Suitable materials for these insulation layers include thermal insulation boards, thermal insulation blanks, fiberglass, mineral wool, polymers, and foams. For instance, multiple layers of Carbolane blankets and boards, of different specifications, can be used to prevent thermal energy loss. It will also be appreciated that any insulation that is able to accommodate the high temperatures can be used in the energy storage apparatus 100. It will be appreciated that the energy storage apparatus 100 depicted in FIG 1 has four layers of insulation, however, for convenience these four layers have been labelled as insulation 170.

[0055] The heat conduit 140 is located adjacent the crucible 120 so that it can collect the thermal energy from the phase change material 150. The heat conduit 140 can be a high pressure pipe network which facilitates collection of the stored thermal energy from the phase change material 150 and converting said thermal energy to electricity. The heat conduit 140 has an inlet and an outlet. The inlet of the heat conduit 140 is generally connected to a high pressure pump and the outlet will generally be connected to a turbine. In this regard, the heat conduit 140 has an inlet where a liquid can be added. As the liquid travels through the heat conduit 140 it is converted to a gas, by absorbing the thermal energy from the phase change material 150, which in turn rotates a turbine at the outlet to convert the thermal energy to electrical energy.

[0056] The turbine is well known in the art, and those skilled in the art will appreciate that any turbine or device that can produce electricity from moving

gas or liquid can be used with this energy storage apparatus.

[0057] The high pressure and high temperature gas passing through the turbine may be condensed and the residual/waste heat from the hot liquid can be used for co-generation and tri-generation to achieve higher efficiencies.

5 [0058] The heat conduit 140 has a high thermal conductivity value to facilitate the transfer of heat from the phase change material 150 to the liquid. The heat conduit 140 is suitably made of steel, copper, aluminium oxide, boron nitride, mullite, silicon nitride, silicon carbide, zirconium oxide, ductile iron, cast iron, stainless steel, brass, alloys of columbian, tantalum, molybdenum, tungsten
10 or combinations thereof. It will be appreciated that the above list of materials is not an exhaustive list but merely a list that exemplifies types of materials that can be used.

[0059] The heat conduit 140 can suitable run along the sides of the crucible to collected the stored thermal energy. Alternatively, the heat conduit 140 can
15 circle around the crucible to ensure efficient transfer of thermal energy from the crucible 120. It will be clear to the person skilled in the art that different designs can be used to efficiently transfer heat from the heating elements 130 to the crucible 120, and from the crucible 120 to the heat conduit 140.

[0060] The liquid used in the heat conduit 140 is suitably water. Additives
20 such as ethylene glycol, diethylene glycol, propylene glycols, betain, hexamine, phenylenediamene, dimethylethanolamine, sulphur hexafluoride, benzotriazole, zinc dithiophosphates, nanoparticles, polyalkylene glycols or combinations thereof can be added to inhibit corrosion, alter the viscosity and enhance thermal capacity.

25 [0061] Referring to FIG 1a there is shown a cross-sectional view of another embodiment of the energy storage apparatus 100. For convenience, the numbering of the casing 110, the crucible 120, heating element 130, heat conduit 140, phase change material 150, thermal interface 160 and insulator 170 have been maintained as per FIG 1. The Applicant submits that these features
30 are as described herein for FIG 1.

[0062] This embodiment of the energy storage apparatus 100 comprises multiple crucibles 120, a heat conduit 140, multiple heating elements 130, multiple layers of thermal interface 160 and insulation 170. In one embodiment, the energy storage apparatus 100 comprises three crucibles 120. It will be appreciated that in between the three crucibles 120 are located heating elements 130, a heat conduit 140 and a thermal interface 160 to, as mentioned hereinabove, facilitate thermal energy transfer from the crucible (and the phase change material 150 therein) with the heating elements 130 and heat conduit 140. In one embodiment, the energy storage apparatus 100 comprises four heating elements. Additionally, heating elements 130 are also located on the outer side of the outer crucibles 120. These heating elements 130 are adjacent the outer side of the crucibles 120 to further supplement heat transfer to the crucible 120, and thus the phase change material 150 therein. In one embodiment, the heating elements are arranged in between the crucibles. In one embodiment, the heating elements 130 and heat conduit(s) are located substantially in between the crucibles 120.

[0063] During operation of this energy storage apparatus, the heating elements 130 provide thermal energy to the crucible 120 (and the phase change material 150 therein) through the thermal interface 160 such that the phase change material 150 stores the thermal energy (discussed hereinabove). The thermal energy collected by the phase change material 150 can then be reconverted to electrical energy by passing a liquid through the heat conduit 140, which absorbs thermal energy from the phase change material 150 and the crucible 120. The liquid is then converted to a gas which can then be passed through a turbine (not shown) to generate electricity. It will be appreciated that this embodiment is efficient as the heating conduit 140 can absorb thermal energy from multiple crucibles 120 and phase change materials 150, and this is particularly useful in making the energy storage apparatus smaller and more efficient. In one embodiment, the heat conduits are arranged in between the crucibles.

[0064] Additionally, this embodiment also allows for efficient transfer of thermal energy to the phase change material 150 by use of multiple heating

elements 130 located adjacent the crucibles 120. As previously mentioned, the heating element 130 is formed of a material that has a high thermal conductivity value, and as such facilitates thermal energy transfer from the crucible 120 and the phase change material 150 to the heat conduit 140. Finally, there is a layer of insulation 270 on the outer side of the outermost heating elements 130 to ensure that the casing 110 does not get hot and alleviates the problem of an operator burning themselves.

[0065] It will be appreciated that the above embodiment only exemplifies one energy storage apparatus 100 that comprises multiple crucibles and multiple heating elements. It will be appreciated by the person skilled in the art that the energy storage apparatus 100 may include additional crucibles, heating elements, heat conduits, and layers of thermal interface to provide an energy storage apparatus that has higher energy storage ability. The person skilled in the art will appreciate that the layout of the apparatus may also be changed so that there is efficient transfer of thermal energy from the heating elements to the crucibles and from the crucibles to the heat conduits.

[0066] Referring to FIG 2 there is shown a perspective sectional view of energy storage apparatus 200. To clearly depict the energy storage apparatus 200, FIG 2 does not depict the phase change material or the thermal interface, and only depicts casing 210, crucible 220, heating element 230, heat conduit 240 and insulation 270. The casing 210, the crucible 220, the heating element 230, the heat conduit 240 and the insulation 270 are as substantially described as the casing 110, the crucible 120, the heating element 130, the heat conduit 140 and the insulation 170 described hereinabove. The energy storage apparatus 200 depicted in FIG 2 has three layers of insulation, however, for convenience these three layers have been labelled as insulation 270.

[0067] Referring to FIG 2a there is shown a perspective section view of another embodiment of the energy storage apparatus 220. To clearly depict the energy storage apparatus 200, FIG 2a does not depict the phase change material. In this embodiment, the crucibles 220 are arranged in an array in a block of thermal interface 260. The crucibles 220 can be inserted into the thermal interface 260

such that they have a snug fit which allows for efficient thermal energy transfer. Also within the thermal interface 260 are located heating elements 230 which are substantially in between the crucibles 220. The heating elements 230 may also be inserted into preformed holes in the thermal interface 260. Additional heating elements 230 are located adjacent the thermal interface 260. These heating elements 230 provide thermal energy to the crucibles 220 through thermal interface 260. Multiple heat conduits 240 are located in the thermal interface 260 adjacent and in between the crucibles 220. This embodiment allows for multiple crucibles 220 to absorb thermal energy from the heating elements 230, whilst also allowing multiple heating conduits 240 to absorb thermal energy from the crucibles when reconvertng the thermal energy to electricity. In one embodiment, the heating elements 230 are located adjacent, or within, the thermal interface 260.

[0068] The outer heating elements 230 are surrounded by insulation 270 to ensure that the casing 210 does not get hot for the reasons presented hereinabove. In one embodiment, the energy storage apparatus 200 comprises an array of crucibles 220. The array may be in the form of a 3 x 3 array. It will be appreciated that any array can be used with the present invention. The array of crucibles 220 may be placed or formed in the thermal interface 260. In this regard, the crucibles 220 may be inserted into preformed holes in the thermal interface 260. In another embodiment, at least a portion of the heating elements 230 are formed in the thermal interface 260. In yet another embodiment, at least a portion of the heating elements 230 are inserted into preformed holes in the thermal interface 260. In an embodiment, the heat conduits 240 are located within the thermal interface 260 and adjacent the crucibles 220. In yet another embodiment, the heat conduits 240 are inserted into preformed holes in the thermal interface 260.

[0069] In one embodiment, the thermal interface 260 is present as a solid block. The thermal interface 260 may include preformed holes in which the crucible 220, heating elements 230 and heating conduit 240 may be formed or inserted. The thermal interface 260 may have a preformed array of holes for crucibles 220 to be inserted.

[0070] Referring to FIG 2b is shown the crucible 220 in a perspective sectional view of the crucible 220 and its positioning in the thermal interface 260. To clearly depict the energy storage apparatus 200, FIG 2a does not depict the phase change material.

5 [0071] In a second aspect, the invention resides in a method of storing and retrieving energy comprising the steps of:

a. providing an energy storage apparatus comprising:

a casing

at least one crucible;

10 at least one heating element adjacent the crucible;

at least one heat conduit, having an inlet and outlet, adjacent the crucible;

and

a phase change material located within the at least one crucible, the phase change material selected from the group consisting of aluminium-silicon alloys, aluminium, magnesium chloride, sodium chloride and potassium chloride;

15 b. heating the at least one heating element to cause a phase change in the phase change material, to thereby store energy;

c. introducing a liquid to the at least one heat conduit; and

20 d. converting the liquid to a gas through absorption of thermal energy stored in the phase change material; to thereby retrieve stored energy.

[0072] The energy storage apparatus is as substantially described in the first aspect and hereinabove.

25 [0073] As previously mentioned, electrical energy can be stored in the phase change material through the collection of thermal energy. The heating element converts the electrical energy to thermal energy which is transferred to the crucible and thus the phase change material. As the phase change material is heated it changes phase to store the thermal energy.

30 [0074] The thermal energy collected by the phase change material is then reconverted to electrical energy by passing a liquid through the heat conduit. The

liquid absorbs the thermal energy from the phase change material and is converted to a gas. This high pressure and high temperature gas is then passed through a turbine to generate electricity. Therefore, the stored thermal energy in the phase change material is retrieved as electricity.

5 [0075] The high pressure and temperature gas can be condensed and the residual/waste heat from the hot liquid can be used for co-generation and tri-generation to achieve a higher efficiency.

[0076] The present energy storage apparatus alleviates the problems of known storage systems which suffer from the disadvantage of significant thermal
10 energy loss to the surroundings. The present energy storage apparatus achieves this through the use of a phase change material which is able to store large amounts of energy without the accompanying increasing in temperature. Further to this, the present invention is able to efficiently transfer thermal energy from the heating element to the crucible, and from the crucible to the heat conduit,
15 through the use of a thermal interface.

[0077] The above description of various embodiments of the present invention is provided for purposes of description to one of ordinary skill in the related art. It is not intended to be exhaustive or to limit the invention to a single disclosed embodiment. As mentioned above, numerous alternatives and
20 variations to the present invention will be apparent to those skilled in the art of the above teaching. Accordingly, while some alternative embodiments have been discussed specifically, other embodiments will be apparent or relatively easily developed by those of ordinary skill in the art. Accordingly, this invention is intended to embrace all alternatives, modifications and variations of the
25 present invention that have been discussed herein, and other embodiments that fall within the spirit and scope of the above described invention.

CLAIMS

1. An energy storage apparatus comprising:

a casing;

at least one crucible;

at least one heating element adjacent the crucible;

at least one heat conduit, having an inlet and outlet, adjacent the crucible;

and

a phase change material located within the at least one crucible, the

phase change material selected from the group consisting of aluminium-silicon alloys, aluminium, magnesium chloride, sodium chloride and potassium chloride.

2. The energy storage apparatus of claim 1, wherein the phase change material is an aluminium-silicon alloy.

3. The energy storage apparatus of claim 2, wherein the aluminium-silicon alloy comprises between about 1% and about 30% aluminium.

4. The energy storage apparatus of any one of the preceding claims, wherein the crucible is selected from silicon carbide, graphite, reinforced polymer, clay, porcelain, ceramics, carbon nanotubes, aluminium nitride, aluminium oxide, boron nitride, silicon nitride, steel, copper, mullite, zirconium oxide, ductile iron, cast iron, stainless steel, brass, alloys of columbian, tantalum, molybdenum, tungsten or a combination thereof.

5. The energy storage apparatus of any one of the preceding claims, further comprising a thermal interface between the casing and the crucible.

6. The energy storage apparatus of any one of the preceding claims, wherein the thermal interface is selected from the group consisting of graphite and carbon nanotubes.

7. The energy storage apparatus of any one of the preceding claims, further comprising insulation.
- 5 8. The energy storage apparatus of claim 5, wherein the thermal interface is in the form a block comprising preformed holes for insertion of the at least one crucible, the at least one heating element and the at least one heat conduit.
- 10 9. The energy storage apparatus of any one of the preceding claims, comprising 1 to 9 crucibles.
10. The energy storage apparatus of any one of the preceding claims comprising 9 crucibles.
- 15 11. The energy storage apparatus of claim 10, wherein the crucibles are arranged in a 3x3 array.
12. The energy storage apparatus of any one of the preceding claims, wherein the heating elements are arranged in between the crucibles.
- 20 13. The energy storage apparatus of any one of the preceding claims, wherein the heat conduits are arranged in between the crucibles.
14. The energy storage apparatus of claim 7, wherein the insulation is located adjacent the casing.
- 25 15. The energy storage apparatus of claim 5, wherein the thermal interface is between the heating elements and the crucible.
- 30 16. The energy storage apparatus of claim 5, wherein the thermal interface is between the heat conduits and the crucible.
17. A method of storing and retrieving energy comprising the steps of:
- 35 a. providing an energy storage apparatus comprising:
a casing
at least one crucible;

at least one heating element adjacent the crucible;

at least one heat conduit, having an inlet and outlet, adjacent the crucible;

and

a phase change material located within the at least one crucible, the
5 phase change material selected from the group consisting of aluminium-silicon
alloys, aluminium, magnesium chloride, sodium chloride and potassium chloride;

b. heating the at least one heating element to cause a phase
change in the phase change material, to thereby store
energy;

10 c. introducing a liquid to the at least one heat conduit; and

d. converting the liquid to a gas through absorption of thermal
energy stored in the phase change material;
to thereby retrieve stored energy.

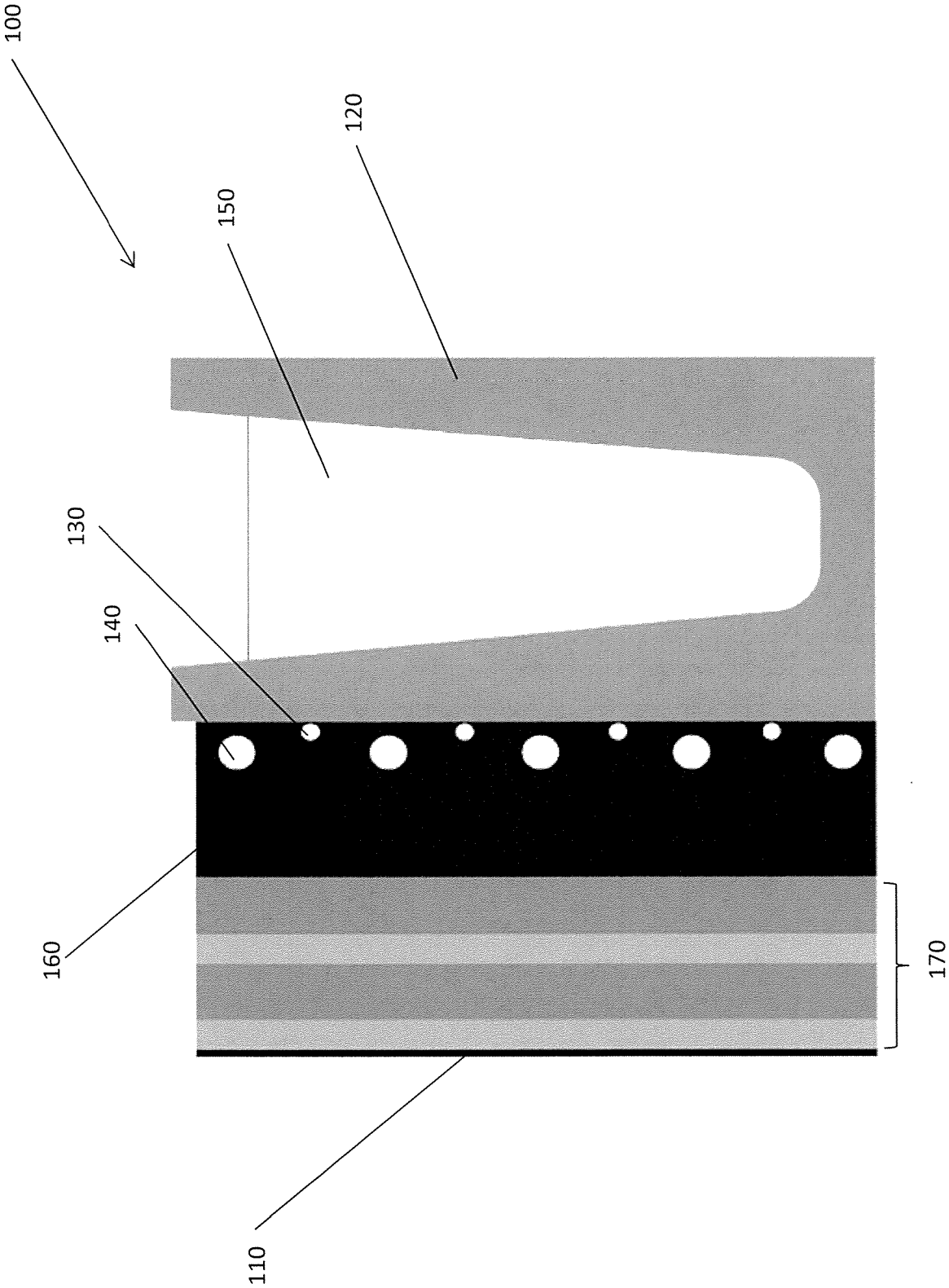


FIG 1

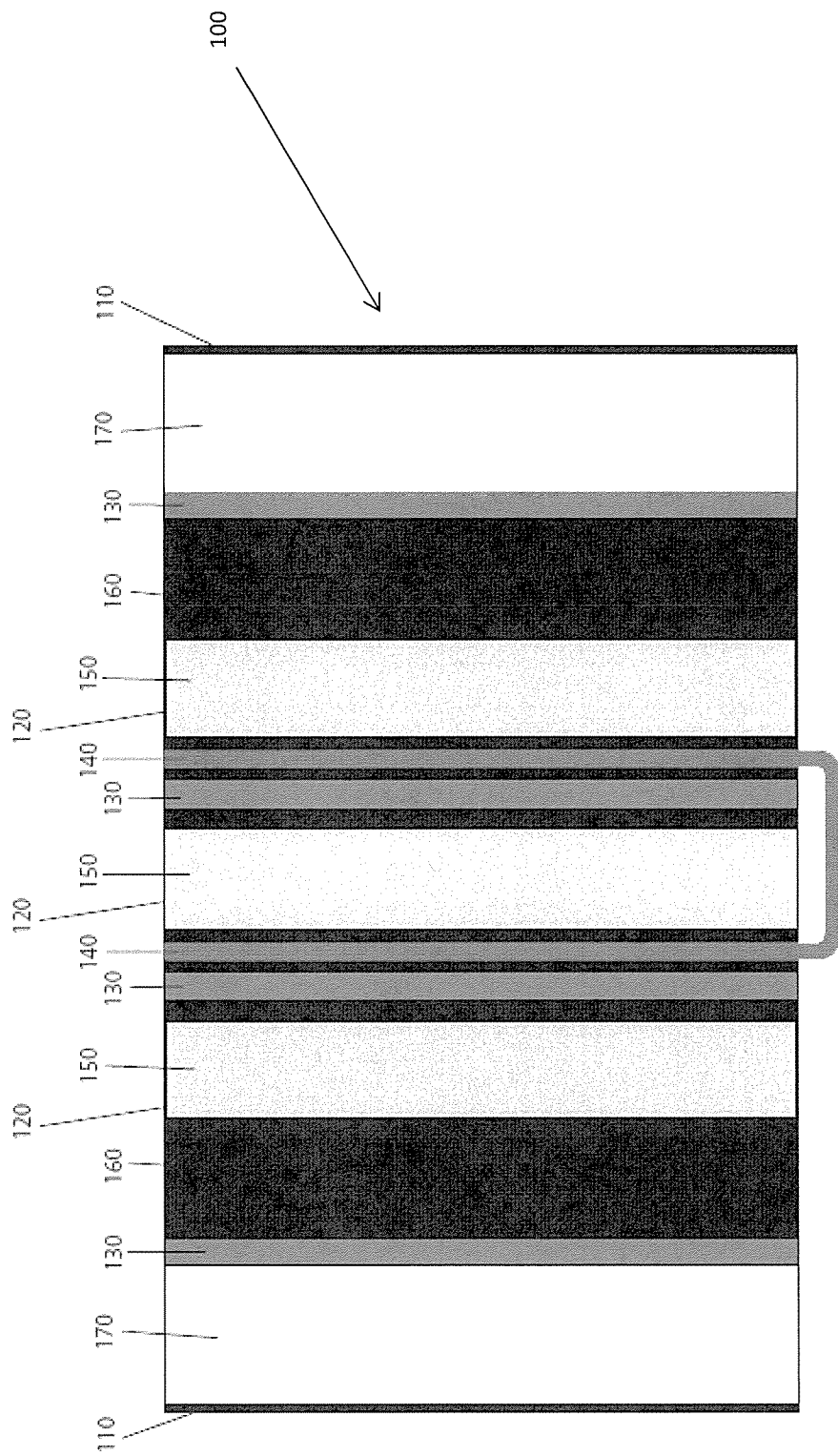


Fig 1a

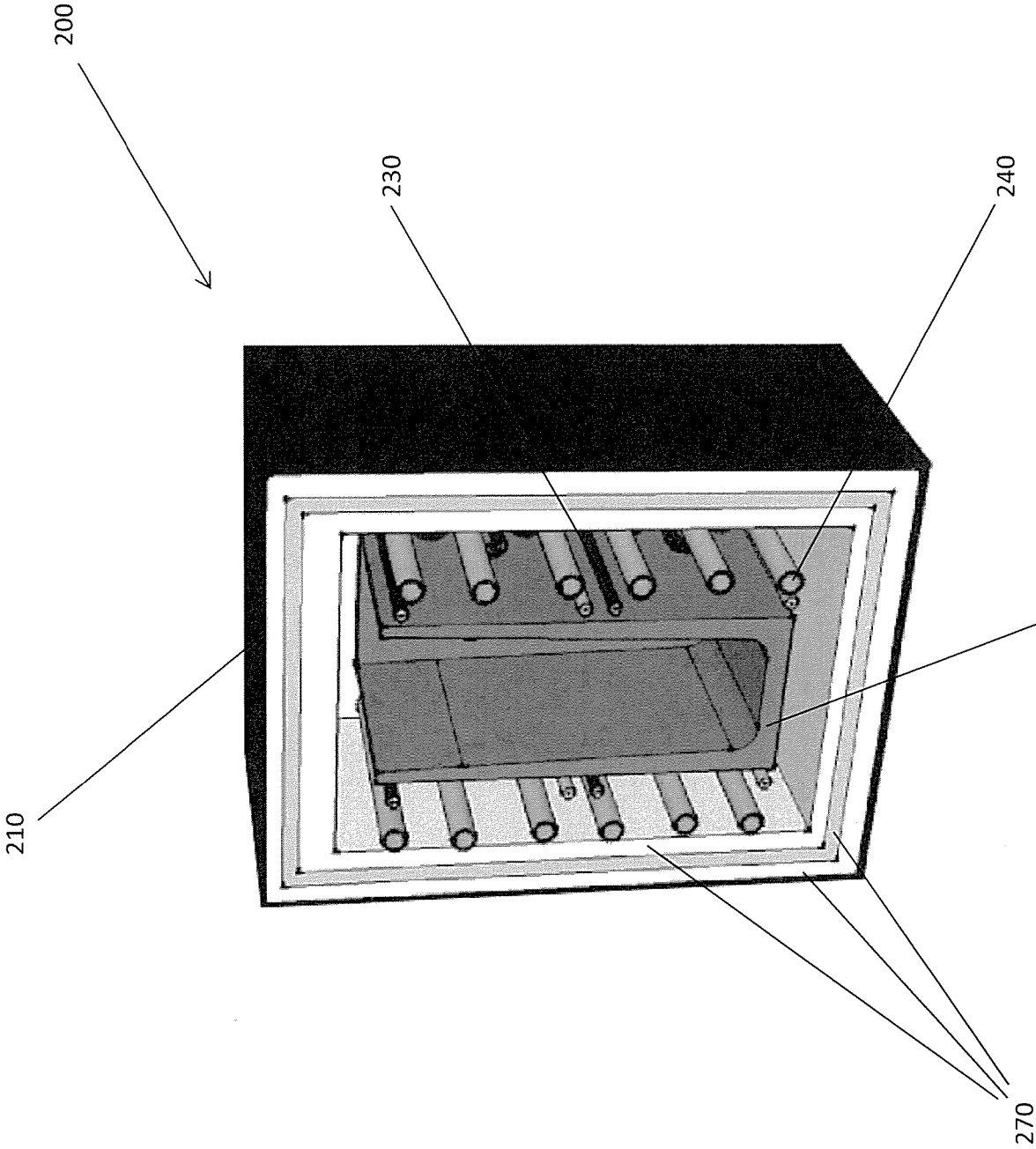


FIG 2

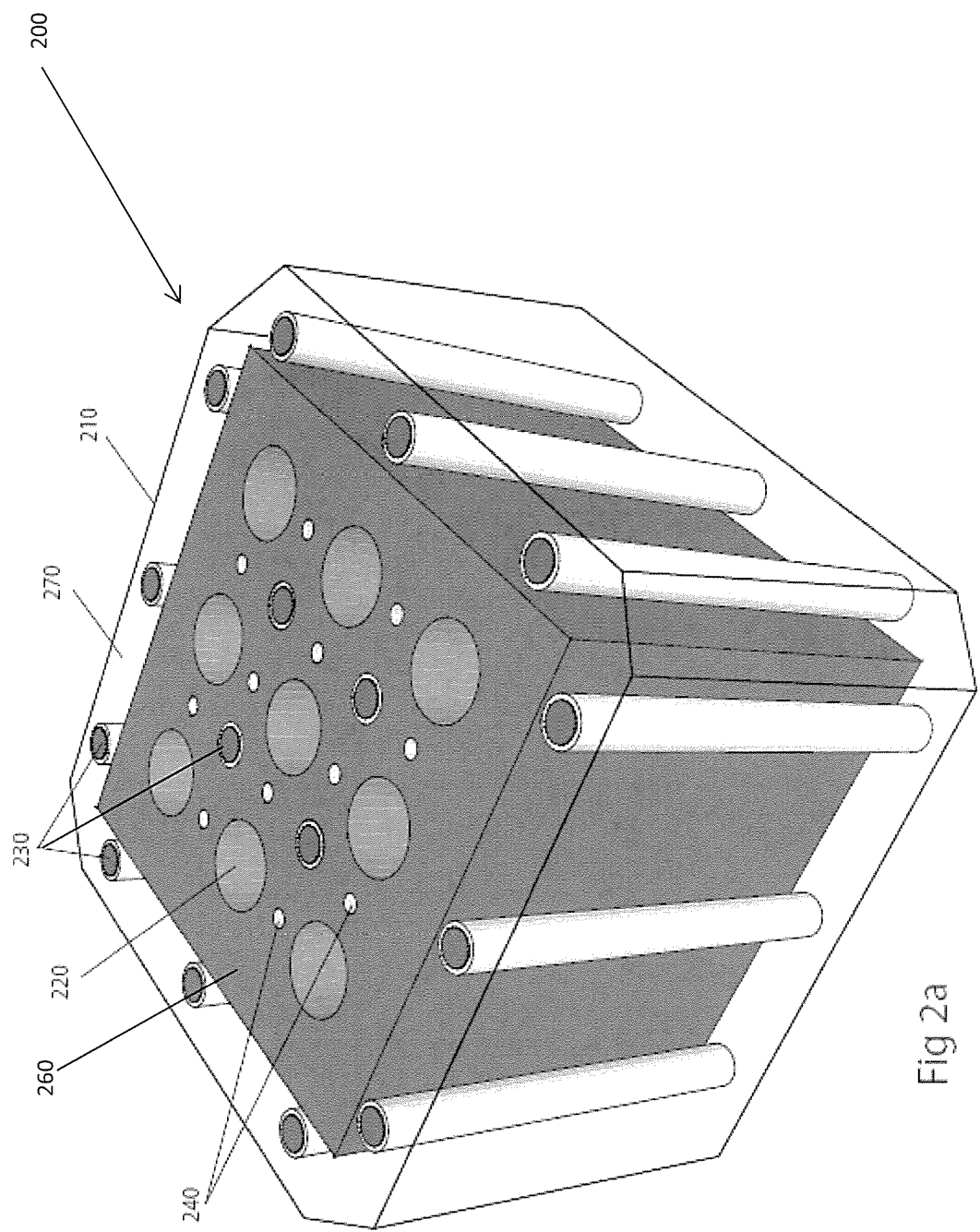
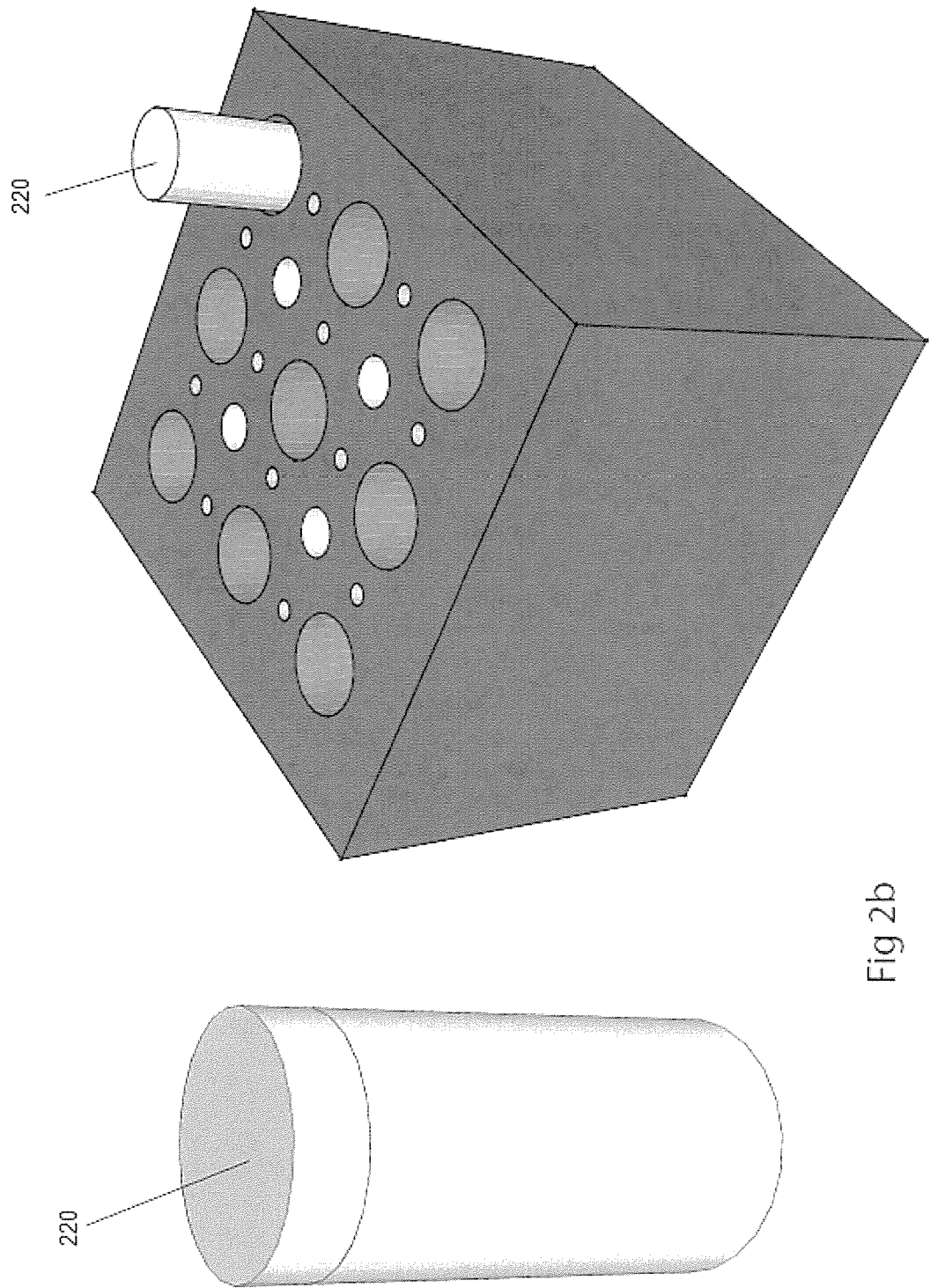
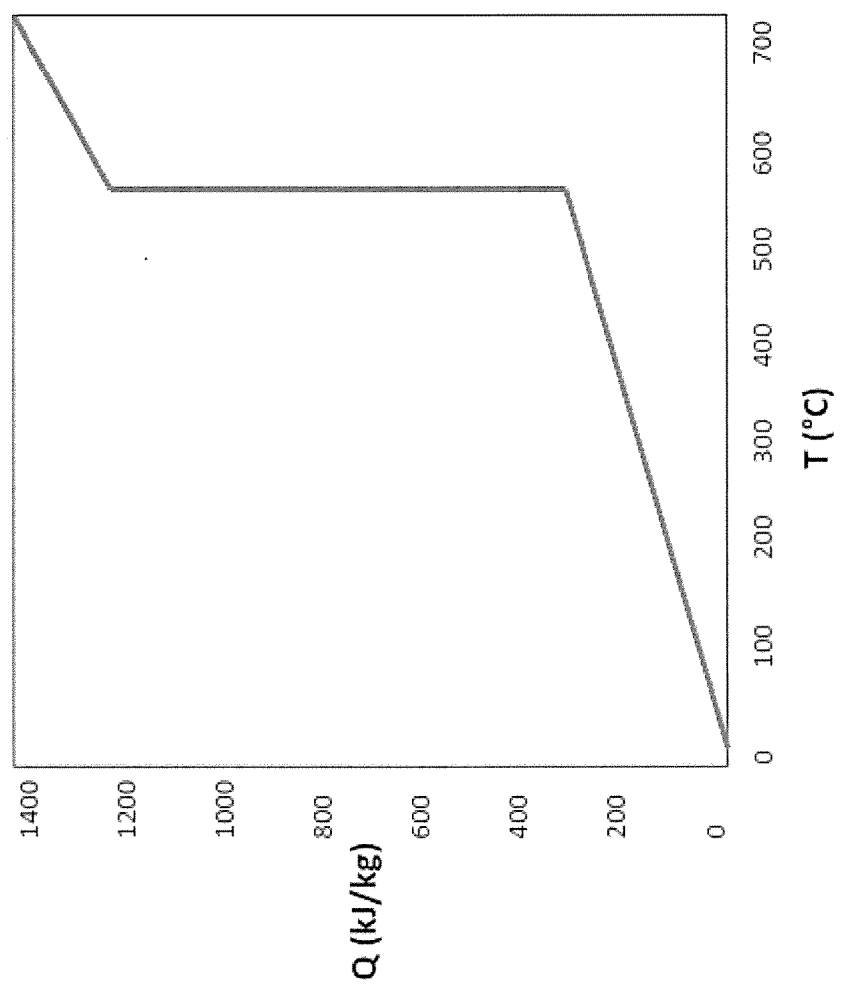


Fig 2a





Heat Storage capacity per Unit Mass of AlSi₁₂

FIG 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2017/050302

A. CLASSIFICATION OF SUBJECT MATTER

F28D 20/02 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Databases: Espacenet, Google, Google Patents, Google Scholar, EPODOC, WPIAP, TXPEA, TXPEB, TXPEC, TXPEE, TXPEF, TXPEH, TXPEI, TXPEP, TXPEPEA, TXPES, TXPUSE0A, TXPUSE1A, TXPUSEA, TXPUSEB, TXPW0EA. IPC/CPC Marks (and lower): F28D20/02, Y02E60/145, F28D2020/0047, C09K5/063, F22B1/06, F24H7/0208, F24H7/002, F22B1/06, F28D2020/0013. Keywords (along with synonyms and proximity operators): Aluminium, silicon, steam, heating element, phase change, freeze, melt, water pipe, extract, discharge. Applicant (THERMAPOWER) and inventor names (Avon Phillips, Wolfgang Klette, James Slade) were searched in Espacenet, Auspat and in internal databases provided by IP Australia

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	



Further documents are listed in the continuation of Box C



See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search 8 June 2017		Date of mailing of the international search report 08 June 2017	
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustalia.gov.au		Authorised officer Jason Schiemer AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. 0262832810	

INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/AU2017/050302
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/0110993 A1 (WHITTAKER et al.) 10 May 2012 [0011], [0017]-[0018], [0054], [0071], [0073]-[0074], [0090]	1-7, 9, 14-17
X	US 2016/0201996 A1 (VERDICORP, LLC) 14 July 2016 [0024], [0134], [0138], figures 14, 17-18	4
X	WO 2016/012573 A1 (MULLER & CIE) 28 January 2016 & EPOQUE used for English translation Page 5, lines 25-30, page 12, line 25 – page 13, line 4, page 15, lines 23-31, figure 5, claim 14	1-7, 9-13, 15-16
A	US 2014/0109895 A1 (MASSACHUSETTS INSTITUTE OF TECHNOLOGY and THE TRUSTEES OF BOSTON COLLEGE) 24 April 2014 Figures 6, 12A, 12B, 16, 25, [0043], [0048]-[0049]	1-17
A	US 2015/0253039 A1 (ERICKSON et al.) 10 September 2015 [0054], figure 1	2-3
A	US 2014/0216027 A1 (IIDA et al.) 07 August 2014 [0116]-[0120], table 4, figures 8, 15, 24	1-17
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INTERNATIONAL SEARCH REPORT		International application No.	
Information on patent family members		PCT/AU2017/050302	
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
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		ES 2544002 A2	26 Aug 2015
		ES 2544002 B1	06 Oct 2016
		WO 2014062464 A1	24 Apr 2014
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		WO 2012133790 A1	04 Oct 2012
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End of Annex			
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001. Form PCT/ISA/210 (Family Annex)(July 2009)			