A phase-change material heat exchanger includes a frame configured to define a chamber therein and house a first fluid, the first fluid being water. At least one heat exchange element is configured to have a second fluid pass through an interior of the heat exchange element, the at least one heat exchange element moveably retained within the chamber. When the second fluid passes through the heat exchange element at a first temperature, the first fluid changes from a liquid to a solid, and the second fluid exits the heat exchange element at a second temperature that is higher than the first temperature.
FIG. 5

1. Pump operating fluid at first temperature into water phase-change material heat exchanger
2. Cause a freeze front to form through the heat exchanger
3. Convey operating fluid at second temperature out of water phase change material heat exchanger
4. Pump operating fluid at third temperature into heat exchanger
5. Cause ice to melt
6. Convey operating fluid at fourth temperature out of water phase change material heat exchanger
PHASE-CHANGE MATERIAL HEAT EXCHANGER

BACKGROUND

[0001] The subject matter disclosed herein generally relates to heat exchangers and, more particularly, to phase-change material heat exchangers.

[0002] Recent advances in the design and fabrication of electronic components has dramatically increased their speed and density but has, at the same time, led to significant challenges for thermal engineers seeking to provide heat-transfer solutions for such components.

[0003] In some applications, phase-change material heat exchangers may be used for high capacity and high energy applications. A phase-change material used in such heat exchangers is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, phase-change materials are classified as latent heat storage units and provide excellent media in heat exchangers for rapid cooling.

[0004] For example, in traditional phase-change material heat exchangers, wax may be used as the phase-change material. The heat of fusion needed to melt wax is often used to remove heat from operating systems and/or operating fluids. As heat is applied or transferred to the wax from another medium, such as an operating fluid, normally in a heat exchanger configuration, the wax melts. This phase change in the wax, from a solid to a liquid, removes heat from the operating fluid passing through the heat exchanger, thus lowering the operating fluid temperature. After the wax is melted, it may then be re-frozen, and converted back to a solid, so that the heat transfer process may be repeated multiple times. The amount of energy translated depends on the property “heat of fusion” or melting energy.

SUMMARY

[0005] According to one embodiment a phase-change material heat exchanger is provided. The heat exchanger includes a frame configured to define a chamber therein and house a first fluid, the first fluid being water. At least one heat exchange element is configured to have a second fluid pass through an interior of the heat exchange element, the at least one heat exchange element movably retained within the chamber. When the second fluid passes through the heat exchange element at a first temperature, the first fluid changes from a liquid to a solid, and the second fluid exits the heat exchange element at a second temperature that is higher than the first temperature.

[0006] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the at least one heat exchange element includes a plurality of surface area structures on an exterior surface thereof.

[0007] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the plurality of surface area structures are at least one of fins and pins.

[0008] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the at least one heat exchange element has a plate configuration.

[0009] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the at least one heat exchange element is configured to define a freeze front of the first fluid along an exterior surface of the at least one heat exchange element.

[0010] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the second fluid is an operating fluid for a high powered laser.

[0011] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the frame defines a tapered shape with a bottom of the frame being narrower than a top of the frame.

[0012] In addition to one or more of the features described above, or as an alternative, further embodiments may include that at least one expansion element configured to support the at least one heat exchange element within the chamber.

[0013] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the at least one expansion element is a spring.

[0014] In addition to one or more of the features described above, or as an alternative, further embodiments may include a membrane retained about the frame and configured to expand when the first fluid changes from a liquid to a solid.

[0015] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the at least one heat exchange element comprises a first support and a second support, with a body extending between the first support and the second support.

[0016] In addition to one or more of the features described above, or as an alternative, further embodiments may include an enclosure, wherein the enclosure includes the frame and at least a portion of the enclosure is configured to expand in response to water freezing.

[0017] According to another embodiment, a method of using a phase-change material heat exchanger is provided. The method includes conveying an operating fluid at a first temperature through at least one heat exchange element, the at least one heat exchange element disposed within a chamber of a phase-change material heat exchanger, the chamber filled with water, causing the water to phase change from a liquid to a solid within the chamber, and conveying the operating fluid out of the at least one heat exchange element at a second temperature that is higher than the first temperature.

[0018] In addition to one or more of the features described above, or as an alternative, further embodiments may include conveying the operating fluid through the at least one heat exchange element at a third temperature when the chamber is filled with ice.

[0019] In addition to one or more of the features described above, or as an alternative, further embodiments may include that the third temperature is a temperature sufficiently high to phase change the ice to liquid water when passing through the at least one heat exchange element.

[0020] In addition to one or more of the features described above, or as an alternative, further embodiments may include forming a freeze front progression within the chamber such that a volumetric expansion of the water when freezing does not damage the phase-change material heat exchanger.

[0021] Technical effects of embodiments of the present disclosure include providing a phase-change material heat
exchanger that employs water as the phase-change material, with ice serving as the absorbing phase of the material to cool an operating fluid, and during this process the ice melts to become water.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The subject matter is particularly pointed out and distinctly claimed at the conclusion of the specification. The foregoing and other features, and advantages of the present disclosure are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0023] FIG. 1 is a partial cut-away schematic illustration of a phase-change heat exchanger in accordance with an embodiment of the present disclosure;

[0024] FIG. 2 is a schematic illustration of a phase-change heat exchanger in accordance with another embodiment of the present disclosure showing an example flow path of an operating fluid;

[0025] FIG. 3 is a schematic illustration of a heat exchange element in accordance with an embodiment of the present disclosure;

[0026] FIG. 4A is a first example of a surface area structure configuration in accordance with the present disclosure;

[0027] FIG. 4B is a second example of a surface area structure configuration in accordance with the present disclosure;

[0028] FIG. 4C is a third example of a surface area structure configuration in accordance with the present disclosure;

[0029] FIG. 4D is a fourth example of a surface area structure configuration in accordance with the present disclosure, and

[0030] FIG. 5 is a process in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0031] Traditionally, wax has been used as a phase-change material in phase-change material heat exchangers because there is a minimal volume change in wax when changing from a liquid to a solid, and yet the wax has a relatively high heat of fusion. As such, wax configurations have enabled phase-change material heat exchangers to work relatively efficiently without providing increased structural components to compensate for volume expansion during phase changes of the phase-change material. The wax would be enclosed within the heat exchanger, and thermal expansion is managed as known in the art.

[0032] In contrast, water/ice has a much higher latent heat or heat of fusion as compared to wax, and thus is more desirable in terms of thermal efficiency. For example, paraffin wax that may be used as a phase-change material in heat exchangers has a heat of fusion of 63.2 BTU/lb\text{m}, whereas ice has a heat of fusion of 144 BTU/lb\text{m}. The much greater heat of fusion of water/ice is desirable for high energy applications, as a cooling process may occur at a much higher rate, and/or a smaller heat exchanger may be used for the same amount of thermal transfer. An example of a high energy application may be a high powered laser that has a high discharge rate and thus may require a fast cool-down period of an operational fluid used to cool the laser components.

[0033] The problem with employing water/ice as a phase-change material, however, has been the volumetric expansion of the water that occurs during the phase change between a liquid and a solid. The volume efficiency of water as a phase-change material is 227% greater than paraffin wax, but water expands almost 10% by volume as it freezes and changes to ice. Further, the forces of expanding ice are extremely high, having the ability to overcome most enclosing structures. For example, if a heat exchanger volume is filled with water, and the water freezes, the force of the volume expansion of the ice may be sufficient to damage, break, or destroy the housing structure. As such, water/ice is a problematic material in a phase-change material heat exchanger.

[0034] However, in accordance with embodiments disclosed herein, water/ice may be employed as the phase-change material in a phase-change material heat exchanger, without the risk of damage to the heat exchanger structure. FIG. 1 is a partial cut-away schematic illustration of a heat exchanger in accordance with an embodiment of the disclosure. Heat exchanger 100 is a phase-change material heat exchanger configured to employ ice as a phase-change material in order to cool an operating fluid that passes through heat exchange elements 106 of the heat exchanger 100. That is, during operation, heat exchanger 100 may be filled with ice, and as a hot operating fluid passes through the heat exchanger 100, the ice may melt and change to water, thus absorbing large amounts of thermal energy from the operating fluid. In preparation of this operation, the heat exchanger 100 must be filled with ice, not water, and thus water within the heat exchanger 100 must be frozen.

[0035] The heat exchanger 100 is configured to allow a phase-change material, such as water, to expand relatively unrestrained during the phase change to a solid, i.e., to ice. This is achieved by the heat exchanger 100 including a frame 102 that defines a chamber 104 therein. The frame 102 may form a tank or other similar structure that may form fluidly contained chamber or volume, such as a bath. The chamber 104 may be configured to house one or more heat exchange elements 106. The heat exchange elements 106 may be plate heat exchange elements, as shown in FIG. 1. In alternative embodiments, the shape, geometry, and configuration of the heat exchange elements 106 may be varied, for example, in some embodiments the heat exchange elements 106 may be configured as tubes in a shell-and-tube heat exchanger, or in other configurations known in the art or that may become known.

[0036] In the embodiment shown in FIG. 1, the heat exchange elements 106 are connected to each other by expansion elements 108. The expansion elements 108 may be springs, rods, wires, etc., that are configured to enable the heat exchange elements 106 to be able to move relative to each other. For example, the expansion elements 108 are configured to allow for the heat exchange elements 106 to move apart from each other during a freezing of water contained within the chamber 104. As the water freezes, it may push outward on the heat exchange elements 106, and the expansion elements 108 permit the heat exchange elements 106 to move without damage occurring thereto. The expansion elements 108 may also be configured to provide shock or vibration absorption or reduction due to movement of the heat exchanger 100, such as when installed on a vehicle.
[0037] The heat exchange elements 106 may include structures or configurations that increase or optimize the surface area of the heat exchange elements 106. For example, as shown, surface area structures 110 may be configured in the form of fins or ridges. The fins may optionally be in the form of perforated foams, as described below. In alternative embodiments, the surface area structures 110 may be formed as pins, blades, corrugations, grooves, channels, etc. Those of skill in the art will appreciate that the surface area structures of the heat exchange elements may be any shape, geometry, and/or configuration that may be configured to increase the thermal transfer through a surface of the heat exchange elements 106.

[0038] As shown in FIG. 1, the frame 102 is configured having an expanding cross-section as the elevation changes from the base to the top of the heat exchanger 100. This allows an ice front to grow and expand, moving up the frame 102. The frame 102 may be formed from a polymer or other material that enables the frame 102 to deflect to increase the internal volume without exceeding the plastic limit of the frame 102. Further, a membrane 112 may line the chamber 104 within the frame 102. The membrane 112 may be configured to allow the volume contained within the membrane 112 to expand, such as by 10% in the case of water being contained within the frame 102. The membrane 112 is configured to seal the frame 102 to define the chamber 104 such that a fluid, such as water, will be contained within the frame 102. In some embodiments, the frame may form an open top such that the water is exposed to the ambient air. In other embodiments, the frame may include an optional and/or removable top or cap that may be configured to fluidly contain the water within the chamber 104.

[0039] An operating fluid may be configured to pass into the heat exchanger 100 and specifically, the operating fluid may be pumped, pass, or flow through the heat exchange elements 106, with the heat exchange element 106 moveably retained within the frame 102. As such, the operating fluid may pass through an inlet manifold 114 and into one or more flexible hoses 116. The operating fluid will then enter the heat exchange elements 106 to be in thermal contact with the phase-change material (water) contained within the chamber 106 of the frame 102. The operating fluid will then exit the heat exchanger 100 at outlet 120, which may include one or more flexible hoses and an outlet manifold (not shown).

[0040] In operation, to form an ice bath within the chamber 104, a cold operating fluid may be pumped or passed from the inlet manifold 114, which may be on the bottom or lower portion of the heat exchanger 100, through the heat exchanger 100 and to an outlet, which may be on the top or upper portion of the heat exchanger 100. Thus, a cold operating fluid may be introduced at the bottom of the heat exchanger 100 and may be of sufficiently low temperature to cause a phase change in the water contained in the chamber 104. For example, when the operating fluid enters at the inlet manifold 114 with the phase-change material being water, ice may begin to form at the bottom of the frame 102. This will form or create freeze progression through the heat exchange 100 that begins at the bottom and expands upward. As shown in FIG. 1, the configuration of the frame 102 has a narrower bottom and a wider top which is configured to accommodate the volumetric expansion of the water as it freezes. That is, the frame 102 may define a tapered geometry wherein the base is narrower than the top, or the base may define a smaller area than the top.

[0041] In some embodiments, the heat exchanger 100 may be configured to employ the cooling of an operating fluid using sensible heat transfer. In other embodiments, the heat exchanger 100 may be configured to have the operating fluid (in addition to the phase-change material within the chamber 104) to experience a phase change. For example, the operating fluid may be configured to condense during an ice-melt cycle and then act as an evaporator during a freeze cycle.

[0042] Once the water is frozen, the phase-change material heat exchanger is ready to cool an operating fluid rapidly. For example, after the ice is formed, the operating fluid may be used to cool a high temperature application by absorbing thermal energy and carrying it away from the high temperature application. The heated operating fluid may be conveyed away from the high temperature application to the heat exchanger 100. As the hot operating fluid enters the heat exchanger 100, the ice may be converted back to water, thus absorbing high amounts of thermal energy from the hot operating fluid. This results in a rapidly cooled operating fluid. After completion and the ice has turned to water, the process may be repeated, with a cold operating fluid used to convert the water to ice.

[0043] Turning now to FIG. 2, an alternative embodiment of a phase-change material heat exchanger is shown. In FIG. 2, a phase-change material heat exchanger 200 is shown. The schematic shown in FIG. 2 also depicts the flow path of an operating fluid, indicated in part by the arrows. The phase-change material heat exchanger 200 includes a frame 202 configured to be filled by a phase-change material such as water. The frame 202 may have a similar construction as the frame 102 of FIG. 1, including a membrane and/or cover. Contained within the frame 202 and submerged within the water may be one or more heat exchange elements 204. As shown in FIG. 2, in contrast to the embodiment shown in FIG. 1, the heat exchange elements 204 are configured with a vertical separation or are vertically stacked heat exchange elements 204.

[0044] An operating fluid may flow through a flow path 206, either as a hot fluid or as a cold fluid, depending on the phase change to be achieved within the phase-change material. The operating fluid may be conveyed through the flow path 206 by means of a fluid pump 208. The fluid pump 208 may pump the operating fluid into a heating and cooling element 210. The heating and cooling element 210 includes a coolant tank 212 and a heater 214. If the water is to be converted to ice, the coolant tank 212 may be used to bring the operating fluid down to a temperature insufficient to freeze water. However, if the ice is to be converted to water, the heater 214 may be used to warm the operating fluid. Thus, in some embodiments, the heater 214 may be thermally connected to a high energy application, such as a laser, that may require rapid cooling. Heating and cooling element 210, as depicted in FIG. 2, is merely representative and those of skill in the art will appreciate that the heating and cooling elements of the phase-change material heat exchanger 200 may be more than a single element, with the heating element(s) separate and distinct from the cooling element(s). In some embodiments, with separate heating and cooling elements, the elements may be in fluid communication or may be fluidly isolated from each other, depending on the desired configuration and particular system employed.

[0045] After passing through the heating and cooling element 210, the operating fluid may be conveyed into the frame 202 and the heat exchange elements 204 contained...
therein. The operating fluid will then exit the heat exchange elements 204 and the frame 202 and then flow back to the pump for continuous operation.

[0046] Along the flow path 206 may be one or more thermal gages 216. The thermal gages 216 may be configured to monitor the temperature of the operating fluid within the flow path 206, monitor the temperature within the heating and cooling element 210, and/or be configured to monitor the temperature of the phase-change material within the frame 202. Additionally, one or more flow meters 218 may be configured along the flow path 206 to monitor the flow rate of the operating fluid through the flow path 206 and may monitor the flow rate of the operating fluid into the frame 202/heat exchange elements 204, as shown in FIG. 2.

[0047] Turning now to FIG. 3, a schematic of a heat exchange element in accordance with embodiments of the disclosure is shown having a partial cut-away showing an interior thereof. Heat exchange element 300, as shown, is a plate-type heat exchange element that is configured to have a fluid pass through a body 302 of the heat exchange element 300. A second fluid, such as a phase-change material may be in fluid contact with an exterior of the body 302. The body 302 of the heat exchange element 300 is configured to prevent fluid communication through the body 302, thus fluidly separating the two media, but allowing thermal communication between the media.

[0048] The heat exchange element 300 includes a first support 304 and a second support 306, with the body 302 extending therebetween. The first support 304 and the second support 306 may each be hollow supports that allow for fluid to pass through the interior of the supports 304, 306 or a portion of the interior of the supports 304, 306. An operating fluid may enter the heat exchange element 300 at an inlet 308 that is on the first support 304. The operating fluid may then pass through the body 302 of the heat exchange element 300. The operating fluid may then exit the heat exchange element 300 through an outlet (not shown) that is configured on the second support 306. The inlet 308 and the outlet may be positioned on opposite ends of the heat exchange element 300.

[0049] The first support 304 and the second support 306 may each contain mounts 310 that are configured to enable the heat exchange element 300 to be mounted within a frame, similar to that shown in FIGS. 1 and 2. The mounts 310 may be configured to be retained by or engage expansion elements, such as springs, wires, and/or rod elements, thus allowing the heat exchange element 300 to move within the frame.

[0050] In FIG. 3, the operating fluid may move from the bottom of the page to the top of the page, with the operating fluid exiting the heat exchange element 300 at the top right portion on the page. Thus, the operating fluid flow will start at the base or bottom of the page and then progress upward. This enables a controlled or directed freeze front as phase-change material that is in contact with an exterior of the heat exchange element 300 changes phase, e.g., from a liquid to a solid or a solid to a liquid.

[0051] Also shown in FIG. 3 is a cut-away 312 interior view of the body 302. As shown, the cut-away 312 shows the structure of the interior of the body 302. The interior of the body 302 may be formed with one or more channels 314 that are configured to direct the operating fluid as it passes through the body 302 of the heat exchange element 300. The channels 314 as shown run from left to right on the page, but it will be appreciated that the channels may be configured to run from bottom to top, or in some other manner, without departing from the scope of the disclosure.

[0052] The structure of the body 302 may include a plurality of surface area structures 316 housed between parting sheets 318 (only a portion of the parting sheet 318 is shown for illustrative purposes). The surface area structures 316, in some embodiments, may be configured as fins. That is, fins or folds may be housed beneath parting sheets so that the surface area is maximized.

[0053] As shown, the surface area structures 316 may include a plurality of perforations 320. The perforations 320 may be holes, apertures, etc., that allow the operating fluid to be directed through the body 302 of the heat exchange element 300. In some embodiments, the parting sheets 318 may be omitted allowing direct fluid contact between an operating fluid and a phase-change material at the surface of the surface area structures 316. However, in such embodiments, the perforations 320 must also be omitted to prevent fluid mixing of the two media.

[0054] The configuration of surface area structures 316 and/or perforations 320 may be configured to control the freeze front as it passes along the body 302. For example, the number of surface area structures 316 per inch (e.g., surface area structure density) within the body may allow the amount of thermal contact to be controlled or defining the surface area of contact. Thus, the heat exchange element 300 may be configured to direct a freeze front within a frame or tank, such as shown in FIGS. 1 and 2. In some embodiments, the surface area structure density may be greatest in the center of the body 302, encouraging the phase-change material to solidify (change to ice) in the center and grow outward. The growth of the ice is the freeze front. In some embodiments, in combination with or instead of a central start to the freeze front, the operating fluid may be introduced at the bottom of the heat exchanger element 302 and encourage a freeze front that expands upward relative to the heat exchange element 302.

[0055] A controlled freeze front is one factor that enables water to be used as the phase-change material in a phase-change material heat exchanger. By defining where the ice will form first, packets or trapped water may be prevented, thus eliminating the risk posed by ice forming within an enclosed space and causing damage. Further, by allowing the heat exchange elements to be moveable with respect to each other, as the ice expands, the heat exchange elements may not impeded the expansion of the ice along the freeze front.

[0056] Turning now to FIGS. 4A-4D, various configurations of surface area structures in accordance with various embodiments are shown. FIG. 4A shows the surface area structures configured as perforated folds or fins. Due to the perforations, parting sheets (not shown) may be placed on the exterior or peaks of the folds or fins to prevent fluid mixing.

[0057] FIG. 4B shows the surface area structures configured as extended fins. In FIG. 4B, the fins extend further away from a central body than the fins shown in FIG. 4A. In FIG. 4C the surface area structures are configured as a plurality of pins. In FIG. 4D the surface area structures are configured as enhanced pins, having a large three dimensional structure than the pins shown in FIG. 4C. The various configurations shown in FIGS. 4A-4D are merely for illustrative purposes, and those of skill in the art will appreciate
that the surface area structures may take any form, shape, geometry, configuration, density, etc., without departing from the scope of the disclosure.

[0058] Turning now to FIG. 5, a process in accordance with the disclosure is shown. Process 500 is a method for employing water as a phase-change material in a phase-change material heat exchanger. At step 502, an operating fluid at a first temperature is pumped into a phase-change material heat exchanger. The phase-change material in the phase-change material heat exchanger is water, and the operating fluid at the first temperature is at a temperature sufficiently low to freeze the water, i.e., convert the liquid water to solid ice.

[0059] As the operating fluid is pumped into the heat exchanger, at step 504 a freeze front is caused to form such that the water in the heat exchanger may freeze into ice, thus expanding, without damaging the heat exchanger. The freeze front is configured or formed such that the volumetric expansion of the water turning to ice is accommodated for.

[0060] At step 506, the operating fluid, now at a second temperature that is warmer than the first temperature, is conveyed out of the heat exchanger, and the heat exchanger is filled with solid ice.

[0061] At step 508, operating fluid at a third temperature may be pumped or conveyed into the heat exchanger. The temperature may be sufficiently hot to melt ice, thus converting the ice back to water.

[0062] At step 510, the operating fluid now at a fourth temperature is conveyed out of the heat exchanger. The fourth temperature is lower than the third temperature.

[0063] It will be appreciated that the process 500 may employ a heat exchanger that is similar to that described above and shown in FIGS. 1 and 2. Further, the process may employ surface area structures, as described above, to assist in generating and controlling a freeze front to compensate for the volumetric expansion of water as it is converted to ice. Furthermore, the heat exchange elements within the heat exchanger used in the process 500 may be similar to that described above and configured to be moveable relative to each other to further compensate for the volumetric expansion of the water as it is converted to ice.

[0064] It will be appreciated that the above heat exchangers and processes are described with respect to forming ice within a chamber from liquid water, but that the opposite transition is also important. That is, once the ice is formed, it will be ready to absorb thermal energy from a hot operating fluid. As noted above, the latent heat of ice is significantly higher than the latent heat of wax, which has been traditionally used in phase-change material heat exchangers. As such, when ice is contained within the chamber of the heat exchanger, the operating fluid, at a very high temperature, may be passed through the heat exchanger and the ice may be melted, changing the phase of the water from a solid to a liquid by the absorption of thermal energy from the operating fluid.

[0065] Advantageously, embodiments described herein provide a phase-change material heat exchanger that employs water/ice as the phase-change material. Further, advantageously, embodiments described herein allow for a 225% increase in volume efficiency over wax-based phase-change material heat exchangers. That is, for the same amount of thermal cooling, a much smaller heat exchanger may be used, or in contrast, based on the same size, a much larger or faster cooling may be achieved with embodiments described herein. For example, the heat exchanger volume may be reduced by about 60% when embodiments disclosed herein are employed, over wax-based heat exchangers.

[0066] Further, advantageously, embodiments described herein allow for easy maintenance because water is a readily available and non-toxic resource that may be easily replenished, flushed from the system, etc.

[0067] While the present disclosure has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the present disclosure is not limited to such disclosed embodiments. Rather, the present disclosure can be modified to incorporate any number of variations, alterations, substitutions, combinations, sub-combinations, or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the present disclosure. Additionally, while various embodiments of the present disclosure have been described, it is to be understood that aspects of the present disclosure may include only some of the described embodiments.

[0068] For example, although shown and described with respect to a plate-type heat exchanger, those of skill in the art will appreciate that a shell-and-tube heat exchanger may be configured by employing embodiments and configurations disclosed herein. In some shell-and-tube heat exchanger embodiments, the heat exchanger may be configured to float within an ice/water bath similar to the plate-fin heat exchanger described herein.

[0069] Accordingly, the present disclosure is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

What is claimed is:

1. A phase-change material heat exchanger comprising: a frame configured to define a chamber therein and house a first fluid, the first fluid being water; and at least one heat exchange element configured to have a second fluid pass through an interior of the heat exchange element, the at least one heat exchange element moveably retained within the chamber; wherein when the second fluid passes through the heat exchange element at a first temperature, the first fluid changes from a liquid to a solid, and the second fluid exits the heat exchange element at a second temperature that is higher than the first temperature.

2. The heat exchanger of claim 1, wherein the at least one heat exchange element includes a plurality of surface area structures on an exterior surface thereof.

3. The heat exchanger of claim 2, wherein the plurality of surface area structures are at least one of fins and pins.

4. The heat exchanger of claim 1, wherein the at least one heat exchange element has a plate configuration.

5. The heat exchanger of claim 1, wherein the at least one heat exchange element is configured to define a freeze front of the first fluid along an exterior surface of the at least one heat exchange element.

6. The heat exchanger of claim 1, wherein the second fluid is an operating fluid for a high powered laser.

7. The heat exchanger of claim 1, wherein the frame defines a tapered shape with a bottom of the frame being narrower than a top of the frame.

8. The heat exchanger of claim 1, further comprising at least one expansion element configured to support the at least one heat exchange element within the chamber.
9. The heat exchanger of claim 8, wherein the at least one expansion element is a spring.

10. The heat exchanger of claim 1, further comprising a membrane retained about the frame and configured to expand when the first fluid changes from a liquid to a solid.

11. The heat exchanger of claim 1, wherein the at least one heat exchange element comprises a first support and a second support, with a body extending between the first support and the second support.

12. The heat exchanger of claim 1, further comprising an enclosure, wherein the enclosure includes the frame and at least a portion of the enclosure is configured to expand in response to water freezing.

13. A method of using a phase-change material heat exchanger, the method comprising:
   conveying an operating fluid at a first temperature through at least one heat exchange element, the at least one heat exchange element disposed within a chamber of a phase-change material heat exchanger, the chamber filled with water;
   causing the water to phase change from a liquid to a solid within the chamber; and
   conveying the operating fluid out of the at least one heat exchange element at a second temperature that is higher than the first temperature.

14. The method of claim 13, the method further comprising conveying the operating fluid through the at least one heat exchange element at a third temperature when the chamber is filled with ice.

15. The method of claim 14, wherein the third temperature is a temperature sufficiently high to phase change the ice to liquid water when passing through the at least one heat exchange element.

16. The method of claim 13, further comprising forming a freeze front progression within the chamber such that a volumetric expansion of the water when freezing does not damage the phase-change material heat exchanger.

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