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(54) **ACTIVE AND PASSIVE COOLING FOR AN ENERGY STORAGE MODULE**

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(57) **ABSTRACT**

The present disclosure relates to cooling an energy storage module using passive and active cooling techniques. Passive cooling is provided by storing heat in a phase change material that is contact with the energy storage cells of the energy storage module. Active cooling is provided by circulating coolant through coolant passages that are in thermal contact with the energy storage cells. A control system for determining the temperature of the energy storage module and controlling coolant flow when the temperature reaches a predetermined threshold is disclosed.

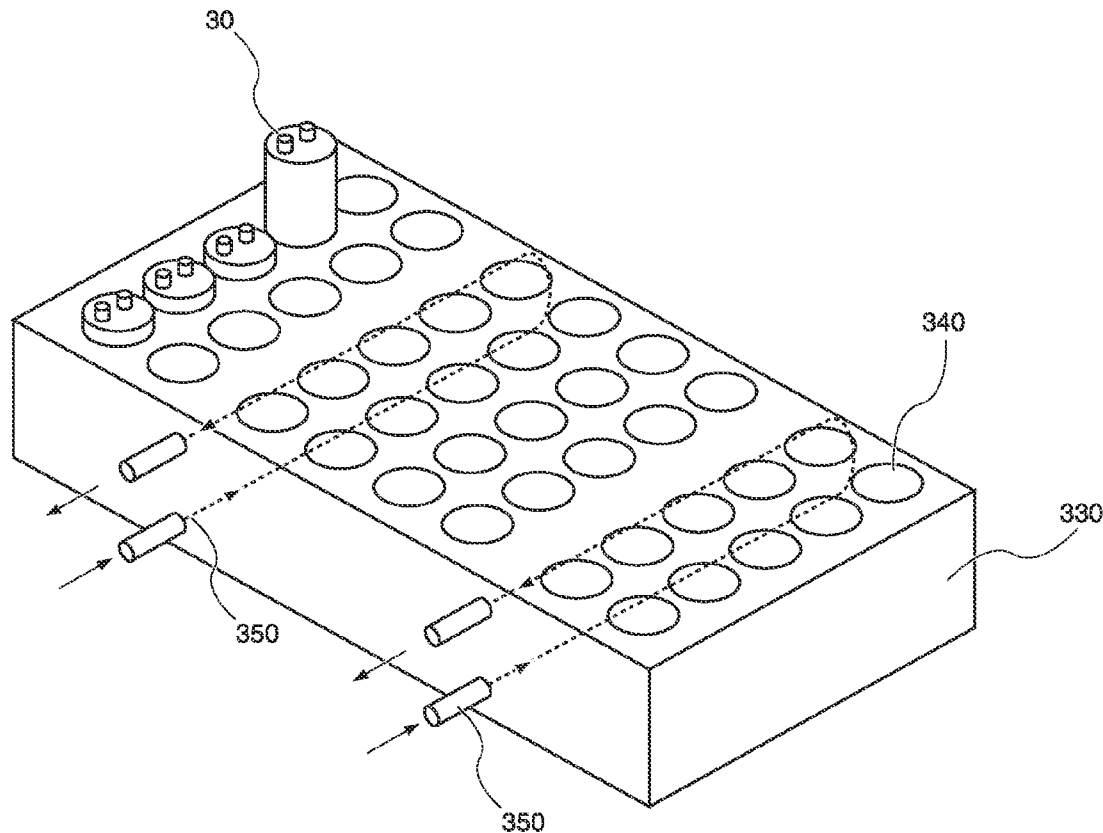
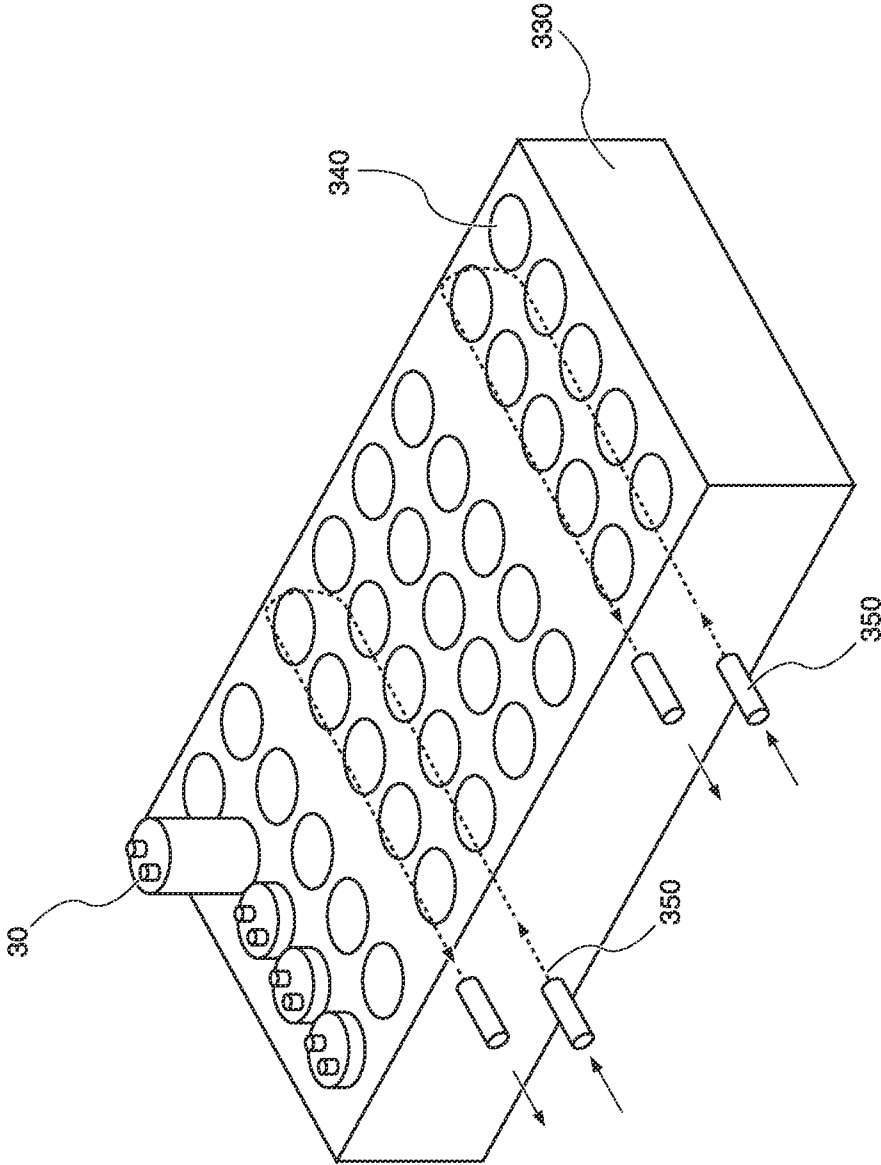


FIG. 1



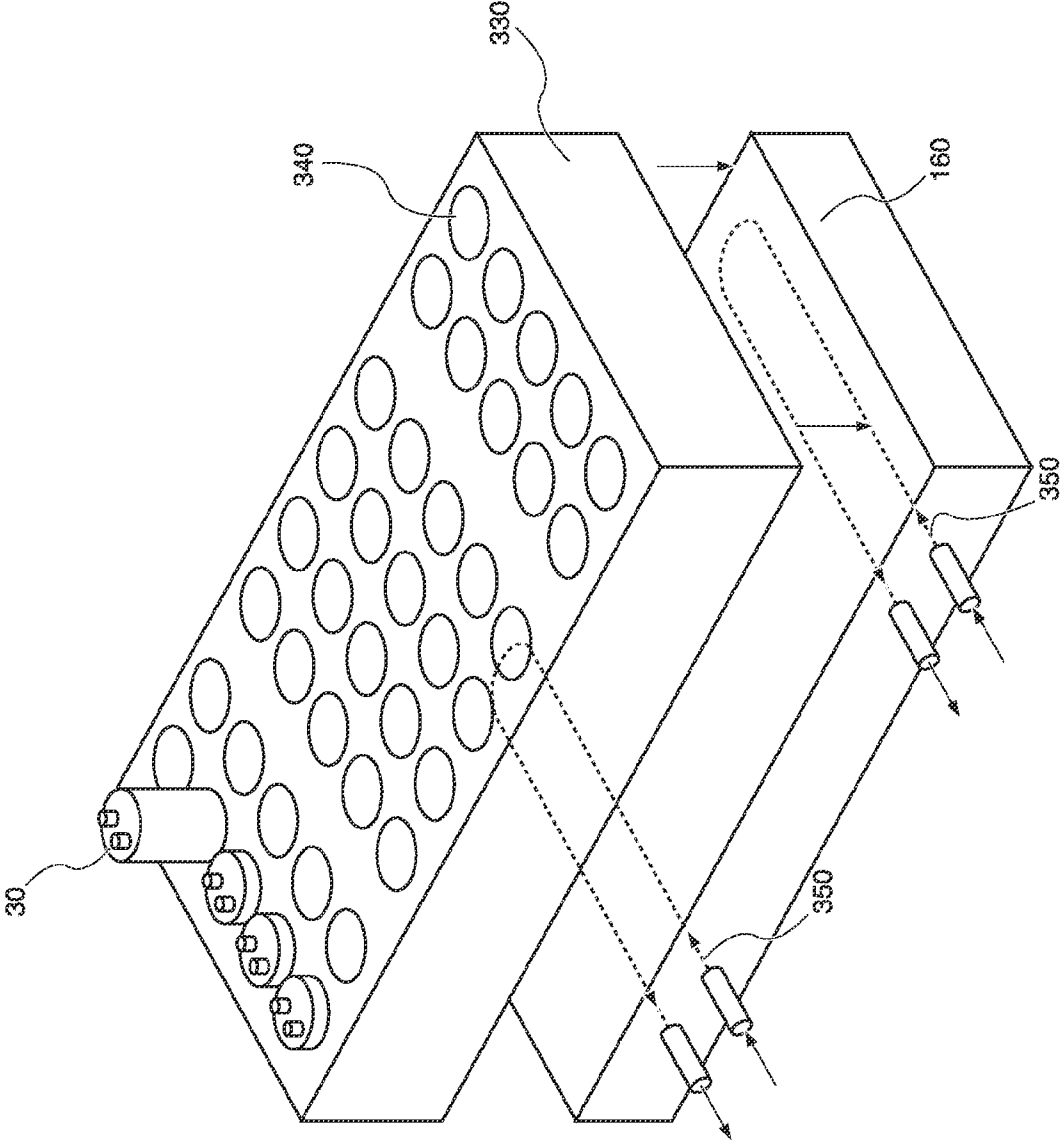
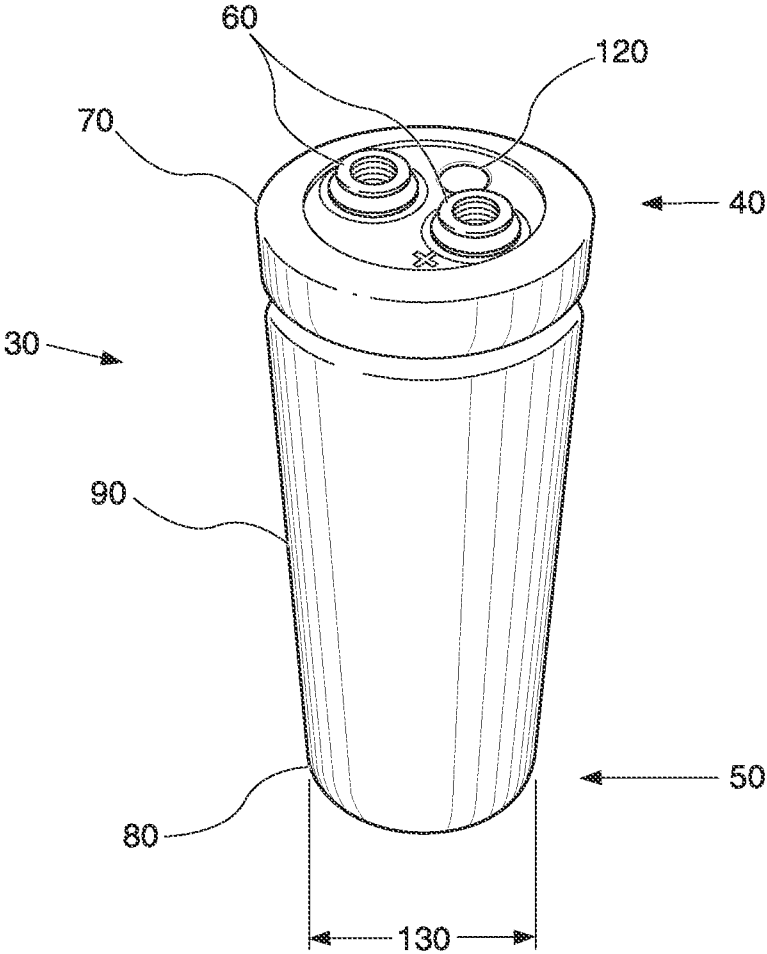
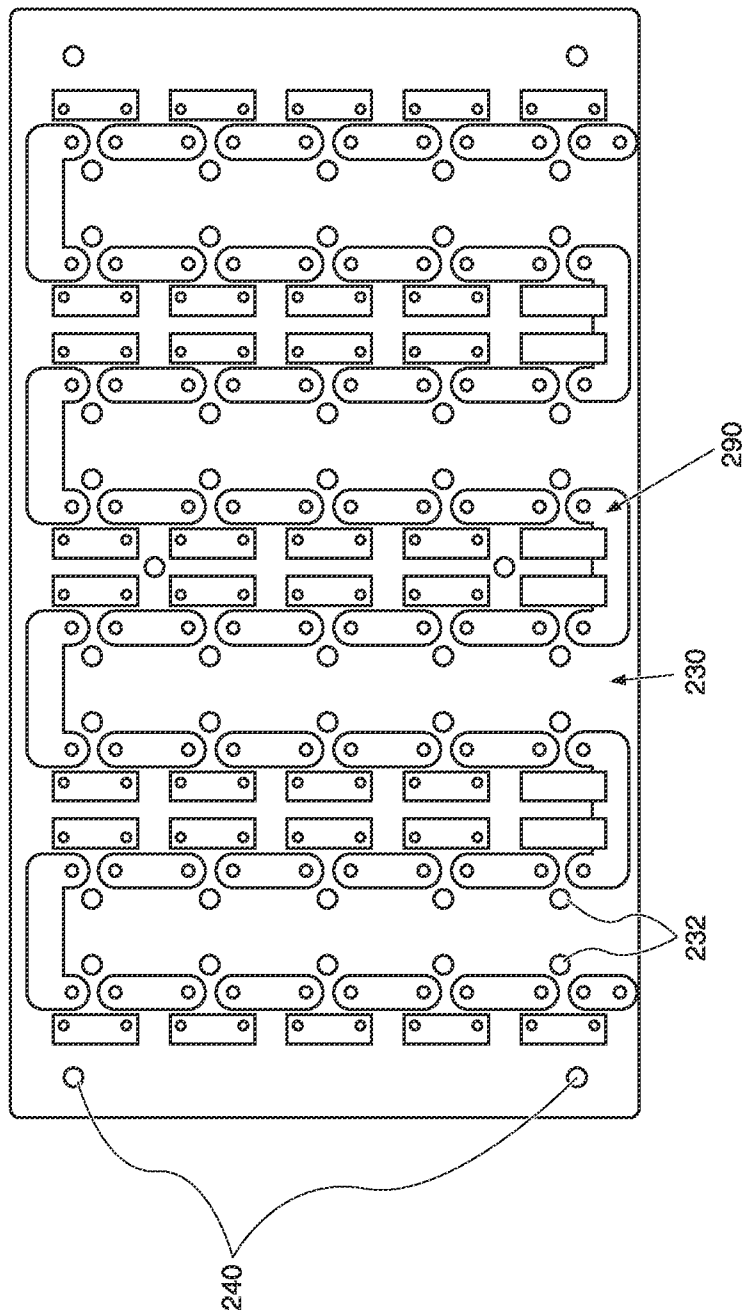


FIG. 2

**FIG. 3**



**FIG. 4**



**FIG. 5**

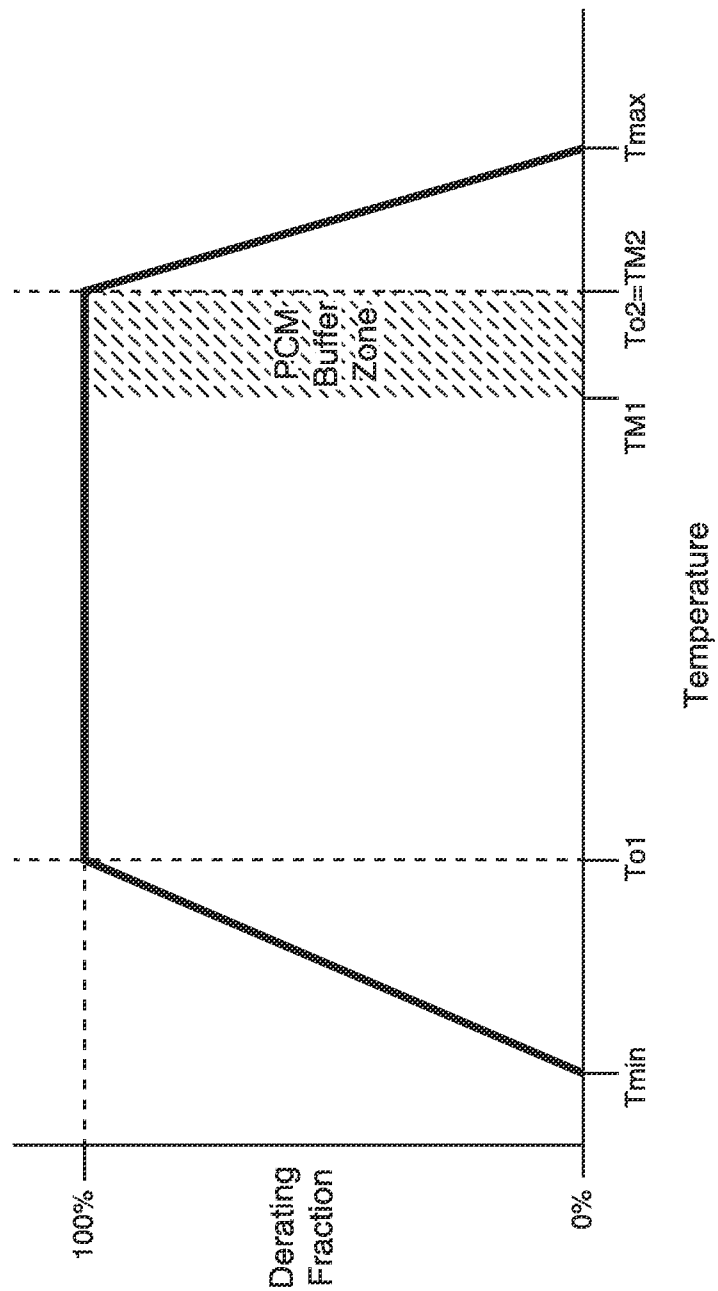


FIG. 6

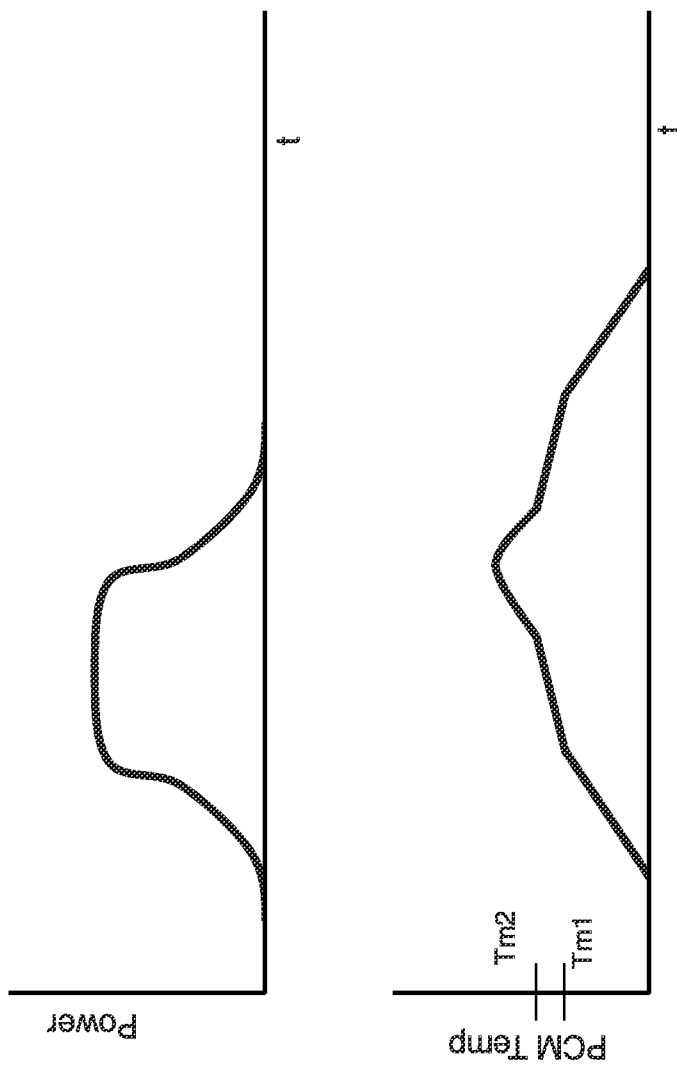


FIG. 7

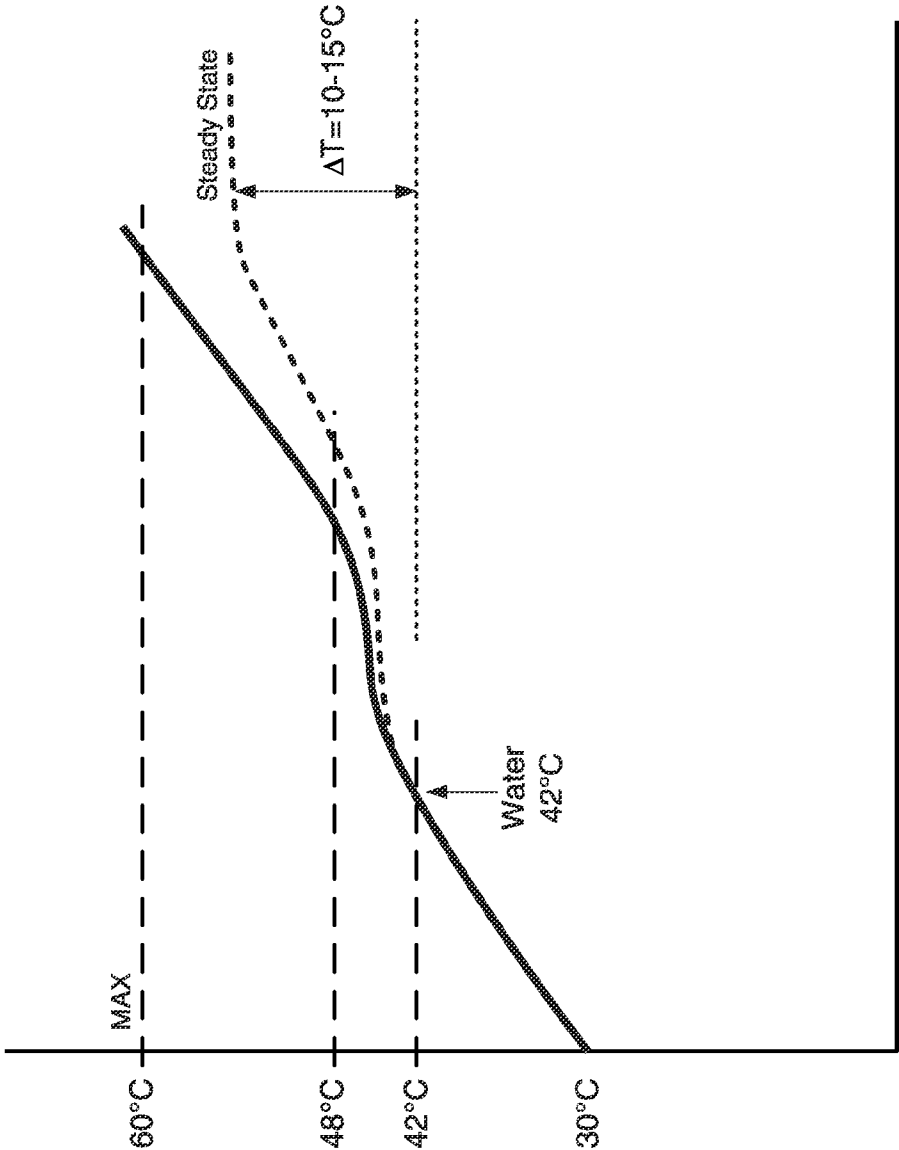
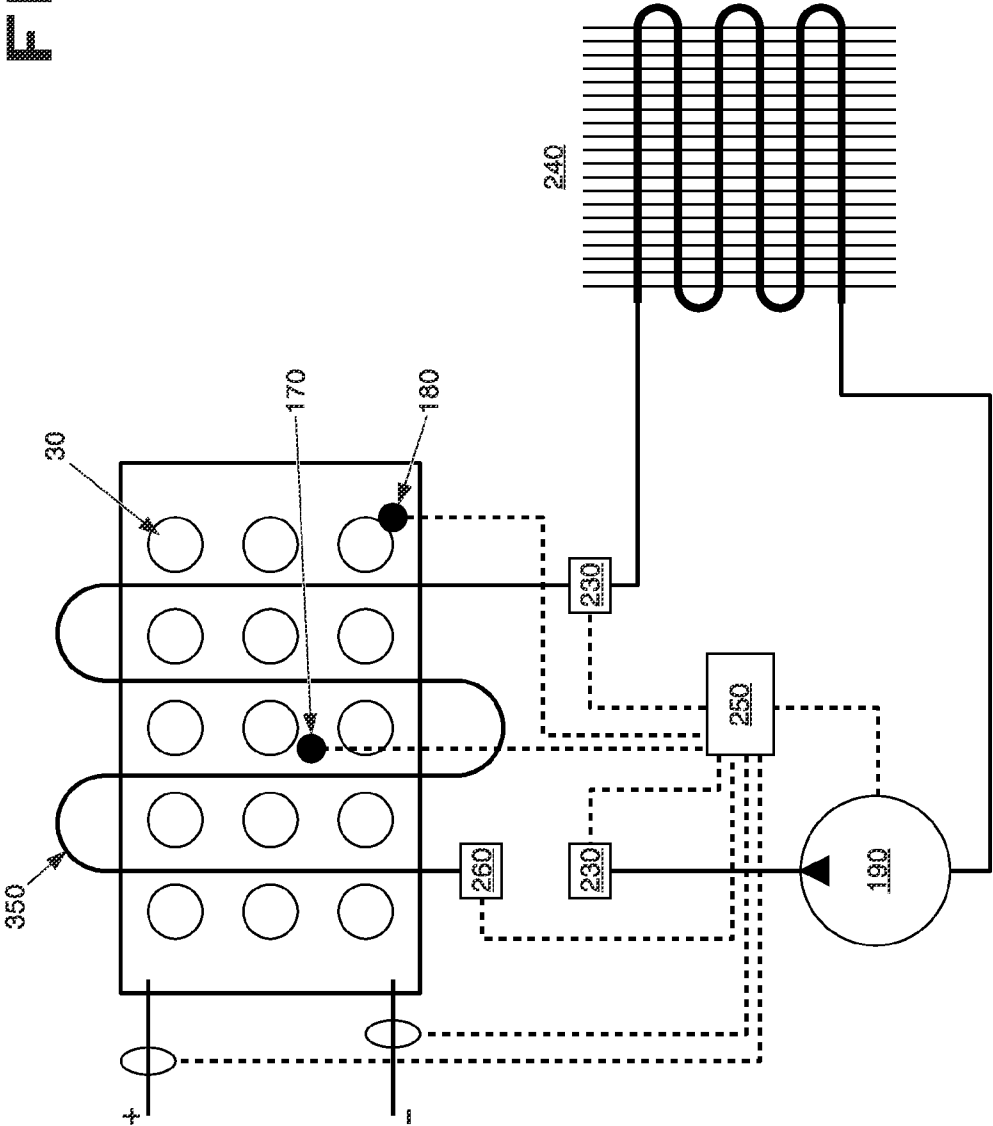
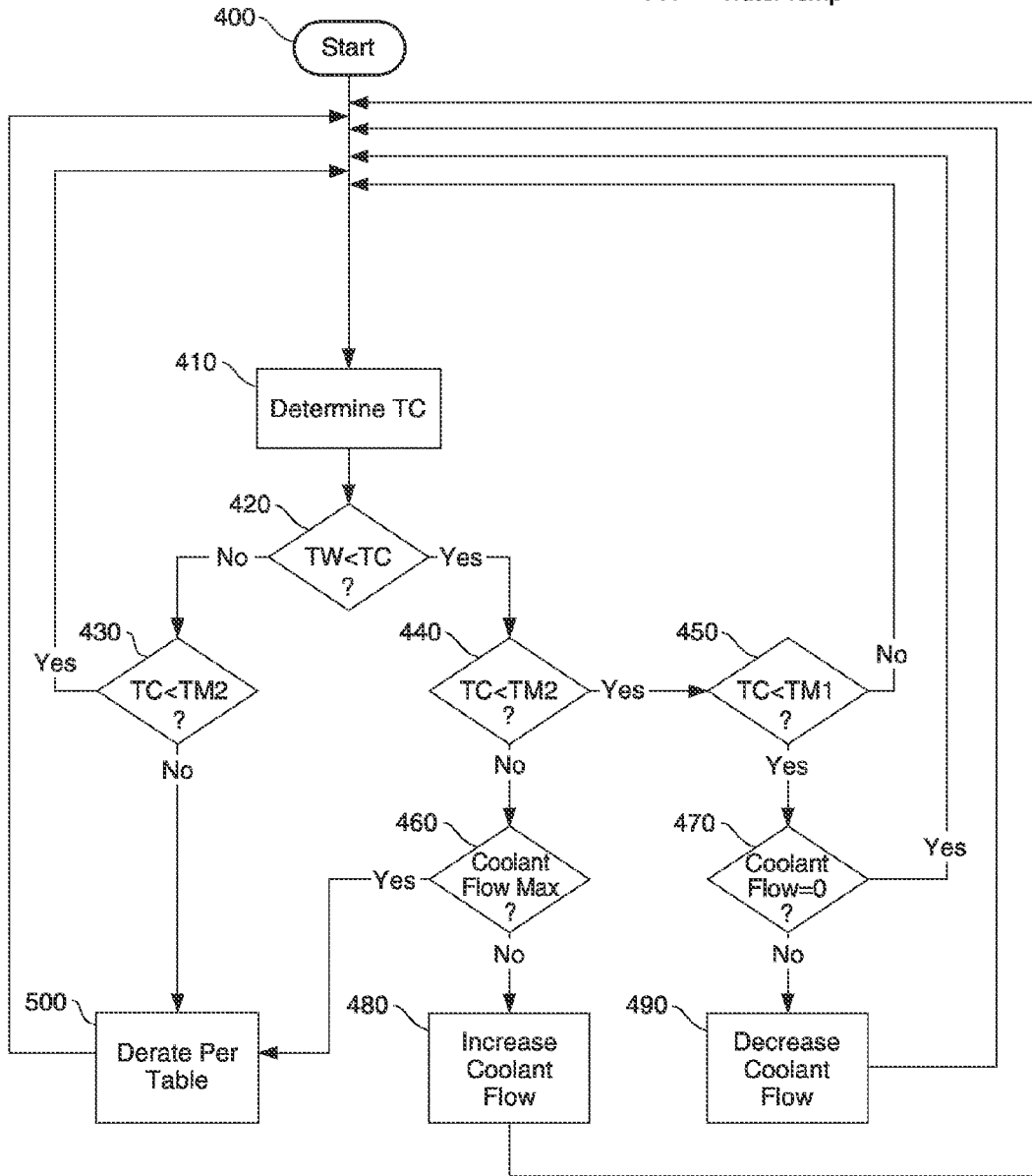


FIG. 8



# FIG. 9

TC = Sensed Temp  
TM1= Begin Melt  
TM2= End Melt  
TW = Water Temp



## ACTIVE AND PASSIVE COOLING FOR AN ENERGY STORAGE MODULE

### TECHNICAL FIELD

[0001] The present disclosure relates cooling an energy storage module, and more particularly, an energy storage module equipped with coolant passages and a phase change material.

### BACKGROUND

[0002] Energy storage modules are increasingly used in mobile and stationary applications. Uses include hybrid and electric drive vehicles, as well as stationary power generation. The modules usually contain battery or ultracapacitor cells as a way of storing electrical energy for long periods of time, and/or rapidly charging or discharging as needed. The charge/discharge process quickly generates a large amount of heat, which should be managed. Also, the performance and life of the cells depends upon their temperature. Therefore, the steady state temperature of the cells should be managed.

[0003] A further requirement of the energy storage module is that it is capable of operation when exposed to harsh environments. Shock and vibration are problematic when packaging energy storage cells into an energy storage module. The cells should be packaged such that they are not allowed to move rotationally, radially, or axially. Such movement can break inter-cell connections or wear through the protective case of the cell. The energy storage module should protect against shock and vibration while still managing thermal issues.

[0004] Excess heat or a manufacturing defect can lead to high levels of heat in a cell which can then cause the destruction of the cell, known as thermal runaway. Destruction of a cell can cause heat damage to adjacent cells which can in turn cause destruction of one or more of the adjacent cells. This is known as cell propagation. Effective thermal management of the energy storage module can prevent thermal runaway and cell propagation.

[0005] A known technique for cooling energy storage modules includes circulating coolant between the energy storage cells. Coolant passages are typically incorporated into the energy storage module such heat within the storage cells is transferred to the circulating coolant. Coolant is circulated by a pump through the energy storage module and then through a radiator or other type of heat exchanger. Coolant must be circulated whenever a predetermined portion of the energy storage module reaches a maximum allowed temperature.

[0006] A phase change material has been used within energy storage modules to eliminate the need for coolant circulation. The material is typically made of graphite that is impregnated with paraffin wax. Such a material is described in U.S. Pat. No. 6,468,689 to Al-Hallaj et al of Chicago, Ill. The phase change material is thermally conductive and is capable of absorbing heat in the form of latent heat as the paraffin changes state from solid to liquid. The phase change material acts as a normal heat sink material after the paraffin has reached the liquid state. The phase change material works well and can eliminate the need for circulation of coolant if either the heat generated by the storage cells or the ambient temperature does not exceed the melting temperature of the paraffin wax.

### SUMMARY OF THE INVENTION

[0007] A method for cooling an energy storage module is disclosed. The method comprises determining a first temperature in an energy storage module. The energy storage module comprises an array of energy storage cells, a phase change material in thermal contact with a coolant passage and the energy storage cells, comparing the first temperature to a first and second threshold, and changing coolant flow through the coolant passage based on the comparison.

[0008] Further, another aspect of a method for cooling an energy storage module is disclosed. The method comprises determining a first temperature in an energy storage module. The energy storage module comprises an array of energy storage cells, a phase change material in thermal contact with a coolant passage and the energy storage cells, measuring a coolant temperature, comparing the first temperature and the coolant temperature, and taking a corrective action based on the comparison.

[0009] Further, a system for managing thermal conditions of an energy storage module is disclosed. The system comprises a pump for providing coolant flow, a valve configured to receive signals from a controller and to control the coolant flow. The controller is configured to receive a first temperature from a first temperature sensor in an energy storage module. The energy storage module comprises an array of energy storage cells, a phase change material in thermal contact with a coolant passage and the energy storage cells, compare the first temperature to a first and second threshold, and send a signal to the valve to control coolant flow through the coolant passage based on the comparison.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 shows one aspect of the current disclosure

[0011] FIG. 2 shows another aspect of the current disclosure

[0012] FIG. 3 shows a storage cell consistent with the current disclosure

[0013] FIG. 4 shows another aspect of the current disclosure

[0014] FIG. 5 shows a plot consistent with the current disclosure

[0015] FIG. 6 shows another plot consistent with the current disclosure

[0016] FIG. 7 shows another plot consistent with the current disclosure

[0017] FIG. 8 shows a control system consistent with the current disclosure

[0018] FIG. 9 shows a flow chart consistent with the current disclosure

### DETAILED DESCRIPTION

[0019] The present disclosure relates to an energy storage module 10 as shown in FIG. 1. The energy storage module 10 secures energy storage cells 30 in a manner suitable for use in harsh environments or heavy duty mobile applications.

[0020] The energy storage cells 30 could be battery cells or capacitors, particularly ultracapacitors.

[0021] Energy storage packages are commonly used in electric drive vehicles, hybrid vehicles, and stationary power generators. In electric drive applications, the energy storage package stores energy from deceleration and provides power for traction motors in order to propel a vehicle. In hybrid applications, the energy storage package stores energy from

deceleration and augments an engine in providing power in order to propel a vehicle. In stationary power generator applications, the energy storage package can be used to augment the primary engine and generator. Large amounts of power are charged to and discharged from the energy storage package in these applications. As the life and performance of the energy storage cells 30 is dependent on temperature, it is important to provide cooling for the cells.

[0022] The storage cells 30 themselves are either a battery or a capacitor. In the case of a battery, voltage of an individual cell will vary between 1.2 V and 3.4 V depending on battery chemistry. Many battery cells are connected in series in order to achieve an energy storage package with enough voltage to supply the higher voltage required in a vehicle propulsion system or stationary power application. This system voltage is typically 300-600 V, but can be as high as 3300 V in high power applications.

[0023] The storage cell 30 may alternatively be a capacitor. Examples include electrolytic capacitors, supercapacitors, and ultracapacitors. Due to their high energy density, electric double-layer capacitors (EDLC) are typically used. EDLCs are commonly known as ultracapacitors. The individual ultracapacitor cells are typically several hundred Farads up to several thousand Farads and have a voltage capacity of 2.5 V. Power capacity varies, but is approximately 40 W in steady-state and up to 180 W peak. Like the battery cells, many ultracapacitor cells are connected in series in order to achieve an energy storage package with enough voltage to supply the higher voltage required in a vehicle propulsion system or stationary power application.

[0024] Referring to FIG. 3, the storage cells 30 are generally cylindrical in shape with a diameter 130. The surface of the cylinder is composed of a case 90. The terminal end 40 and non-terminal end 50 of the cylinder is formed by a terminal end cap 70 and a non-terminal end cap 80. Other external features of the storage cell 30 are the connection terminals 60 and a vent 120. The connection terminals 60 serve to electrically connect the cell between the internal cathode and anode and an external electrical circuit. The connection terminals 60 also provide a means for mechanically connecting to an external circuit. The connection terminals 60 may include a threaded hole, threaded post, a press-fit post, or the like.

[0025] The vent 120 serves to allow gases to escape the cell in the event of an electrical short of or a thermal failure. Gases escaping through the vent 120 prevent the case 90 from bursting during such a failure.

[0026] As stated above, storage cells 30 are typically connected in series in order to meet the voltage and power required in a vehicle propulsion system or stationary power application. This requires a physical package that can accommodate from dozens to hundreds of storage cells 30. In order to achieve the power density required from the package, storage cells 30 are typically packaged in a matrix with their axes aligned physically in parallel. Such an efficient package helps to achieve a high energy density. The package should properly locate the cells, protect them from the environment, and provide adequate thermal management.

[0027] As shown in FIG. 4, storage cells 30 are connected in series by connecting the anode of one to the cathode of another and so on until the number of required series storage cells 30 is reached. Connection between cells is achieved by means of a conductive bus bar 290. Alternatively a printed circuit board with very thick conductive traces can be used

that includes provisions for connecting to the storage cells 30. The printed circuit board may also mount components related to cell monitoring or balancing.

[0028] One way to control the temperature of the storage cells 30 is by surrounding them in a thermally conductive material 310 that serves as a heat sink. The thermally conductive material 310 would serve to mechanically locate the storage cells 30 as well as conducting heat away from the storage cells 30. The thermally conductive material 310 will conduct the heat throughout the material. Heat from a storage cell 30 may also be conducted into an adjacent storage cell 30.

[0029] The thermally conductive material 310 is to be formed into a block 330. A matrix of generally cylindrical voids 340 is formed into the block in order to accept the storage cells 30. The spacing of the rows and columns of the matrix is such that the gap is small enough to allow for high energy density of the module while large enough to allow proper heat conduction away from the storage cells 30.

[0030] The cylindrical voids 340 are sized so that the storage cells 30 can be inserted in a press-fit relationship. A press-fit ensures that a) there is enough contact to ensure thermal conduction from the storage cell 30 to the thermally conductive material 310 and b) that the storage cell 30 is secured from motion in the radial direction.

[0031] According to the system and method of the current disclosure, the thermally conductive material 310 is a phase change material (PCM) 320. The PCM 320 is capable of temporarily storing heat from the storage cells 30 as latent heat. Such a material is described in U.S. Pat. No. 6,468,689 to Al-Hallaj et al of Chicago, Ill.

[0032] The performance of storage cells 30 is dependent on temperature. In the case of a battery, the charge capacity, internal resistance, and operating life degrade with increasing temperature. In the case of an ultracapacitor, the capacitance, internal resistance, and operating life degrade with increasing temperature. Such storage cells 30 generate a considerable amount of heat during charging and discharging and this heat should be managed in some manner in order to preserve performance.

[0033] FIG. 5 shows the relative performance of a storage cell 30 versus temperature. Storage cell 30 performance is approximately 100% from a lower operating temperature  $To1$  to an upper operating temperature  $To2$ . This represents the normal operating temperature range of the storage cell 30. As an example,  $To1$  may be around 0 degrees C. while  $To2$  may be around 45 degrees C. Storage cell 30 electrical performance is degraded below  $To1$  and above  $To2$ . The minimum operating temperature  $Tmin$  and maximum operating temperature  $Tmax$  are considered the limits of storage cell 30 operation. As an example,  $Tmin$  may be around -30 degrees C., while  $Tmax$  may be around 60 degrees C. Typically the performance of the storage cell 30 is considered to degrade linearly from  $To1$  to  $Tmin$  and from  $To2$  to  $Tmax$ .

[0034] Degradation of the electrical performance of the energy storage cell 30 with temperature is often compensated by limiting the power that is delivered to it. This is commonly known as de-rating the capabilities of the device. De-rating is typically expressed as percentage of the normal electrical performance. A controller 250 may be configured to sense temperature from one or more temperature sensors 170. The controller 250 may then limit the power that is delivered to the energy storage module 10 and therefore the energy storage cells 30. Power may be limited by limiting voltage, current or both.

[0035] Ambient temperature can also cause increase the temperature of the storage cell 30. Ambient heat can be absorbed from outside the energy storage module 10 into the storage cell 30 and limit the operating range. For instance, if the energy storage module 10 is operating in a 40 degree C. environment, there may only be a 5 degree C. margin before the performance of the storage cell 30 needs to be de-rated. Examples of environments that experience high ambient temperatures include deserts, under-hood applications, and generator set enclosures.

[0036] It should also be appreciated that since many storage cells 30 are electrically connected in series, the performance of the entire series network could be limited by the performance of the weakest cell. It should therefore be appreciated that all storage cells 30 should be maintained at approximately the same temperature.

[0037] The PCM 320 provides two primary thermodynamic functions. The first function is to conduct heat away from the storage cells 30. The PCM 320 is thermally conductive, which may be anisotropic. The thermal conductivity of the PCM 320 is provided primarily by the graphite structure. Heat is conducted away from the storage cells 30 and is dissipated in either the housing 150 or into a heat sink configured for this purpose. The second function is to store latent heat. Latent heat capacity is provided by a material, typically paraffin, that is engineered to change phase in a predetermined temperature range. The paraffin begins to change from solid to liquid at temperature  $T_{m1}$ . The paraffin has completely changed phase to a liquid at temperature  $T_{m2}$ . The material properties of the graphite structure of the PCM 320 holds the paraffin in place even after it has changed to a liquid phase. Storage of latent heat in the PCM 320 will be referred to in this disclosure as "passive cooling".

[0038] As the storage cells 30 produce heat, the PCM 320 conducts heat away from the storage cells 30 and the net temperature of the block 330 of PCM 320 increases. Refer to FIG. 6. The temperature of the PCM 320 will continue to rise as the storage cells 30 produce heat until the temperature of the PCM 320 reaches  $T_{m1}$ . At this point, the temperature of the PCM 320 will stabilize as the paraffin begins to change phase and heat from the storage cells 30 is stored as latent heat. The temperature of the PCM 320 will continue to be stable until it reaches  $T_{m2}$ . At this point the paraffin has completed the transition from solid to liquid and can no longer store latent heat. The temperature of the PCM 320 will then continue to rise as before.

[0039] The melting temperature range ( $T_{m1}$  to  $T_{m2}$ ) can be engineered to generally coincide with the upper operating temperature  $To2$  of the storage cells 30. For instance,  $T_{m2}$  can be engineered to approximately equal  $To2$ . During charging and discharging the energy storage module 10, the PCM 320 will conduct heat away from the storage cells 30. If the charging and discharging cycle is low enough in power or short enough in duration or ambient temperature is low enough, the storage cells 30 will remain below their upper operating temperature  $To2$ . Charging/discharging cycles that are higher in power or longer in duration or higher ambient temperature will cause the temperature of the PCM 320 to rise above  $T_{m1}$  and the extra heat will be absorbed as latent heat, and the storage cells 30 will still remain below their upper operating temperature  $To2$ . Charging/discharging cycles that are still higher in power or still longer in duration or still higher ambient temperature will cause the temperature of the PCM 320 to rise above  $T_{m2}$ . In the latter condition, the PCM 320

can no longer store latent heat. The performance of the energy storage module 10 must be de-rated in order to keep the energy storage cell 30 below  $To2$  unless some other way to remove heat is provided.

[0040] In addition to the passive cooling provided by the block 330 of PCM 320, an active cooling loop 322 could be incorporated. Refer to FIGS. 1 and 2. An active cooling loop 322 is to be provided such that a heat transfer fluid can be circulated through coolant passages 350 and circulate through the block 330 of PCM 320. The active cooling loop 322 could be used in combination with a pump 190 and heat exchanger 240 as is known in the art. The active cooling loop 322 could for instance be formed by a pipe made of thermally conductive metal such as copper or aluminum. Efforts should be made to secure the active cooling loop 322 in the graphite material of the PCM 320 while the graphite material is compressed. A supporting structure, such as a rack or standoffs could be incorporated either inside or outside the graphite material during the manufacturing process. In addition, a supporting medium 324 within the active cooling loop 322 may be needed to keep the active cooling loop 322 from being deformed or crushed during the manufacturing process. The supporting medium 324 would need to be capable of removal after the manufacturing process in order for the heat transfer fluid to be able to flow through the active cooling loop 322. Examples of suitable supporting medium 324 could be sand, paraffin wax (melted and removed afterwards), or an incompressible fluid such as water or oil. The open ends of the active cooling loop 322 would need to be blocked during manufacturing in order to retain the supporting medium 324.

[0041] Alternatively, the PCM 320 could be mounted to and thermally connected to a cold plate 160 as shown in FIG. 2. The cold plate 160 could be made from a thermally conductive metal such as copper or aluminum. The cold plate 160 would incorporate one or more coolant passages 350 and may include fittings for connecting hoses and such.

[0042] The coolant passages 350 incorporated into the energy storage module 10 may be connected to other components needed circulate coolant and dissipate heat as shown in FIG. 8. Such components include a pump 190, a valve 230, and a heat exchanger 240. Other components such as bypass valves, hoses, tanks, and fittings are not shown. A controller 250 is electrically connected to a first temperature sensor 170 and possibly a second temperature sensor 180. The controller 250 is also electrically connected to and configured to control pump 190 and valves 230.

[0043] One or more temperature sensors may be placed within the energy storage module 10. For example, it may be useful to have a first temperature sensor 170 close to a centrally-located storage cell 30. During charging and discharging, the centrally-located storage cell 30 may be the hottest part of the energy storage module 10. It may also be useful to have a second temperature sensor 180 close to the outside of the energy storage module 10. During charging and discharging, the second temperature sensor 180 may be the coolest part of the energy storage module. However, during high ambient temperature conditions, the second temperature sensor 180 may be the hottest part energy storage module 10. The controller 250 may use information from the first temperature sensor 170 when high temperatures are caused by charging and discharging, and may use the second temperature sensor 180 when high temperatures are caused by high ambient temperatures.

[0044] The controller 250 is programmed with a first threshold temperature and a second threshold temperature. The first threshold temperature corresponds approximately with  $T_{m1}$  and the second threshold temperature corresponds approximately with  $T_{m2}$ . As an example of operation, consider when the heat is being generated in the energy storage module 10 during a charge/discharge cycle. The controller 250 may sense when the first temperature sensor has reached a second threshold temperature. This indicates that the paraffin has melted and that the PCM 320 is no longer able to store latent heat. The controller may then start or increase coolant flow through coolant passages 350 by opening valve(s) 230 and/or starting pump 190. Coolant will continue to circulate through the coolant passages 350 until either the first or second temperature sensor 170, 180 indicate that the PCM 320 has cooled below a first threshold temperature. At this point the paraffin in the PCM 320 has reached a solid state again and is ready to store latent heat. The controller 250 will then stop or decrease coolant flow through coolant passages 350 by either closing valve(s) 230 and/or stopping pump 190.

[0045] The controller 250 may use information from one temperature sensor to start or increase coolant flow and another temperature sensor to stop or decrease coolant flow. For instance, during a charge/discharge cycle, the controller 250 may use information from the first temperature sensor 170 to start or increase coolant flow and information from the second temperature sensor 180 to stop or decrease coolant flow. This may be useful because the first temperature sensor 170, near a centrally-located storage cell 30, will be one of the hottest parts of the energy storage module 10. The controller 250 is then able to control coolant flow in order to keep the storage cell 30 below its upper operating temperature  $To2$ . The controller 250 may then use the information from the second temperature sensor 180 to determine when the outer, and presumably coolest, part of the energy storage module 10 has cooled below  $T_{m1}$ . The controller 250 can then be certain that the paraffin in the entire block 330 of PCM 320 has reached the solid state again. The controller may choose to de-rate the performance of the energy storage module 10 if sufficient coolant flow is not available to keep below its upper operating temperature  $To2$ .

[0046] Likewise, during a high ambient temperature condition, the controller 250 may use information from the second temperature sensor 180 to start or increase coolant flow and information from the first temperature sensor 170 to stop or decrease coolant flow. This may be useful because the second temperature sensor 180, near an outer storage cell 30, will be one of the hottest parts of the energy storage module 10. The controller 250 is then able to control coolant flow in order to keep the outer storage cell 30 below its upper operating temperature  $To2$ . The controller 250 may then use the information from the first temperature sensor 170 to determine when the central, and presumably coolest, part of the energy storage module 10 has cooled below  $T_{m1}$ . The controller 250 can then be certain that the paraffin in the entire block 330 of PCM 320 has reached the solid state again.

[0047] The example shown in FIG. 7 shows heat from a charge/discharge cycle in a high ambient temperature environment. In this example,  $T_{m1}=42$  degrees C.,  $T_{m2}=48$  degrees C.,  $T_w=42$  degrees C., and the ambient temperature is 30 degrees C.

[0048] It should be understood that the current disclosure anticipates the use of as many temperature sensors as needed. Additional temperature sensors can be located throughout the

energy storage module 10, near storage cells 30, on the housing 150, the cold plate 160, or in the coolant passage 350.

[0049] The first and second threshold temperature can be modified during operation based on how much power is going into or out of the energy storage module 10. Power is calculated from multiplying the current in amperes with the voltage in volts and is expressed in watts. The power,  $P$ , is then used in an expression of Fourier's Law shown below in Equation 1.

$$T_j = T_c + P * \theta_{jc} \quad (1)$$

[0050] The internal temperature of the storage cells 30 is assumed to be  $T_j$ , while  $T_c$  is either the first or second temperature sensor 170, 180 depending on the situation. The term  $\theta_{jc}$  is the thermal resistance of the material between the two points and will be considered as a constant. It is seen that for low power,  $T_j$  and  $T_c$  will be very close. Therefore, the second threshold can be set to very near  $T_{m2}$ . But for large power,  $T_j$  and  $T_c$  will not be close and the second threshold may be set lower to ensure that there is a safety margin between the second threshold and the upper operating temperature  $To2$  of the storage cell 30.

[0051] The controller 250 is configured to sense voltage and current sensors, calculate power into or out of the energy storage module 10, and adjust the second threshold based on the power calculation. A person of ordinary skill in the art will recognize that the power calculation may be used in several ways without departing from the scope of the current disclosure. For instance, instantaneous power may be used to adjust the second threshold. Additionally, an average power over a period of several seconds may be used. A rolling average of power may also be used. The rolling average may be chosen based on the thermal time constant of the energy storage module 10. The rolling average may be as short as 0.1 seconds or as long as 20 seconds.

[0052] FIG. 9 (flowchart) shows a method consistent with the current disclosure. The method starts at block 400 then proceeds to block 410 where  $T_c$  is determined. If one temperature sensor is present, then this value is used as  $T_c$ . If more than one temperature sensors are present,  $T_c$  may be determined in a number of ways. For instance, the  $T_c$  may be the maximum of all temperature sensors present or the average of all temperature sensors present. Alternatively, a first temperature sensor 170 may be used for  $T_c$  if temperature is increasing, while a second temperature sensor 180 may be used for  $T_c$  if the temperature is decreasing. For the method shown in FIG. 9, it is assumed that  $T_c$  is the maximum of all temperature sensors present.

[0053] From block 410, the method proceeds to decision block 420 where  $T_c$  is compared to coolant temperature  $T_w$ . Coolant temperature  $T_w$  is provided by a sensor somewhere in the coolant passage 350 or elsewhere in the coolant circulation system. If  $T_w$  is greater than  $T_c$ , the method proceeds to decision block 430. If  $T_c$  is less than  $T_{m2}$ , then the method returns to block 400. If  $T_c$  is greater than  $T_{m2}$ , then the method proceeds to action block 500 where the performance of the energy storage module 10 is de-rated according to FIG. 5 before returning to block 400.

[0054] Returning to decision block 420, if  $T_w$  is less than  $T_c$ , the method proceeds to decision block 440. If  $T_c$  is less than  $T_{m2}$ , the method proceeds to decision block 450. At decision block 450,  $T_c$  is compared to  $T_{m1}$ . If  $T_c$  is greater than  $T_{m1}$ , the method returns to block 400. If  $T_c$  is less than  $T_{m1}$  the method proceeds to decision block 470 which checks to see if the coolant flow is zero or not. This can be

determined by the controller 250 by determining how far valve(s) 230 are displaced or whether pump 190 is running. If the coolant flow is zero, the method returns to block 400. If the coolant flow is not zero, the method proceeds to action block 490, which decreases coolant flow before returning to block 400. Alternatively, the slope of Tc can be used to determine whether

[0055] From block 440, if Tc is greater than Tm2 the method proceeds to decision block 460 which checks to see if the coolant flow is at maximum or not. If the coolant flow is at maximum, the method proceeds to action block 500 where the performance of the energy storage module 10 is de-rated according to FIG. 5. If the coolant flow is not at maximum, the method proceeds to action block 480 where flow is increased before returning to block 400. Alternatively, the slope of Tc can be used to determine whether the method proceeds to action block 480. Even if Tc is less than Tm2, a rapidly increasing Tc may indicate that increased coolant flow will soon be needed. In this way, coolant flow may be increased before Tc is actually greater than Tm2.

#### INDUSTRIAL APPLICABILITY

[0056] The energy storage module 10 of the present disclosure is suitable for use as energy storage for hybrid and electric drive vehicles, as well as stationary power generation. The phase change material 320 used to conduct and store heat from the storage cells 30 allows the energy storage module 10 to be used at higher power levels and at higher ambient temperatures than is allowed by conventional heat sinks. The PCM 320 can be designed such that heat from most charge/discharge cycles and ambient temperatures can be stored and dissipated without need for additional cooling. This saves the energy needed to run a pump 190 and valves 230.

[0057] However, higher power levels and higher ambient temperatures can overload the latent heat capacity of the PCM 320. Some applications using a PCM 320 may then benefit from the use of additional cooling from an active cooling loop 322 during high heat loads while still benefiting from the latent heat capacity of the PCM 320. Use of an active cooling loop 322 along with a PCM 320 may allow for a smaller capacity heat exchanger 240.

What is claimed is:

1. A method for cooling an energy storage module comprising:

determining a first temperature in an energy storage module, the energy storage module comprising:

an array of energy storage cells;

a phase change material in thermal contact with a coolant passage and said energy storage cells;

comparing the first temperature to a first and second threshold; and

changing coolant flow through said coolant passage based on the comparison.

2. The method of claim 1 wherein the change comprises increasing coolant flow through said coolant passage when the first temperature reaches the second threshold.

3. The method of claim 1 wherein the change comprises decreasing coolant flow when the first temperature reaches the first threshold.

4. The method of claim 1 wherein the first threshold is modified based on the net electrical power flowing into or out of said energy storage module over a predetermined period of time.

5. The method of claim 2 wherein said predetermined period of time is between one and ten seconds.

6. The method of claim 1 wherein said coolant passage is incorporated within a block of said phase change material.

7. The method of claim 1 wherein said coolant passage is incorporated within a cold plate that is in thermal contact with said phase change material.

8. The method of claim 1 wherein the method further comprises:

determining a second temperature in said energy storage module; and

decreasing coolant flow when the second temperature reaches the first threshold.

9. The method of claim 8 wherein the first threshold is modified based on the net electrical power flowing into or out of said energy storage module over a predetermined period of time.

10. The method of claim 9 wherein said predetermined period of time is.

11. The method of claim 8 wherein said coolant passage is incorporated within a block of said phase change material.

12. The method of claim 8 wherein said coolant passage is incorporated within a cold plate that is in thermal contact with said phase change material.

13. The method of claim 1 wherein the first temperature is determined by choosing the maximum of two temperatures.

14. A method for cooling an energy storage module comprising:

determining a first temperature in an energy storage module, the energy storage module comprising:

an array of energy storage cells;

a phase change material in thermal contact with a coolant passage and said energy storage cells;

measuring a coolant temperature;

comparing the first temperature and the coolant temperature; and

taking a corrective action based on the comparison.

15. The method of claim 14 wherein the corrective action comprises increasing coolant flow through a coolant passage in the energy storage module if the coolant temperature is less than the first temperature and when the first temperature reaches a second threshold.

16. The method of claim 14 wherein the corrective action comprises decreasing coolant flow through a coolant passage in the energy storage module if the coolant temperature is less than the first temperature and when the first temperature reaches a first threshold.

17. The method of claim 14 wherein the corrective action comprises derating the performance of the energy storage module if the coolant temperature is greater than the first temperature.

18. The method of claim 15 wherein the second threshold is modified based on the net electrical power flowing into or out of said energy storage module over a predetermined period of time.

19. The method of claim 18 wherein said predetermined period of time is between one and ten seconds.

20. The method of claim 14 wherein said coolant passage is incorporated within a block of said phase change material.

21. The method of claim 14 wherein said coolant passage is incorporated within a cold plate that is in thermal contact with said phase change material.

22. The method of claim 16 wherein the corrective action further comprises:

measuring a second temperature in said energy storage module; and  
decreasing coolant flow when the second temperature reaches the first threshold.

**23.** The method of claim **22** wherein the first threshold is modified based on the net electrical power flowing into or out of said energy storage module over a predetermined period of time.

**24.** A system for managing thermal conditions of an energy storage module comprising:

a pump for providing coolant flow;

a valve configured receive signals from a controller and to control said coolant flow;

the controller configured to:

receive a first temperature from a first temperature sensor in an energy storage module, the energy storage module comprising:

an array of energy storage cells;

a phase change material in thermal contact with a coolant passage and said energy storage cells;

compare the first temperature to a first and second threshold; and

send a signal to said valve to control coolant flow through said coolant passage based on the comparison.

**25.** The method of claim **24** wherein said coolant passage is incorporated within a block of said phase change material.

**26.** The method of claim **24** wherein said coolant passage is incorporated within a cold plate that is in thermal contact with said phase change material.

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