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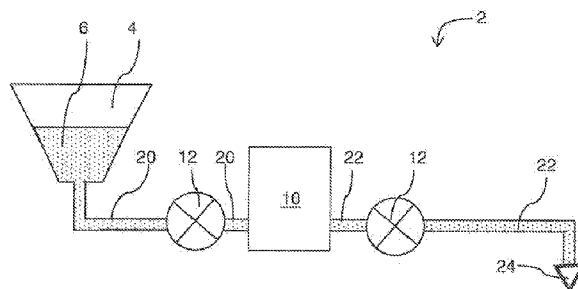


FIG. 1A

(57) Abstract: An apparatus (2), system and method (100) for dispensing thermal energy storage materials, such as phase change materials (6) as a liquid to make encapsulated pack (60) of such thermal energy storage materials for various applications.

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**APPARATUS, SYSTEMS AND METHODS FOR DISPENSING
PHASE CHANGE MATERIAL AS LIQUID**

CLAIM OF BENEFIT OF FILING DATE

[0001] The present application claims the benefit of the filing date of U.S. Provisional Application Serial No. 61/472,448, filed on April 6, 2011, which is hereby incorporated by reference for all purposes.

FIELD OF THE INVENTION

[0002] The present invention relates to a method and a system for dispensing thermal energy storage materials (i.e., TESM), such as phase change materials (i.e., PCMs), as a liquid to produce an article (i.e., "a pack") with the TESM encapsulated in the article. The pack may be used for various automotive and non-automotive applications. For example, the pack may be used in a device for storing heat in a vehicle.

BACKGROUND OF THE INVENTION

[0003] Thermal energy storage materials (TESMs) are known and have been used in applications for storing heat for subsequent use. Many TESMs are PCMs, meaning they undergo a phase change, typically between solid state and liquid state, and can store (or release) a considerable amount of the heat, regarded as latent heat from the phase change. Much attention has been devoted toward heat storage devices that contain TESMs, and use of the TESMs to store and discharge thermal energy. Some of these devices have been called "heat batteries." U.S. Patent Nos. 7,225,860; 6,784,356; and 6,102,103 provide some examples of heat batteries. Heat batteries have been proposed for use in a number of applications. For example, U.S. Patent No. 6,875,407 purports to use a vacuum insulated heat battery for improving catalytic efficiency. Other applications are identified, for example, in U.S. Patent Nos. 6,102,103 (addressing engine warming, defrosting, or passenger compartment heating).

[0004] Despite efforts to develop such heat storage devices, it is observed that their structures may vary, dependent upon such factors as the desired operating temperatures to which the systems are exposed, the desired rate of heat exchange, the nature of the TESM employed or others. One particular respect in which heat storage devices vary is in the structures employed for containing the TESM. Another is in the manner in which individual containers that holds the TESM interface with any other such containers to afford a desired heat exchange response.

[0005] U.S. Patent No. 7,225,860 purports to depict the use of encapsulation tubes to hold

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TESM. U.S. Patent No. 6,102,103 purports to depict a jacket to contain TSM.

[0006] An example of an array of capsules carried on a common planar carrier has been offered by a company named Rubitherm GmbH, using a designation CSM Panel. It is believed that those structures, while potentially suitable for paraffin or hydrated salt TESMs, which tend to find utility at relatively low operating temperatures, may be not be suitable for applications subject to more rigorous conditions. In use, it appears that the CSM panels are stacked relative to each other in a housing to define modules through which a heat exchange fluid is passed.

[0007] Efforts to achieve good results from an encapsulation technique may further be complicated based upon the application under consideration. For example, some TESMs are very corrosive. Some TESMs will only function over a limited temperature range. Some encapsulation techniques are not sufficiently robust to withstand repeated thermal cycling.

[0008] To create an efficient thermal energy storage device of TSM such as PCM, an efficient means to dispense the material into the container, e.g. encapsulated container, is also needed. By dispensing the PCM in its liquid state, it enables a few key advantages. For example, the dispensing process would be a relatively clean process. The process will release the absorbed moisture in the PCM from the material before encapsulation. The process also allows for precise metering of the dispensed amount of PCM.

[0009] To dispense the PCM as a liquid, the temperature must be raised above such PCM's melting point, T_m . Typical PCMs are a mixture of various salts as disclosed in U.S. Patent Publication No. 20090211726. For some PCMs that exhibit high thermal energy density, T_m can be 200°C or greater. There are few, if any, known dispensing systems that are able to function over long periods of time at such high operating temperatures. Most common seal materials start to degrade at temperatures above 200°C. In addition, since the PCM will abruptly solidify if any cooler than T_m areas are present in the system, this provides additional difficulty in designing a dispensing system. Furthermore, the system must withstand the corrosive nature of PCMs. Due to the low viscosity of the molten PCMs, additional precautions are needed to prevent unwanted dripping of the liquid PCM out the dispensing end of the system, e.g. nozzle. Check valves must work at these high temperatures and within the corrosive environment of the molten salt. There are many other requirements for the system that must be met for the application to function properly.

[0010] Previous needs for filling cavities with a PCM having a high melting temperature have generally been met using methods that dispense the PCM in a solid form. Attempts to fill cavities with such PCM in a liquid state have been frustrated by problems in maintaining a seal in a pump, difficulties caused by the PCM freezing, problems caused from solid materials that

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block the flow of the PCM, problems in precisely pumping a desired volume of PCM, problems with leaking of low viscosity PCMs from an nozzle, problems with corrosion of components of the pumping equipment, and problems with PCM contaminating a surface that needs to be sealed. Such problems are further compounded when the PCM is corrosive and/or when a small cavity needs to be filled with a large amount of PCM. As such, packs including these PCMs that are mechanically filled, have generally been restricted to having cavities having large volumes and/or generally low concentrations of PCM in the cavity, such as may be achieved using solid phase dispensing. The problem of PCM contaminating a surface may result in an inability to form a durable seal of the cavity. Such contamination may occur while filling the cavity or while moving the pack. It has been found that even small amounts of the PCM on a surface being sealed may result in failure of the seal during use of a pack in a heat storage device. Such a leakage may reduce the efficiency of the device, block the flow of a heat transfer fluid, contaminate a heat transfer fluid, or possibly cause corrosion to various components in a heat storage system.

[0011] There is a need for apparatus, systems, and methods for solving one or more of these problems. For example there is a need for apparatus and systems that include one or more of the following features: improved sealing of a liquid PCM dispensing apparatus, improved corrosion resistance of a liquid PCM dispensing apparatus, prevention of solid particle blockage in a liquid PCM dispensing apparatus, improved dosing capabilities of a liquid PCM, and improved systems and methods for avoiding contamination of a surface with a PCM. By solving one or more of these problems, it may be possible to produce packs with higher concentrations of PCM, produce packs that have smaller cavities filled with PCM, produce cavities with more precise amounts of PCM, dispense PCM as a liquid, produce packs that are more durable, or any combination thereof.

SUMMARY OF THE INVENTION

[0012] The present invention provides an efficient TESM dispensing apparatus and system that may withstand the high temperature and corrosive environment needed to melt and pump the TESM in liquid form. For example, the dispensing apparatus and system may be capable of dispensing a TESM that is a molten salt, a molten PCM, or both. The dispensing apparatus and system may enable a precise amount of PCM to be dispensed in a controlled fashion.

[0013] One aspect of the invention is directed at an apparatus comprising a container for storing a phase change material; a dosing device in fluid communication with the container and capable of pumping a predetermined volume of the phase change material, wherein the dosing

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device is downstream of the container; one or more seals capable of maintaining a seal at a temperature of about 200 °C, so that the phase change material does not leak out of the apparatus, wherein at least one seal is in contact with the phase change material; a discharge opening for discharging the phase change material into a cavity of a pack, wherein the discharge opening is in fluid communication with the dosing device and downstream of the dosing device; and one or more heating components that provide sufficient heat for maintaining the phase change material in a liquid state between the container and the discharge opening; wherein the apparatus is capable of dispensing a liquid phase change material at a temperature of about 200 °C or more.

[0014] Another aspect of the invention is directed at an apparatus for dispensing a phase change material wherein the phase change material has a liquidus temperature of about 200 °C or more; the phase change material includes a substantially anhydrous metal salt that includes a nitrate; the phase change material includes a substantially anhydrous metal salt that includes a nitrite; or any combination of (i), (ii) and (iii).

[0015] Another aspect of the invention is a system comprising a dispensing apparatus, such as a dispensing apparatus according to the teachings herein; a fixture for holding a pack, wherein the pack includes a fill opening for receiving the phase change material from the exit opening of the apparatus, and the fixture holds the pack in a fixed position with the fill opening at the top; a devices for sealing the fill opening of the pack by sealingly attaching two facing surfaces near the fill opening; and one or more mechanical or robotic devices for removing the exit opening from the region of the fill opening and for bringing the sealing device to the region of the fill opening, so that the pack can be filled and sealed in subsequent steps without the need for moving the pack prior to the sealing step and so that splash of the phase change material onto one of the facing surfaces in the sealing region during such a moving step is avoided.

[0016] A method related aspect of the invention is directed at a process for dispensing a phase change material comprising the steps of: heating the phase change material to a temperature of about 200 °C or more so that the phase change material is in a liquid state; wherein the phase change material includes a metal salt, and wherein the phase change material has a liquidus temperature of about 120 °C or more; pumping the phase change material into a metal pack having a cavity by flowing the phase change material through a fill opening of the metal pack, so that a cavity is filled with a predetermined volume of the phase change material; and sealingly attaching the metal of the pack in the region of the fill opening so that the phase change material in the cavity is sealed from the outside of the pack; wherein the

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step of filling and the step of sealing are performed without moving the pack, so that a complete and durable seal is produced without phase change material in the entrapped at the location of the seal.

[0017] As discussed herein, the various aspects of the invention may be used to solve one or more of the aforementioned problems using improved liquid PCM dispensing apparatus, using an improved system, and/or using an improved process. For example, the apparatus may include features that improve the capability of delivering precise amounts of the PCM, that improve the capability of filling a cavity with high concentrations of PCM, that improve the durability of the packs, that prevents blockage in the apparatus, or any combination thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The present invention is further described in the detailed description which follows, in reference to the noted plurality of drawings by way of non-limiting examples of embodiments of the present invention, in which like reference numerals represent similar parts throughout the several views of the drawings, and wherein:

[0019] FIG. 1A, FIG. 1B, and FIG. 1C are schematics drawings illustrating some of the components that may be employed in a PCM dispensing apparatus.

[0020] FIG. 2 is a cross-sectional view of a pack having a cavity during a step of filling the cavity with PCM.

[0021] FIG. 3A and FIG. 3B are cross section views showing a portion of an illustrative dosing device including a piston and cylinder arrangement at two times in a dosing cycle.

[0022] FIG. 3A and FIG. 3B are cross section views showing a portion of an illustrative dosing device including a piston and cylinder arrangement at two times in a dosing cycle.

[0023] FIG. 4A and FIG. 4B are cross section views showing a portion of an illustrative dosing device including a tube and cylinder arrangement at two times in a dosing cycle.

[0024] FIG. 5A is a schematic drawing illustrating features that may be employed in a PCM dispensing apparatus.

[0025] FIG. 5B is a schematic drawing illustrating features that may be employed in a PCM dispensing apparatus

[0026] FIG. 6A is a drawing illustrating features of steps that may be employed in a process of dispensing liquid PCM and /or preparing a pack with PCM sealed in a cavity.

[0027] FIG. 6B is another drawing illustrating features of steps that may be employed in a process of dispensing liquid PCM and /or preparing a pack with PCM sealed in a cavity.

DETAILED DESCRIPTION OF THE INVENTION

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[0028] In the following detailed description, the specific embodiments of the present invention are described in connection with its preferred embodiments. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present techniques, it is intended to be illustrative only and merely provides a concise description of the exemplary embodiments. Accordingly, the invention is not limited to the specific embodiments described below, but rather; the invention includes all alternatives, modifications, and equivalents falling within the true scope of the appended claims. The present invention is further illustrated by the figures.

[0029] The invention is generally directed at apparatus, systems and methods for dispensing phase change materials in a liquid state at generally high temperatures, such as above 200 °C or more. Prior methods for filling cavities with these materials have generally focused on dispensing the materials in a solid state. Despite the problems with reliability in feeding these materials in the solid state and the generally low fill factors obtainable with solid state feeding, such solid state feeding continues to be employed due to the lack of equipment for the liquid dispensing of these materials and/or due to processing difficulties which need to be overcome when handling these materials in a liquid state. The teachings herein show improvements in the apparatus, systems, and processes so that one or more of the difficulties in dispensing molten PCM are overcome.

[0030] Some of the key components which may be used in an apparatus for dispensing a molten PCM are shown in FIG. 1A. The dispensing apparatus 2 may include a container 4 suitable for containing molten PCM 6. Although the PCM may be provided to the container in a solid or liquid form, the container should be capable of heating the PCM and/or maintaining a sufficiently high temperature so that when the PCM flows out of the container it is in a molten state. It will be appreciated that the container may be divided into a plurality of containers. For example, the apparatus may have a container for melting the PCM, a container for drying the PCM, a container for maintaining a reservoir of PCM for the dispensing apparatus, or any combination thereof. The container 4 is upstream from and in fluid communication with a dosing device 10. The fluid communication between the container 4 and the dosing device 10 may include one or more transfer lines 20 for flowing the PCM from one component to another. The fluid communication between the container 4 and the dosing device 10 may be interruptible, such as by closing a valve 12. The apparatus generally includes a discharge component 24 positioned downstream of the dosing device 10 and in fluid communication with the dosing device. The fluid communication between the dosing device 10 and the discharge component 24 may include one or more transfer lines 22 for flowing the PCM from one component to

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another. The fluid communication between the dosing device 10 and the discharge component 24 may be interruptible, such as by closing a valve 12 positioned between the dosing device and the discharge component. As illustrated in FIG. 1B and 1C, the dispensing apparatus may employ a transfer line 20, 22, that is a flexible transfer line 18. Such a flexible transfer line may make one or more portions of the apparatus become more mobile.

[0031] Each of the components in FIG. 1A may have one or more surfaces that contact the molten PCM. As such, it is necessary for these surfaces to be resistant to corrosive attack from the PCM and for the components to be able to withstand the high temperatures required for pumping the PCM in a liquid state. Corrosion resistant materials should be used when contact with liquid PCM is unavoidable. Suitable corrosion resistant materials include materials that do not corrode after being in contact with the molten PCM for about 554 hours or more, and preferably for about 1008 hours or more. The corrosion resistant material may be a corrosion resistant metal, such as stainless steel or titanium. Such materials may be particularly useful for surfaces of components that contact the PCM and also need a generally high strength. Other nonmetallic materials that may be used include a fluoropolymers, graphite, carbon fibers, other material consisting only of carbon atoms, and boron nitride. It will be appreciated that a corrosion resistant surface may be provided by a coating or laminate on a material that otherwise has insufficient corrosion resistance.

[0032] The apparatus for dispensing PCM may be used for filling one or more cavities with the PCM. FIG. 2 is a cross-sectional view illustrating feature of a step of filling 110 a cavity 62 of a pack 60 with liquid PCM 6. The pack 60 has a fill opening 66 for receiving the PCM 6 and at least partially filling the cavity 62. The fill opening 62 preferably is oriented so that the PCM 6 can fill the cavity 64 by gravitational forces without flowing out of the fill opening. A preferred pack 60 is formed from two or more encapsulant sheets 64, which may be metal or otherwise. The pack 60 may have regions that are already sealed 76, such as regions where two encapsulant sheets 64 have been sealingly attached. The pack may include one or more regions 67 that will be sealed, such as in a step subsequent to the step of filling 100 the cavity. During such a sealing step, two facing surfaces 68, 68' in regions to be sealed 67 may be sealingly attached. Preferably, the pack is sufficiently heated prior to and/or during the filling step, so that the PCM remains in a liquid state during the filling step. During the filling step, the PCM may flow through a transfer line 22 from a dosing device to a discharge component 24. The discharge component may be a nozzle. The discharge component 24 has one or more exit openings 25 for flowing the PCM out of the discharge component. The step of filling 110 results in the cavity 62 becoming a cavity that is at least partially filled 70 with the PCM 6. According to

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the teachings herein, it may be particularly desirable to reduce or even completely avoid any contacts between the PCM 6 and the surfaces 68, 68' in the regions to be sealed 67.

[0033] The dosing device preferably includes one or more seals that sufficiently seals the space between two metal surfaces so that the PCM from leaking out of the dosing device. The seals should generally allow one of the metal surfaces to slide relative to the other surface so that the liquid PCM can be pumped by the dosing device. The seal should be made of a material capable of functioning (e.g., providing sealing and/or sliding capabilities between two surfaces) at the temperatures required to maintain the PCM in a liquid state. For example, the material of the seal should be capable of functioning at a temperature of about 200 °C or more, about 220 °C or more, about 240 °C or more, about 260 °C or more, about 280 °C or more, or about 300 °C or more. Preferably, the seal is made of a material having good corrosion resistance so that the material generally does not react (e.g., does not corrode and/or does not degrade) from a contact with molten PCM material. Although some amounts of reaction with the molten PCM may be tolerated, the rate of corrosion and/or degradation should be sufficiently small so that the seal can function for a generally long time at the required dispensing temperature. Suitable seals may be capable of function for about 1 week or more, about 1 month or more, about 1 year or more, or about 3 years or more. Suitable seals may be capable of functioning at a temperature above the melting temperature of the PCM, such as a target dispensing temperature.

[0034] It will be appreciated that material used in the seals of the dosing device may be used in other seals in the apparatus, or in other components of the apparatus where such high temperatures will be encountered.

[0035] The material of the seal may be a material having substantially a single phase, or a composite material including two or more phases and/or two or more structures. Examples of materials that may be used for the seal include materials that are generally free of hydrogen, or entirely free of hydrogen. Such materials preferably include hydrogen at a concentration of about 1 atomic % or less, more preferably about 0.2 atomic % or less, and most preferably about 0.1 atomic % or less. By way of example, the seal may include or consist essentially of a graphite, a carbon fiber, a boron nitride, a fluoropolymer, or a mixture thereof. Carbon fibers may be in any form, such as a woven fabric or a nonwoven mat. The boron nitride preferably is a hexagonal boron nitride. Other materials that may be used in the seal include reinforcing materials. Such reinforcement material may be particulates (e.g., having an aspect ratio of 5 or less), platelets (e.g., having an aspect ratio greater than 5), or fibers (e.g., having an aspect ratio greater than 5), or a combination thereof.

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[0036] The fluoropolymer preferably is sufficiently compliant so that it can act as a seal, has a sufficiently low coefficient of friction so that a metal surface can easily slide over it, or both. Preferred fluoropolymers are characterized as fluoroelastomers, perfluoropolymers, or both (e.g., a perfluoroelastomer). The fluoroelastomer preferably is sufficiently elastomeric so that the seal deforms substantially entirely in an elastic manner while being used as a seal in the dosing device. Particularly preferred fluoropolymers consist substantially of, or entirely of carbon and fluorine atoms. Examples of fluoroelastomer that may be used include Kalrez™ brand fluoroelastomer which is commercially available from E. I. du Pont de Nemours and Company.

[0037] An example of a composite material that may be employed in the seals is a composite including a first phase that is relatively hard phase and a second phase that is relatively soft and/or elastomeric relative to the first phase. Suitable composites include composites having phases in a layered arrangement including one or more layers of the first phase and one or more layers of the second phase; composites having a coated structure including one phase coated with the other phase; composites having a dispersed structure with one phase dispersed in the other phase; composites in which the two phases are co-continuous, or any combination thereof. The relatively hard phase, which may be a dispersed phase, a substrate phase, or otherwise, may include or consist essentially of graphite, carbon fiber boron nitride or any combination thereof. The relatively soft phase may include or consist essentially of a fluoropolymer. Preferably the relatively soft phase includes a fluoroelastomer or a perfluoroelastomer. Composite material may have a particularly good combination of high stiffness (e.g., due to the relatively hard phase) and high elasticity (e.g., due to the relatively soft or elastomeric phase).

[0038] The seals may be employed between two surfaces that move or slide relative to each other, such as a seal 40 between an inner surface 42 of a cylinder 52 and an outer surface 44 of a piston 54 (see e.g., FIG. 3A), or a seal 40 between an inner surface 42 of a cylinder 52 and an outer surface 44 of a tube 54' (see e.g., FIG. 4A).

[0039] The seal may have any shape that is i) capable of forming a seal between two components; ii) allows for the relative movement of the two components; or both. The size of the seal should be sufficiently small so that it can be assembled into the space between the two components. It will be appreciated that one of the components, such as a cylinder, a tube, or a piston, may have a groove, flange, recess or other feature suitable for receiving the seal. The seal may have an initial shape that does not seal the space between the two components. However, when a compressive force is applied to the seal, the seal may be sufficiently flexible that it contacts the surfaces and forms a tight seal. Such a compressive force may be applied by

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any suitable means. For example a compressive force may be applied by a spring, a washer, a screw, or any combination thereof. A force distributing component may be employed for more uniformly distributing the compressive force on the seal. The force distributing component may contact a perimeter of the seal so that compressive force is distributed throughout the seal. By way of example, the force distributing component may be a plate, ring or other shape capable of spreading a force over a larger area and/or applying a force more uniformly over an area.

[0040] The dosing device generally includes an inner dosing component having a portion that is capable of moving into and out of a cavity of an outer dosing component, such as by the motion of a piston in a cylinder or by the motion of a hollow tube in a cylinder. In a first position, such as a closed position, the inner dosing component may be inserted into the cavity of the outer dosing component so that the total volume of space in the cavities of the inner dosing component and the outer dosing component available for holding the molten PCM, is relatively low. In a second position, such as an open position, the inner dosing component may be more withdrawn from the cavity of the outer dosing component so that the total volume of space in the cavities of the inner dosing component and the outer dosing component available for holding a molten PCM is relatively high. The operation of the dosing device may include a step of charging the dosing device by moving from a first position to a second position in which PCM flows into the cavity of the outer dosing component. During the charging step, PCM may flow out of a reservoir containing the PCM. The operation of the dosing device may include a discharging step in which the PCM flows out of the cavity of the outer dosing component so that a predetermined volume of PCM is delivered to one or more cavity of a pack.

[0041] The surfaces of the inner dosing component and the outer dosing components should be made of materials that are generally corrosion resistant, such as described hereinbefore, or have a sufficient coating so that the surface does not corrode when in contact with the molten PCM. Particularly preferred materials for the inner dosing component, the outer dosing component, or both, include stainless steel and titanium.

[0042] FIGs. 3A and 3B illustrate features that may be employed in a dosing device according to the teachings herein. The dosing device may include an outer dosing component 52 and an inner dosing component 54. The outer dosing component may be a cylinder and the inner dosing component may be a generally solid piston 54, such as illustrated in FIG. 3A. The outer dosing component 52 includes a cavity 53 suitable for holding liquid PCM 6. In FIG. 3A, the dosing components 52, 54 are in a closed position 57 compared to the relatively open position 58 of the dosing component in FIG. 3B. By closing the dosing components 52, 54, a volume of PCM 6 may be displaced, as shown in FIG. 3B by the displacement volume 50. The

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dosing device may include one or more seals 40 that sealingly contact the surfaces of the dosing components 52, 54. One of the dosing components 52, 54, may include a flange, groove, or other recess capable 45 positioning the seal. The dosing component may include a compression ring 46 capable of distributing a compressive force along one or more seals 40. The dosing component may include one or more, preferably 2 or more, and more preferably 3 or more compression screws 48 capable of adjusting the compressive force being applied to one or more seals 40. For example, by loosening a screw 48, the resistance to moving the inner dosing component 54 relative to the seal 40 may be reduced. By tightening a screw 48, the ability of the seal 40 to prevent leakage of the PCM past the seal 40 may be increased.

[0043] FIGs. 4A and 4B illustrate features that may be employed in a dosing device according to the teachings herein. The dosing device may include an outer dosing component 52 and an inner dosing component 54'. The outer dosing component may be a cylinder and the inner dosing component may be a generally hollow tube 54', such as illustrated in FIG. 4A. The outer dosing component 52 includes a cavity 53 suitable for holding liquid PCM 6 and the inner dosing component also contains a cavity 55 suitable for holding liquid PCM 6. In FIG. 4A, the dosing components 52, 54' are in a closed position 57 compared to the relatively open position 58 of the dosing component in FIG. 4B. By closing the dosing components 52, 54', a volume of PCM 6 may be displaced, as shown in FIG. 4B by the displacement volume 50.

[0044] The dosing device preferably includes a driver for moving the inner dosing component relative to the outer dosing component. It will be appreciated that the inner dosing component or the outer dosing component may be fixed. However, at least one of the components should be movable with respect to the other. While the device and process may be described by the movement of one of the inner or outer dosing components, it will be appreciated that the other dosing component may be the component actually being moved. Suitable drivers for use in the dosing device include a driver capable of mechanically moving the inner dosing component from a predetermined first position to a predetermined second position. The driver may be an actuator. The driver may use any suitable source of power, such as pneumatic power, hydraulic power, electric power, spring power, or any combination thereof. A particularly preferred driver is an electric actuator. The driver may move the inner dosing component inside the outer dosing component so that PCM is drawn into or expelled from the dosing device. The inner dosing component may move along a generally axial direction, however other types of motion may also be used. By way of example the inner dosing component may function similar to a syringe style piston. The cross-sectional area of the inner dosing component in the direction normal to the axis of the inner dosing component and the

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precise axial movement or displacement of the inner dosing component, such as by the actuator, will determine the volume of PCM dispensed. The driver may be made of, or include a material having low thermal conductivity so that the driver is thermally isolated from the inner dosing component and the outer dosing component. Such a thermal isolation may prevent damage to the driver from heat. Alternatively, the distance between the cavity of the dosing device containing the PCM may be separated from the driver by a sufficiently long distance so that heat being conducted towards the driver is mostly lost, such as to the environment. For example an inner dosing component may be sufficiently long so that the portion that contacts the driver has a low temperature that will not damage the driver.

[0045] The cavity of the outer dosing component may be in fluid communication with a reservoir of liquid PCM upstream of the dosing device, with a discharge nozzle downstream of the dosing device, or both. If the inner dosing component is a hollow tube, it may function as either an inlet or an outlet to the outer dosing component. If the inner dosing component is a piston, the outer dosing device may have an inlet and an outlet, where the PCM does flow through the inner dosing component.

[0046] The apparatus may include one or more valves which may independently be in the dosing device or external to the dosing device. Preferably the apparatus includes one or more valves located downstream (i.e., towards the discharging end of the apparatus) of the outer dosing component. Such a valve may be in a closed position while charging the dosing device so that only material upstream of the dosing device is drawn into the cavity of the outer dosing component. Such a valve may be in an open position while discharging the dosing device so that PCM can flow downstream from the cavity. The apparatus may include one or more valves located upstream of the outer dosing component. Such a valve may be in an open position while charging the dosing device so that molten PCM can be drawn into the cavity from upstream of the outer dosing component. Such a valve may be in a closed position during a step of discharging the dosing device so that the PCM only flows downstream during the discharge step and so that the desired volume of PCM is discharged. These upstream and downstream valves may be any valves capable of controlling the flow. When the inner dosing component is moving, one of these valves will be open and one of these valves will be close. Preferred valves are check valves. Any suitable check valve that allows for flow in only one direction may be used. For example, the check valve may include a construction including a ball, a spring, or both. Alternatively, the valves may be mechanically opened and closed. For example, the mechanical opening and closing of the valves may be controlled by a controller and/or synchronized with the control of a driver, a shut-off valve, or both.

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[0047] The apparatus may have one or more discharge components capable of discharging the molten PCM at the downstream end of the apparatus. The discharge component has one or more exit openings. The molten PCM generally exits the apparatus through the one or more exit openings. A discharging component may include or consist essentially of a nozzle having an exit opening.

[0048] The discharging component may be employed for filling a cavity of a pack with a predetermined volume and/or a predetermined weight of the liquid PCM. The pack may have a fill opening capable of receiving the liquid PCM for filling the cavity. The discharge component preferably is capable of delivering the PCM in a manner so that all of the PCM flowing through the discharge component is delivered to pack cavities. For example, the exit opening may be sufficiently small so that it can completely fit above the fill opening. Preferably, the discharge component has an end that is sufficiently small that it is capable of at least partially entering the fill opening. Preferably the cavity of the pack is filled without any PCM contacting the fill opening region so that this region can later be sealed. By entering the cavity of the pack with an end of the discharge unit, it may be possible to avoid having PCM contact the region of the pack near the fill opening. Although the end of the discharge unit may be placed into the cavity to a generally high depth of the cavity, it is preferred that the cavity is filled in a manner that avoids allowing the outer surfaces of the discharge unit from contacting the PCM in the cavity during filling. For example, the end of the discharge unit may remain at a generally high elevation near the fill opening, or the end of the discharge unit start at a generally low elevation and be at least partially or entirely withdrawn from the cavity as the cavity is filled. Preferably, the size of the exit opening is sufficiently large and/or the volumetric rate of filling the cavity is sufficiently low, so that the PCM enters the cavity at a generally low velocity so that the PCM does not contact the region of the fill opening, such as by splashing.

[0049] The apparatus may include a plurality of exit openings so that cavities of different packs, and/or multiple cavities of a single pack, may be filled at the same time. For example, a plurality of cavities may be filled in a single discharging step, such as a single step of discharging a predetermined volume of PCM.

[0050] The apparatus may include a drip preventing component capable of preventing the flow of material from the exit opening(s) between discharging steps. The drip prevent device may function by causing a back pressure in the PCM material in the discharge component. The drip preventing component may function by covering the exit opening of the discharge component. The drip preventing component may function by closing a valve so that the fluid communication between the PCM in the discharge component and the PCM at a location

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upstream of the discharge component is interrupted. The drip prevention device may prevent unwanted backflow of air into the nozzle. By way of example, the drip preventing component may include or consist of a shut-off valve. In general, the closer the shut-off valve is to the exit opening, the more effective the shut-off valve will be in preventing leakage of the PCM. As such, a preferred location for a shut-off valve is in a discharge component, adjacent to a discharge component, or near a discharge component. A shut-off valve may be operated using any suitable method. For example a shut off valve may be electrically controlled, actuated, controlled by pneumatic pressure, a mechanical means, or any combination thereof. A drip preventing component may be controlled by a controller. For example a drip preventing component may be controlled in a synchronous manner with one or more other components, such as with one or more other valves, a component of the dosing device, or any combination thereof. If the apparatus includes a plurality of discharge components, a drip preventing component may prevent leakage of PCM from a single discharge component or from a plurality of discharge components. Leakage may also be reduced or eliminated by using a sufficiently small exit opening and/or a sufficiently small nozzle so that atmospheric pressure is sufficient to prevent the flow from the opening. In addition to preventing leakage of PCM the drip preventing component may prevent air from entering the flow path of the apparatus. Such air may affect the ability to deliver precise amounts of PCM to a cavity.

[0051] The apparatus may include one or more transfer lines suitable for flowing the PCM between components of the apparatus. The transfer lines may provide fluid communication between the components. For example, one or more transfer lines may be employed between a container and a dosing device, one or more transfer lines may be employed between a dosing device and a discharge component, or both. It may be advantageous for one or more of the transfer lines to be a flexible transfer line. For example, a flexible transfer line may be employed so that the position of the discharge component relative to the container may be variable. As another example, a flexible transfer line may be employed so that the position of the discharge component relative to the dosing device is variable. As yet another example, a flexible transfer line may be employed so that the position of the dosing device relative to the container is variable. Any flexible transfer line that is corrosion resistant and capable of functioning at the temperature of the molten PCM may be used. The flexible transfer line may be a metallic line, or it may be a polymeric line. The material for the flexible transfer line may be any material described herein for use in a component that may contact the PCM. The flexibility of the flexible transfer line may be provided by the selection of a material having flexibility, may be provided by the design of the line, or both. For example, the flexible transfer line may be constructed of a

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corrugated material so that it is flexible. A particularly preferred material for the flexible transfer line is stainless steel.

[0052] The apparatus may include a container for storing the PCM. The PCM may be provided to the container in a molten state or in a solid state. The PCM will generally leave the container in a molten state. As such, the container may include sufficient heating means, such as described hereinafter, for heating melting the PCM and/or for maintaining the PCM in a molten state. The container may include a filtering component suitable for preventing solid phase change material and/or other solid impurities from being dispensed from the dispensing apparatus. It may be desirable for the PCM to be discharged as a material that is substantially or entirely anhydrous. As such, it may be necessary to prevent the PCM from absorbing moisture while in the container and/or it may be necessary to remove moisture from the PCM while in the container. To maintain or reduce the concentration of moisture in the PCM the container may be sufficiently sealed so that the flow of atmospheric air into the container is reduced or substantially prevented. To maintain or reduce the concentration of water in the PCM, the container may include one or any combination of the following features: a flow of a dry purge gas, a vacuum, or a desiccant. The PCM leaves the container as a liquid through one or more outlets in fluid connection with a dosing device. The container may have a sufficient volume so that the PCM can be dried before it leaves the container.

[0053] The apparatus should be capable of maintaining the PCM in a liquid state as it flows from the container to the exit opening. Preferably the PCM is maintained at or above one or more predetermined target dispensing temperatures. The predetermined target dispensing temperature may be any temperature at which flow of the PCM is generally assured throughout the flow paths of the PCM in the apparatus. The predetermined target dispensing temperature may be determined by the physical properties of the PCM being used. There is a need for PCM having generally high liquidus temperatures, and thus, the apparatus should be capable of delivering such PCM in a liquid state. As such, the predetermined target dispensing temperature may be about 120 °C or more, about 140 °C or more, about 160 °C or more, about 180 °C or more, about 200 °C or more, about 220 °C or more, about 240 °C or more, about 260 °C or more, about 280 °C or more, or about 300 °C or more. The predetermined target dispensing temperature may be sufficiently low so that the process is thermally efficient, so that the PCM does not decompose, so that the apparatus is not damaged, or any combination thereof. For example the predetermined target dispensing temperature may be about 450 °C or less, about 400 °C or less, about 350 °C or less, or about 330 °C or less.

[0054] The apparatus may include sufficient heaters and/or insulation so that the PCM is

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heated to about the predetermined target dispensing temperature and/or so that the PCM is maintained at about the predetermined target dispensing temperature. It will be appreciated that a single predetermined target dispensing temperature may be used throughout the apparatus, or that different components may have different predetermined target dispensing temperatures. For example, areas of the apparatus that include a seal may have a lower target temperature that is lower than another region of the apparatus, provided that the temperature is sufficiently high so that the PCM remains in a molten state.

[0055] The apparatus preferably has sufficient insulation and heating components for preventing any low temperature areas to develop which would cause the PCM to freeze and thus block or reduce the flow of PCM. For example, one or more of the components of the apparatus, or even the entire apparatus may be in contact with a heating component, with an insulating material, or both. Any suitable means of heating may be employed. A component of the apparatus may include a heater, a component of the apparatus may have a heater embedded or inserted into the component, a component of the apparatus may have one or more surfaces in contact with a heater, a component of the apparatus may be in thermal communication with a heater, such as via a heat transfer fluid, or any combination thereof. The heater may be an electric heater. For example, a component of the apparatus may be in contact with an electric resistance heating element. The apparatus may include one or more heaters that are sufficiently flexible so that it can wrap a component of the apparatus. A heater, such as a flexible heater, may contact or wrap a transfer line, a dosing device, a valve, a discharge component, a container, or any combination thereof.

[0056] One or more components of the apparatus may be insulated so that heat losses are reduced, so that the PCM remains molten, or both. For example, the insulation may be employed in areas that are not heated so that the PCM does not undergo a liquid to solid phase transition. Any insulation capable of reducing heat loss from a component may be employed. The insulation may include one or more materials having a generally low thermal conductivity. The insulation may have a thermal conductivity that is at least about 2 or 3 orders of magnitude lower than the thermal conductivity of stainless steel, titanium, or both. The insulation may include a gas phase layer, a vacuum layer, a porous material including, a fibrous material, or any combination thereof. For example the insulation may include a layer of fiberglass and a protective outer layer.

[0057] The heaters may be controlled using one or more controllers. The controllers preferably are capable of maintaining the temperature of a component at or near the predetermined target dispensing temperature. The controller may be capable of controlling the

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heater so that absolute value of the difference between the temperature of a component and predetermined target temperature is about 50 °C or less, preferably about 40 °C or less, more preferably about 30 °C or less, even more preferably about 20 °C or less, even more preferably about 10 °C or less, and most preferably about 5 °C or less. It may be important to more precisely control the temperature of certain components of the apparatus compared with other components. For example, it may be desirable to more precisely control the temperature of a component including a seal and/or a component including an exit opening, compared for example to a transfer line.

[0058] FIGs. 5A and 5B show portions of an illustrative dispensing apparatus. The apparatus according to the teachings herein may include one or any combination of the features illustrated in FIGs. 5A and 5B. FIG. 5A illustrates an upstream portion of the apparatus and FIG. 5B illustrates a downstream portion of the apparatus. It will be appreciated that these portions may be connected, such as by a PCM transfer line 22. The apparatus 2 may include one or more heaters 28 so that the PCM 6 does not solidify in the apparatus. For example, the apparatus 2 may include a container 4 that has a heater 28 for melting the PCM 6 and/or maintaining the PCM in a liquid state. The container may include one or more filters 8, so that solid particles, such as impurity particles, are generally excluded from the flow of PCM. The apparatus may include valves 12 on either side of a discharging device 10. The discharging device may have a driver 59, such as an electric actuator, that moves an inner dosing component 54, such as a piston, in an axial direction so that the piston slides into and out of an outer dosing component 52, such as a cylinder. The dosing device 10 may be heated with one or more heaters 28, such as with a resistance heater wrapped around one or more outer surfaces. The valves 12 may be check valves. The check valves may function by allowing only PCM to be drawn from the container 3 during a charging step when, such as when the piston slides out of the cylinder. The check valves may function by allowing only PCM to be pushed towards the exit opening 25, when during a discharging step, such as when the piston slides into the cylinder. As illustrated in FIG. 6B, the apparatus may include a shut-off valve 26, such as a hydraulically driven shut off valve. Such a shut-off valve may prevent leakage of the PCM. As such, the shut-off valve may be open during a discharging step. At other times, the shut-off valve may be closed, such as during a step of charging the dosing device.

[0059] The dispensing apparatus may be used for dispensing an art known PCM. Examples of PCMs that may be employed in the pack compartments include the materials described in Atul Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, "Review on thermal energy storage with phase change materials and applications ", Renewable and Sustainable Energy Reviews 13 (2009)

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318–345, and in Belen Zalba, Jose Ma Marin, Luisa F. Cabeza, Harald Mehling, “Review on thermal energy storage with phase change: materials, heat transfer analysis and applications”, *Applied Thermal Engineering* 23 (2003) 251–283, both incorporated herein by reference in their entirety. Other examples of suitable PCMs that may be employed in the heat transfer device include the Thermal Energy Storage Materials described in U.S. Patent Application No. 12/389,416 entitled “Thermal Energy Storage Materials” and filed on February 20, 2009; and U.S. Patent Application No. 12/389,598 entitled “Heat Storage Devices” and filed on February 20, 2009.

[0060] The PCM may include an organic material, an inorganic material or a mixture of an organic and an inorganic material that exhibits a solid to liquid transition temperature. The PCM may be a compound or a mixture (e.g., a eutectic mixture) having a solid to liquid transition at generally a single temperature. The PCM may be a compound or a mixture having a solid to liquid transition over a range of temperatures (e.g., a range of greater than about 3°C, or greater than about 5°C). Without limitation, the PCM may include one or more inorganic salts that includes one or more waters of hydration, one or more anhydrous salts, or both. The salt may include one or more anions selected from the group consisting of nitrate, nitrite, bromide, chloride, sulfate, sulfide, sulfite, carbonyl, phosphate, phosphate, hydroxide, and fluoride, one or more cations selected from the group consisting of potassium, iron, manganese, magnesium, sodium, calcium, lithium, cobalt, zinc, and aluminum, or both. The PCM may include, consist essentially of, or consist entirely of at least one first metal containing material, and more preferably a combination of the at least one first metal containing material and at least one second metal containing material. One preferred approach is to employ one or more metal containing materials as part of a metal compound; a more preferred approach is to employ a mixture of at least two metal compounds. By way of example, a suitable metal compound may be selected from oxides, hydroxides, compounds including nitrogen and oxygen (e.g., nitrates, nitrites or both), halides, or any combination thereof. It is possible that ternary, quaternary or other multiple component material systems may be employed also. Suitable PCMs include mixtures of two or more materials that exhibit a eutectic. A preferred PCM is a compound that include or consist essentially of one or more metal salts. The phase change material may have a sufficiently high purity so that impurities which may interfere with the flow of the PCM and/or which may interfere with the durability of a pack including the PCM are generally avoided. For example, the phase change material may have a purity of about 90 atomic % or more, about 99 atomic % or more, about 99.5 atomic % or more, about 99.9 atomic % or more, about 99.95 atomic % or more, about 99.99 atomic % or more, or about 99.995 atomic % or more. For

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PCMs that are a mixtures of two or more compounds, the purity may be determined by the percent of the PCM that has been generally homogenized.

[0061] The PCM may have a melting temperature above which the material at 1 atmosphere pressure is entirely a liquid at equilibrium and below which the material at 1 atmosphere is at least partially solid at equilibrium. The melting temperature may be a liquidus temperature or a eutectic temperature. The PCM may have a melting temperature sufficiently high so that it may store large amount of thermal energy. The PCM may have a melting temperature of about 120 °C or more, about 140 °C or more, about 160 °C or more, about 180 °C or more, about 200 °C or more, about 220 °C or more, about 240 °C or more, about 260 °C or more, about 280 °C or more, or about 300 °C or more. The PCM may have a melting temperature sufficiently low so that it can be maintained in a molten state in the dispensing apparatus. For example, the PCM may have a melting temperature of about 450 °C or less, about 400 °C or less, about 350 °C or less, or about 330 °C or less.

[0062] The volume of the PCM in the cavity may be sufficiently high so that the pack can store a large amount of thermal energy. The ratio of the volume of the PCM contained in the cavity to the volume of the cavity (the volumes measured at a temperature of about 25°C) preferably is about 0.5 or more, more preferably about 0.7 or more, and most preferably 0.9 or more. The ratio of the volume of the PCM contained in the cavity to the volume of the cavity is typically less than about 1.0, and more typically about 0.995 or less.

[0063] The sealed cavity may include a volume that contains a gas, such as air, N₂, or an inert gas such as He, Ar, and the like, so that the PCM can expand when heated. For example, the sealed space may have a region that is free of PCM at a temperature of about 25°C, so that upon heating the PCM above its liquidus temperature, the PCM can expand without forming a hole in the encapsulating sheets. The volume of a cavity that is free of PCM (e.g., the volume of the cavity that contains a gas) at 25°C, may be about 0.5% or more, preferably is about 1% or more, and most preferably is about 1.5% or more based on the total volume of the cavity.

[0064] The dispensing apparatus according to the teachings herein may be capable of precision dosing of the PCM, so that apparatus can be used to reproducibly fill cavities of packs with a predetermined target volume of the PCM. Preferably, the precision in the volume dispensed is about 1 cm³ or less, more preferably about 0.3 cm³ or less, and most preferably about 0.1 cm³ or less.

[0065] The dispensing apparatus may be used in a pack preparation system capable of performing one or more additional operations to a pack. For example the pack preparation system may include one or more devices for sealingly attaching material of the pack so that the

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cavity filled with the PCM is sealed, one or more devices for rotating the pack so that an additional cavity may be filled, one or more devices for heating the pack or maintaining the pack above a predetermined pack fill temperature, one or more devices for controlling the vapor pressure in a sealed cavity, one or more devices for controlling any gaseous component in a sealed component, one or more devices for sealingly attaching to encapsulant sheets for producing a cavity having a fill opening; one or more devices for protecting a surface of the pack from being contacted by PCM; or any combination thereof.

[0066] It may be desirable to have a system capable of sealing the cavity in a pack after it is filled with the PCM and prior to moving the pack, so that the PCM does not splash and contact the surfaces of the pack to be sealed. PCM on such a surface may result in failure of the pack, such as by forming an incomplete seal and/or forming a seal that opens during thermal cycling of the pack when used in a device for storing heat. As such, the system may include a fixture which holds the pack in the same fixed position while it is being filled and sealed. The system may include a mechanical device, such as a robotic device, capable of bringing the discharge component to and/or from the fill opening of the cavity of the pack; a mechanical device, such as a robotic device, capable of bringing a sealing device to/from the pack in a region near the fill opening.

[0067] The sealing of the pack may be performed using any sealing device capable of sealingly attaching two sheets or foils of metal. For example, the sealing device may be used for welding the two metal surfaces. Any art known welding method may be employed. A particularly useful attachment method is an attachment method which provides a continuous seal along the region being sealed. Such a continuous seal may be along a line which may be straight or curved. A particularly preferred sealing method is one that uses a laser to heat and melt the metal. It will be appreciated that prior to sealing and/or during sealing, it may be desirable to apply a compressive force sufficient for forcing two facing surfaces to be welded together to contact each other, such as in the region of the fill opening of the pack. The sealing device may be capable of making a generally thin-lined seal so that the seal can be prepared in a generally high speed operation. For example, the width of the seal may be about 800 μm or less, about 200 μm or less, about 100 μm or less, about 60 μm or less, or about 40 μm or less. The seal should be sufficiently wide so that the pack is durable and does not leak.

[0068] The sealing system may include one or mechanical devices. The mechanical device may be a robotic device, such as a device capable of robotically moving objects. A mechanical or robotic device may be used for moving a component towards and/or away from a pack, such as a pack that is being held in a generally fixed position. For example, a mechanical or robotic

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device may be used for moving a discharge component, a sealing device, or a vacuum device, or any combination. The system may include a plurality of mechanical devices which may each move a different component or device. One or more mechanical or robotic devices may be employed for removing the exit opening from the region of the fill opening, for bringing the sealing device to the region of the fill opening, or preferably both, so that the pack can be filled and sealed in subsequent steps without the need for moving the pack prior to the sealing step and so that splash of the phase change material onto one of the facing surfaces in the sealing region during such a moving step is avoided.

[0069] One or more features of the dispensing apparatus and/or the system according to the teachings herein may be employed in a process for making a pack including PCM, such as a pack including PCM in a sealed cavity of the pack. The process for making a pack may include a step of filling the cavity of the pack with liquid PCM using dispensing apparatus according to the teachings herein. For example, the process may include a step of dispensing the PCM at a predetermined target dispensing temperature. After filling the cavity with liquid PCM, the process may include one or more additional operations to the pack, such as a step of removing moisture from the cavity; a step of sealing the cavity; a step of removing air from the cavity; a step of injecting a gas; such as an inert gas into the cavity; a step of removing PCM from an region of the pack to be sealed; a step of rotating or otherwise repositioning a pack so that a second cavity can be filled; a step of cooling the PCM; or any combination thereof.

[0070] Preferably one or more of the aforementioned additional operations is performed while maintaining the pack in a fixed position. For example, the cavity may be first filled with molten PCM and then the cavity may be sealed, while the position of the pack is maintained. As discussed herein, such a process may result in a pack having a better seal that is more durable.

[0071] With reference to FIG. 6A, the process for preparing a pack 100 may include a step of positioning the pack 102, such as in a fixed position in a fixture. The process may include a step of maintaining the pack in the fixed (i.e., stationary) position 104 for a sufficiently long time so the pack does not move will performing a step of filling the cavity 110' with the PCM, and while performing one or more subsequent steps 112. In order to perform a subsequent step, it may be desirable to move the discharge component away from the pack. For example it may be desirable to move the discharge component away from the fill opening of the pack. As such, it may be advantageous to employ one or more flexible transfer lines in the dispensing apparatus, so that the discharge component can more easily be moved after filling the cavity with the PCM.

[0072] With reference to FIG. 6B, the process for preparing a pack 100' may include a plurality of steps, all performed while the pack is maintained in a stationary position 104. For

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example, the process may include steps of moving the discharge component toward the fill opening 106, filling the cavity with PCM 110', moving the discharge component away from the fill opening 108, moving a sealing device towards the region to be sealed 122, sealing the cavity 124, or any combination thereof. One or any combination of the additional steps may be performed while the pack remains in a generally fixed position.

[0073] While the present invention may be susceptible to various modifications and alternative forms, the exemplary embodiments discussed above have been shown by way of example. However, it should again be understood that the invention is not intended to be limited to the particular embodiments disclosed herein. Indeed, the present techniques of the invention are to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

[0074] Any numerical values recited herein include all values from the lower value to the upper value in increments of one unit provided that there is a separation of at least 2 units between any lower value and any higher value. As an example, if it is stated that the amount of a component or a value of a process variable such as, for example, temperature, pressure, time and the like is, for example, from 1 to 90, preferably from 20 to 80, more preferably from 30 to 70, it is intended that values such as 15 to 85, 22 to 68, 43 to 51, 30 to 32 etc. are expressly enumerated in this specification. For values which are less than one, one unit is considered to be 0.0001, 0.001, 0.01 or 0.1 as appropriate. These are only examples of what is specifically intended and all possible combinations of numerical values between the lowest value and the highest value enumerated are to be considered to be expressly stated in this application in a similar manner.

[0075] Unless otherwise stated, all ranges include both endpoints and all numbers between the endpoints. The use of "about" or "approximately" in connection with a range applies to both ends of the range. Thus, "about 20 to 30" is intended to cover "about 20 to about 30", inclusive of at least the specified endpoints.

[0076] The disclosures of all articles and references, including patent applications and publications, are incorporated by reference for all purposes. The term "consisting essentially of" to describe a combination shall include the elements, ingredients, components or steps identified, and such other elements ingredients, components or steps that do not materially affect the basic and novel characteristics of the combination. The use of the terms "comprising" or "including" to describe combinations of elements, ingredients, components or steps herein also contemplates embodiments that consist essentially of the elements, ingredients, components or steps. By use of the term "may" herein, it is intended that any described

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attributes that "may" be included are optional.

[0077] Plural elements, ingredients, components or steps can be provided by a single integrated element, ingredient, component or step. Alternatively, a single integrated element, ingredient, component or step might be divided into separate plural elements, ingredients, components or steps. The disclosure of "a" or "one" to describe an element, ingredient, component or step is not intended to foreclose additional elements, ingredients, components or steps.

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CLAIMS

WHAT IS CLAIMED IS:

1. An apparatus comprising:
 - i) a container for storing a phase change material;
 - ii) a dosing device in fluid communication with the container and capable of pumping a predetermined volume of the phase change material, wherein the dosing device is downstream of the container;
 - iii) one or more seals capable of maintaining a seal at a temperature of about 200 °C, so that the phase change material does not leak out of the apparatus, wherein at least one seal is in contact with the phase change material; and
 - iv) a discharge opening for discharging the phase change material into a cavity of a pack, wherein the discharge opening is in fluid communication with the dosing device and downstream of the dosing device; and
 - v) one or more heating components that provide sufficient heat for maintaining the phase change material in a liquid state between the container and the discharge opening; wherein the apparatus is capable of dispensing a liquid phase change material at a temperature of about 200 °C or more.
2. The apparatus of claim 1, wherein the apparatus includes a heater for melting the phase change material so that a sufficient portion of the phase change material is in a liquid state in the storage container so that the phase change material can be pumped from the storage container as a liquid.
3. The apparatus of claim 1 or 2, wherein the phase change material has a liquidus temperature greater than about 120 °C.
4. The apparatus of any of claims 1 through 3, wherein the system includes one or more transfer lines.
5. The apparatus of any of claims 1 through 4, wherein the dosing device includes an inner dosing component that is at least partially movable in relation to an outer dosing component, wherein the dosing device includes one or more of the seals for sealing a space between the two components while allowing one component to move in relation to the other, and wherein the outer dosing component includes a cavity that is in fluid communication with the container and the exit opening.
6. The apparatus of any of claims 1 through 5, wherein the outer dosing component is a cylinder or tube and the inner dosing component is a hollow tube that at least partially

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- slides in and out of a cavity of the outer dosing component to change the volume of phase change material that is in the dosing device.
7. The apparatus of any of claims 1 through 5, wherein the outer dosing component is a cylinder having an inlet and an outlet and the inner dosing component is a piston that at least partially slides in and out of the outer dosing component to change the volume of phase change material that is in the dosing device.
 8. The apparatus of any of claims 1 through 7, wherein the apparatus includes one or more valves upstream of the dosing device capable of interrupting the fluid communication between the container and the cavity of the outer dosing component, so that during a step of discharging phase change material from the dosing device, a predetermined volume of phase change material flows through the exit opening.
 9. The apparatus of claim 8, wherein the valve is a check valve.
 10. The apparatus of any of claims 1 through 8, wherein the apparatus includes one or more valves downstream of the dosing device capable of interrupting the fluid communication between the outer dosing component and the exit opening so that upstream flow of the phase change material is avoided.
 11. The apparatus of any of claims 1 through 10, wherein the seal includes graphite or other material consisting essentially only of carbon atoms.
 12. The apparatus of any of claims 1 through 11, wherein the metal surfaces that are in contact with the molten phase change material are made of a metal that is substantially corrosion resistant to the phase change material at a temperature of about 200 °C.
 13. The apparatus of any of claims 1 through 12, wherein the metal surfaces that are in contact with the molten phase change material are made of stainless steel so that corrosion is reduced, minimized, or eliminated.
 14. The apparatus of any of claims 1 through 13, wherein the apparatus includes a shut off valve for preventing the discharge of material at the dispensing end of the one or more transfer lines.
 15. The apparatus of any of claims 1 through 14, wherein the apparatus is capable of high precision dosing so that the volume of phase change material being delivered is within about $\pm 0.1 \text{ cm}^3$ of a predetermined target volume.
 16. The apparatus of any of claims 1 through 15, wherein
 - i) the phase change material has a liquidus temperature of about 200 °C or more,
 - ii) the phase change material includes a substantially anhydrous metal salt that includes a nitrate;

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- iii) the phase change material includes a substantially anhydrous metal salt that includes a nitrite;
 - iv) or any combination of (i), (ii) and (iii).
17. A system comprising:
- i) the dispensing apparatus of any of claims 1 through 15;
 - ii) a fixture for holding a pack, wherein the pack includes a fill opening for receiving the phase change material from the exit opening of the apparatus, and the fixture holds the pack in a fixed position with the fill opening at the top;
 - iii) a devices for sealing the fill opening of the pack by sealingly attaching two facing surfaces near the fill opening;
 - iv) one or more mechanical or robotic devices for removing the exit opening from the region of the fill opening and for bringing the sealing device to the region of the fill opening, so that the pack can be filled and sealed in subsequent steps without the need for moving the pack prior to the sealing step and so that splash of the phase change material onto one of the facing surfaces in the sealing region during such a moving step is avoided.
18. The system of claim 17, wherein the apparatus includes a flexible transfer line so that exit opening can be moved without moving the container.
19. A method of dispensing a phase change material comprising:
- i) heating the phase change material to a temperature of about 200 °C or more so that the phase change material is in a liquid state; wherein the phase change material includes a metal salt, and wherein the phase change material has a liquidus temperature of about 120 °C or more;
 - ii) pumping the phase change material into a metal pack having a cavity by flowing the phase change material through a fill opening of the metal pack, so that a cavity is filled with a predetermined volume of the phase change material; and
 - iii) sealingly attaching the metal of the pack in the region of the fill opening so that the phase change material in the cavity is sealed from the outside of the pack;
- wherein the step of filling and the step of sealing are performed without moving the pack, so that a complete and durable seal is produced without phase change material in the entrapped at the location of the seal.
20. The method of claim 19, wherein the method includes a step of drying the phase molten phase change material using a vacuum, and wherein at least a portion of the phase change material in the pack is in a molten state during the sealing step.

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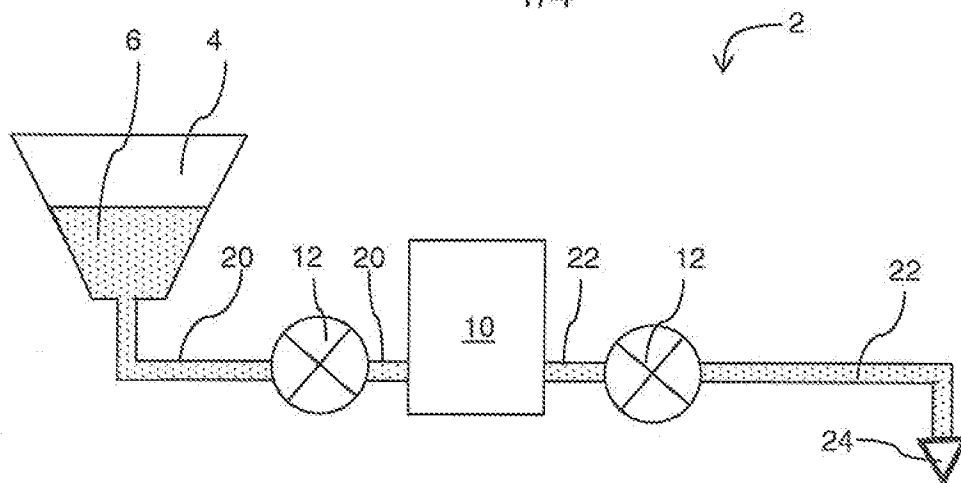


FIG. 1A

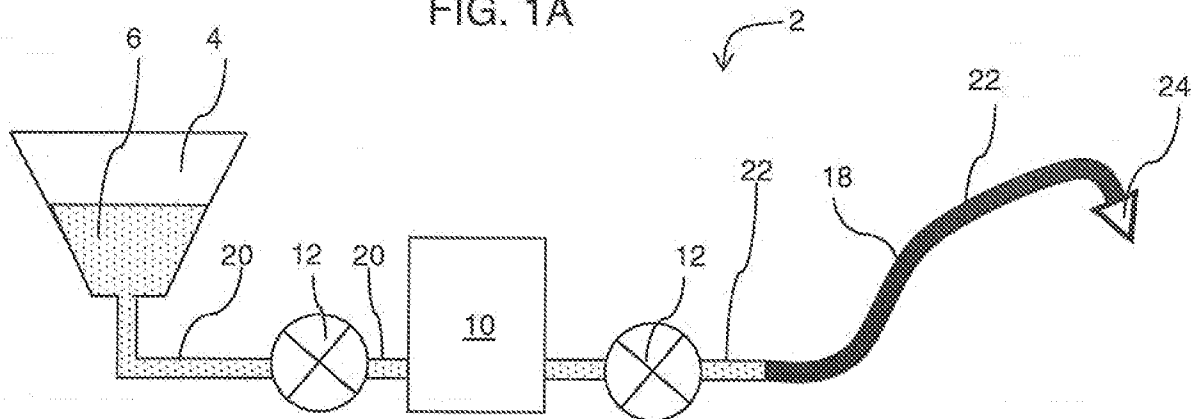


FIG. 1B

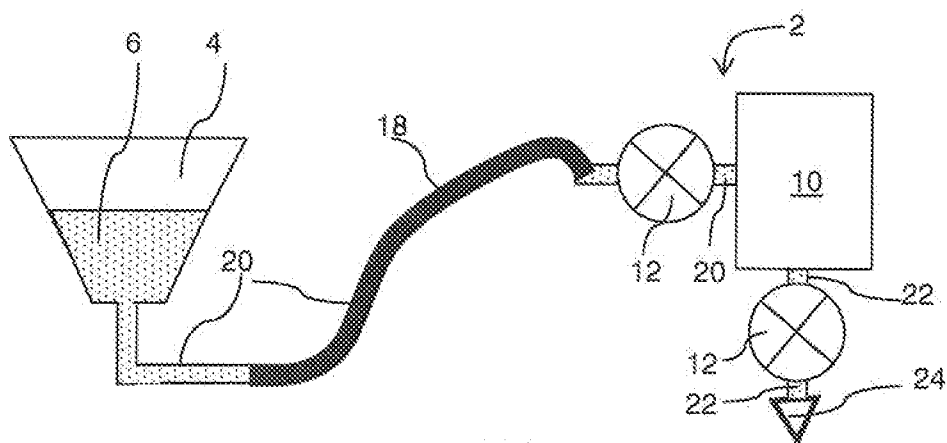


FIG. 1C

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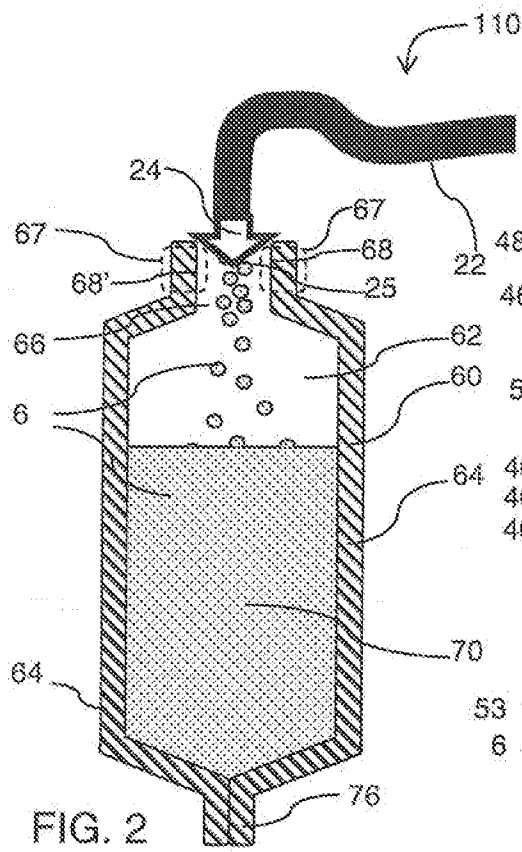


FIG. 2

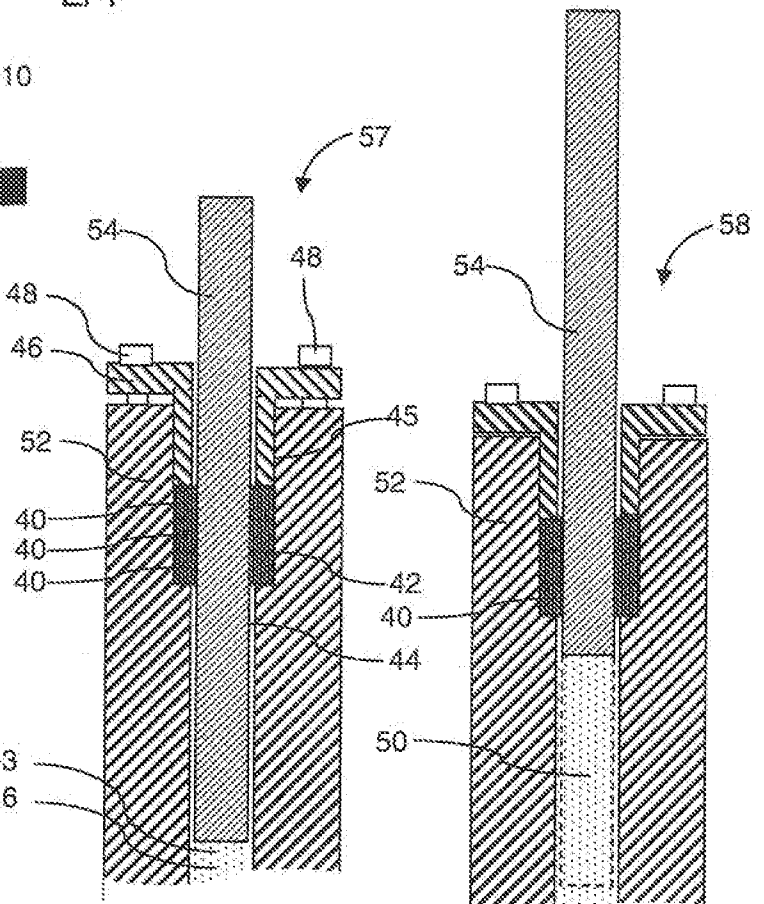


FIG. 3A

FIG. 3B

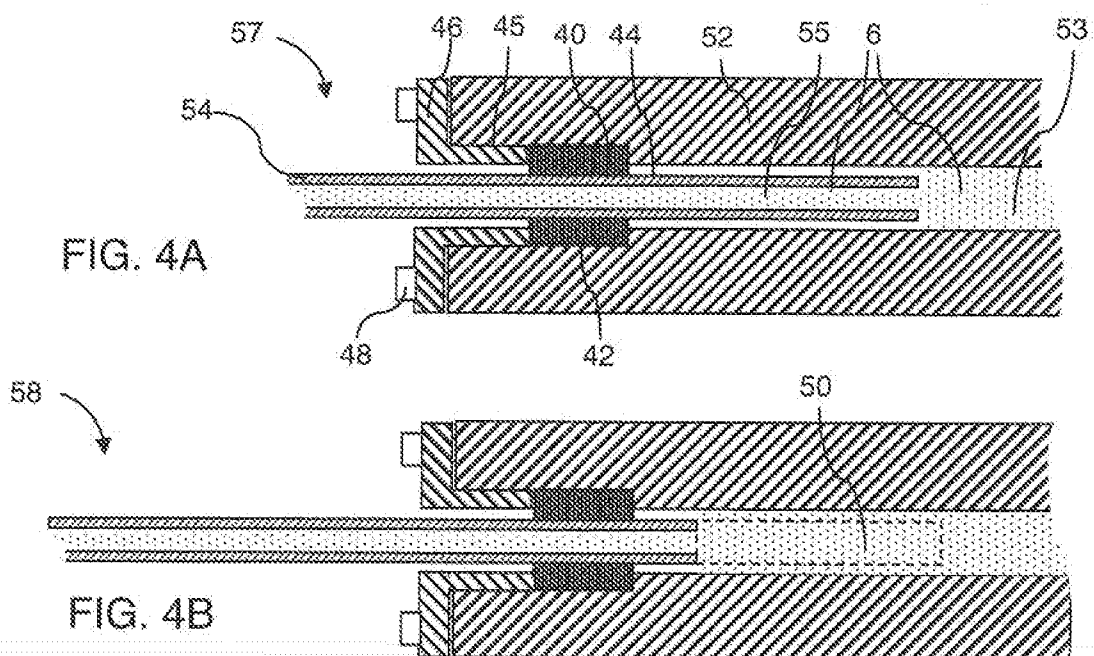
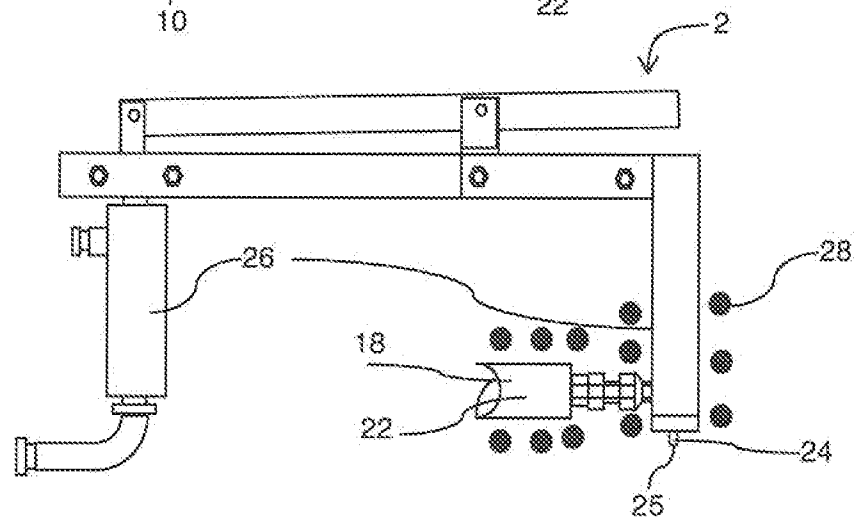
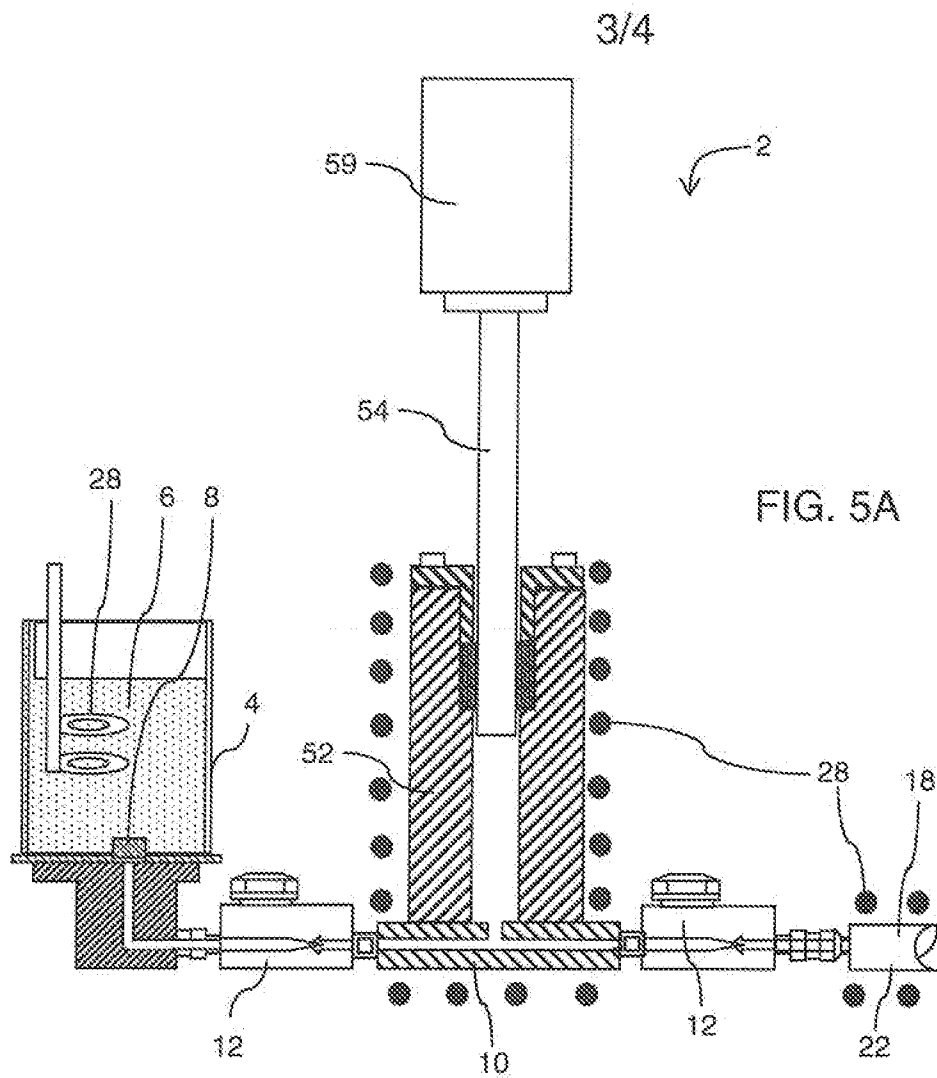


FIG. 4A

FIG. 4B



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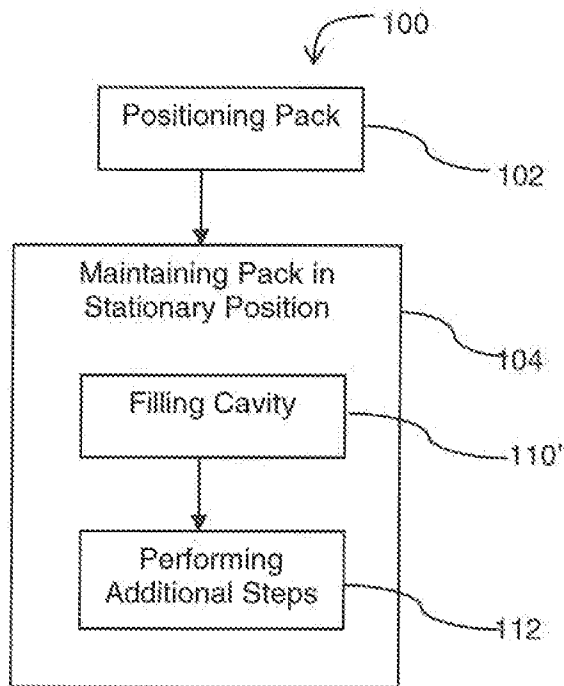


FIG. 6A

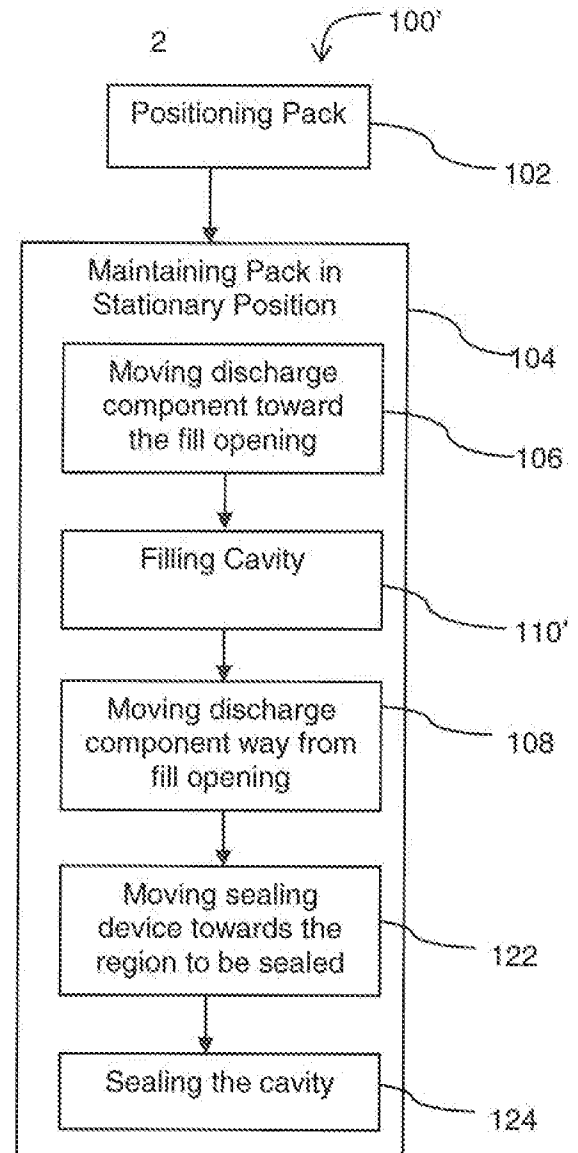


FIG. 6B