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### Thermal management method and thermal management system

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#### Abstract

Embodiments of this application provide a thermal management method and a thermal management system. The thermal management method is applied to a thermal management system including a heating apparatus, a battery pack, and a pipeline subsystem. The pipeline subsystem is in thermal contact with the heating apparatus and the battery pack. The thermal management method includes: measuring temperature of the heating apparatus and battery pack temperature of the battery pack under the condition that the heating apparatus is in operating state; and transferring heat from the heating apparatus to the battery pack via the pipeline subsystem under the condition that the temperature of the heating apparatus is higher than the battery pack temperature. According to the embodiments of this application, the thermal management efficiency can be improved and the thermal management costs can be reduced.

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## **Background/Summary**

CROSS REFERENCE TO RELATED APPLICATION (1) This application is a continuation of International Patent Application No. PCT/CN2021/126254, filed on Oct. 26, 2021, which is incorporated by reference in its entirety.

### **TECHNICAL FIELD**

(1) This application relates to the field of thermal management technologies, and specifically, to a thermal management method and a thermal management system.

### **BACKGROUND**

(2) In general, battery packs are increasingly used as power sources for various electric apparatuses (for example, electric vehicles). However, the performance of the battery packs is affected by the environment in which they are used. For example, the performance of the battery packs may be degraded to some extent in low-temperature environments. Therefore, various technologies can be used to manage the heat of the battery pack.

(3) The existing thermal management has the problems of low efficiency and high costs. For the technology of external heating, heat transfer between among a heat source, a medium, and a heating target is required, resulting in great loss and low efficiency; while for the technology of internal heating, the current needs to flow through the conductor and impedance element, resulting in great loss and heat waste. Using the power of the battery pack to heat itself affects energy consumption and the range of the electric vehicle. In addition, the increase in cost associated with attempting to improve heating efficiency does not match the increase in heating efficiency, resulting in a phenomenon of allowing part of heat to be dissipated.

### **SUMMARY**

(4) In view of the preceding problems, this application provides a thermal management method and a thermal management system so as to overcome or alleviate the problems of low thermal management efficiency and high costs.

(5) According to a first aspect, this application provides a thermal management method applied to a thermal management system including a heating apparatus, a battery pack, and a pipeline subsystem, where the pipeline subsystem is in thermal contact with the heating apparatus and the battery pack; and the thermal management method includes: measuring temperature of the heating apparatus and battery pack temperature of the battery pack under the condition that the heating

apparatus is in operating state; and transferring heat from the heating apparatus to the battery pack via the pipeline subsystem under the condition that the temperature of the heating apparatus is higher than the battery pack temperature.

(6) In the technical solution of this embodiment of this application, the thermal management method is implemented using the thermal management system including the heating apparatus, the battery pack, and the pipeline subsystem. In the system, the thermal contact is formed between the pipeline subsystem and the heating apparatus and between the pipeline subsystem and the battery pack. The thermal contact between the pipeline subsystem and the heating apparatus and the thermal contact between the pipeline subsystem and the battery pack can implement heat transfer from the heating apparatus to the battery pack via the pipeline subsystem under the condition that the heating apparatus is in operating state and the temperature of the heating apparatus is higher than the battery pack temperature.

(7) In some embodiments, the pipeline subsystem includes a heat exchange medium capable of flowing therein, and the pipeline subsystem further includes a battery pack heat exchanger in thermal contact with the battery pack and a heating apparatus heat exchanger in thermal contact with the heating apparatus, such that the heat exchange medium is capable of transferring heat with the heating apparatus and the battery pack. The heat exchange medium, battery pack heat exchanger, and heating apparatus heat exchanger included in the pipeline subsystem can increase the efficiency of heat transfer from the heating apparatus to the battery pack.

(8) In some embodiments, the temperature of the heating apparatus is measured at a medium outflow port of the heating apparatus heat exchanger. By measuring the temperature of the medium at the medium outflow port of the heating apparatus heat exchanger, a time point for heat transfer can be easily determined, to be specific, when the measured temperature of the heating apparatus is higher than the battery pack temperature, heat transfer from the heating apparatus to the battery pack can be implemented.

(9) In some embodiments, the thermal management method further includes: measuring the temperature of the heating apparatus, and under the condition that the measured temperature of the heating apparatus is higher than a first heating apparatus temperature threshold, causing the heat exchange medium in the pipeline subsystem to circulate in a manner of avoiding the battery pack heat exchanger. This step may be performed before measuring the temperature of the heating apparatus and the battery pack temperature. Measuring the temperature of the heating apparatus may be accomplished by measuring temperature of one or more components of the heating apparatus. When the temperature of the heating apparatus is higher than the first heating apparatus temperature threshold, the temperature of the heating apparatus may be considered high enough such that heat from the heating apparatus can be transferred to the heat exchange medium in the pipeline subsystem. In this case, causing the heat exchange medium to avoid the battery pack heat exchanger can avoid the heat transfer from the heat exchange medium to the battery pack, such that the heat from the heating apparatus can be fully transferred to the heat exchange medium, rapidly increasing the temperature of the heat exchange medium and improving the thermal management efficiency.

(10) In some embodiments, the thermal management method further includes: measuring the temperature of the heating apparatus, and under the condition that the measured temperature of the heating apparatus is higher than a second heating apparatus temperature threshold, causing the heat exchange medium in the pipeline subsystem to circulate in a manner of avoiding the battery pack heat exchanger, and turning on a cooling module connected to the pipeline subsystem to cool the heat exchange medium. This step may be performed after transferring heat from the heating apparatus to the battery pack. Measuring the temperature of the heating apparatus may be accomplished by measuring temperature of one or more components of the heating apparatus. When the temperature of the heating apparatus is higher than the second heating apparatus temperature threshold, where the second heating apparatus temperature threshold is higher than the

first heating apparatus temperature threshold, the temperature of the heating apparatus may be considered too high such that the heating apparatus can be cooled. In this case, causing the heat exchange medium to avoid the battery pack heat exchanger and turning on the cooling module can avoid the heat transfer from the battery pack to the heat exchange medium while cooling the heat exchange medium, such that the heat exchange medium can be fully cooled so as to rapidly reduce the temperature of the heating apparatus, improving the thermal management efficiency.

(11) According to a second aspect, this application provides a thermal management system including a battery pack, a heating apparatus, and a pipeline subsystem, where the pipeline subsystem is in thermal contact with the heating apparatus and the battery pack; the thermal management system is configured to measure temperature of the heating apparatus and battery pack temperature of the battery pack under the condition that the heating apparatus is in operating state; and the pipeline subsystem is configured to transfer heat from the heating apparatus to the battery pack under the condition that the temperature of the heating apparatus is higher than the battery pack temperature.

(12) In the technical solution of this embodiment of this application, the thermal management system is formed by the battery pack, the heating apparatus, and the pipeline subsystem. In the system, an electrical connection is formed between the heating apparatus and the battery pack, and thermal contact is formed between the pipeline subsystem and the battery pack and between the pipeline subsystem and the heating apparatus. Through the electrical connection between the heating apparatus and the battery pack, the heating apparatus can apply current to the battery pack to heat the battery pack. The thermal contact between the pipeline subsystem and the heating apparatus and the thermal contact between the pipeline subsystem and the battery pack can implement heat transfer from the heating apparatus to the battery pack via the pipeline subsystem under the condition that the heating apparatus is in operating state and the temperature of the heating apparatus is higher than the battery pack temperature.

(13) In some embodiments, the heating apparatus includes a switch module, an energy storage unit, and a cooling unit, where the switch module and the energy storage unit are electrically connected to each other, and the switch module and the energy storage unit are both in thermal contact with the cooling unit, such that both the switch module and the energy storage unit are capable of transferring heat to the cooling unit. The electrical connection between the switch module and the energy storage unit can realize the heating function of the heating apparatus and thus realize the heating of the battery pack. The thermal contact between the switch module and the cooling unit and the thermal contact between the energy storage unit and the cooling unit provide effective heat dissipation for the switch module and the energy storage unit.

(14) In some embodiments, the heating apparatus further includes a voltage regulator module, where the voltage regulator module is electrically connected to the switch module and is in thermal contact with the cooling unit, such that the voltage regulator module is capable of transferring heat to the cooling unit. The voltage regulator module can regulate voltage of the heating apparatus. In addition, the thermal contact between the voltage regulator module and the cooling unit can provide effective heat dissipation for the voltage regulator module.

(15) In some embodiments, the pipeline subsystem includes a battery pack heat exchanger, a heating apparatus heat exchanger, a first pump, a second pump, a first three-way pipe, a second three-way pipe, a first three-way valve, a second three-way valve, and a heat exchanger; where the battery pack heat exchanger is in thermal contact with the battery pack, and the heating apparatus heat exchanger is in thermal contact with the heating apparatus; the first three-way pipe and the second three-way pipe each include a first port, a second port, and a third port, and the first three-way valve and the second three-way valve each include a common valve port, a first valve port, and a second valve port; a medium outflow port of the heating apparatus heat exchanger is connected to an input port of the first pump, an output port of the first pump is connected to the first port of the first three-way pipe, the second port of the first three-way pipe is connected to a

port of the heat exchanger, another port of the heat exchanger is connected to the common valve port of the second three-way valve, the second valve port of the second three-way valve is connected to an input port of the second pump, an output port of the second pump is connected to a medium inflow port of the battery pack heat exchanger, a medium outflow port of the battery pack heat exchanger is connected to the first port of the second three-way pipe, and the second port of the second three-way pipe is connected to a medium inflow port of the heating apparatus heat exchanger; and the third port of the first three-way pipe is connected to the second valve port of the first three-way valve, the third port of the second three-way pipe is connected to the common valve port of the first three-way valve, and the first valve port of the second three-way valve is connected to the first valve port of the first three-way valve. By providing the pipeline subsystem including the pumps, the three-way pipes, the three-way valves, and the heat exchanger, a set of pipelines for implementing different thermal management modes for different application scenarios can be formed, thereby reducing thermal management costs.

(16) In some embodiments, the pipeline subsystem includes a heat exchange medium circulating therein, where the heat exchange medium is a mixed solution of ethylene glycol and water; and the pipeline subsystem further includes an expansion tank disposed between the first three-way pipe and the heat exchanger for storing and replenishing the mixed solution. By using the mixed solution of ethylene glycol and water as the heat exchange medium, effective heating or cooling of the heat exchange medium can be achieved, and the heat exchange efficiency between the heating apparatus and the battery pack is improved. By providing an expansion tank in the pipeline subsystem, the heat exchange medium can be stored under the condition that there is too much heat exchange medium, and the heat exchange medium can be replenished under the condition that there is not enough heat exchange medium, as needed.

(17) In some embodiments, the thermal management system further includes: a medium outlet temperature sensor of heating apparatus heat exchanger, where the medium outlet temperature sensor of heating apparatus heat exchanger is disposed at the medium outflow port of the heating apparatus heat exchanger to measure the temperature of the heating apparatus; and a cooling module, where the cooling module is connected to the heat exchanger to cool the heat exchanger. By providing the temperature sensor at the medium outflow port of the heating apparatus heat exchanger, the temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger can be measured, and measuring results can then be used for implementing different thermal management modes for different application scenarios. By connecting the cooling module to the heat exchanger, the heat exchanger can be cooled, and then the heat exchange medium in the pipeline subsystem can be cooled according to the actual application scenario.

(18) In some embodiments, the thermal management system further includes a controller, the battery pack includes a battery management module, the heating apparatus includes a heating apparatus control unit, and the controller, the battery management module, and the heating apparatus control unit are connected to each other via a controller area network CAN; the medium outlet temperature sensor of heating apparatus heat exchanger, the first pump, the second pump, the first three-way valve, the second three-way valve, and the cooling module are connected to the controller; the battery management module measures the battery pack temperature; and the heating apparatus control unit measures temperature of at least one of the switch module and energy storage unit in the heating apparatus; where the controller controls at least one of the first pump, the second pump, the first three-way valve, the second three-way valve, and the cooling module based on data from the medium outlet temperature sensor of heating apparatus heat exchanger, the battery management module, and the heating apparatus control unit, so as to implement at least one operating mode of the thermal management system. The battery management module can measure the temperature associated with the battery pack, the heating apparatus control unit can measure the temperatures associated with components of the heating apparatus, and in turn, all the pumps, all the three-way valves, and the cooling module can be controlled by the controller connected to the

battery management module and the heating apparatus control unit, thereby implementing different thermal management modes for different application scenarios.

(19) In some embodiments, under the condition that the heating apparatus is in operating state, when the temperature of the energy storage unit measured by the heating apparatus control unit is higher than an energy storage unit temperature threshold or when the temperature of the switch module is higher than a switch module temperature threshold, the controller turns on the first pump, turns off the second pump, controls the first three-way valve to make only the first valve port communicate with the common valve port, controls the second three-way valve to make only the first valve port communicate with the common valve port, and turns on the cooling module so as to cool the heating apparatus. In this case, the thermal management system according to this embodiment of this application can be used to rapidly cool the heating apparatus when the temperature of the heating apparatus is too high, to be specific, to rapidly cool the heating apparatus and rapidly reduce the temperature of the heating apparatus.

(20) In some embodiments, under the condition that the heating apparatus is in operating state, when the temperature of the energy storage unit measured by the heating apparatus control unit is not higher than an energy storage unit temperature threshold and the temperature of the switch module is not higher than a switch module temperature threshold, the controller further controls at least one of the first pump, the second pump, the first three-way valve, the second three-way valve, and the cooling module based on data from the medium outlet temperature sensor of heating apparatus heat exchanger and the battery management module. In this case, the thermal management system according to this embodiment of this application can be used to compare the temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger with the battery pack temperature when the temperature of the heating apparatus is not too high, and to implement different thermal management modes for different application scenarios based on the comparison results.

(21) In some embodiments, when temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger, measured by the medium outlet temperature sensor of heating apparatus heat exchanger, is higher than the battery pack temperature measured by the battery management module, the controller turns on the first pump, turns on the second pump, controls the first three-way valve to make only the first valve port communicate with the common valve port, controls the second three-way valve to make only the second valve port communicate with the common valve port, and turns off the cooling module so as to transfer heat from the heating apparatus to the battery pack. In this case, the thermal management system according to this embodiment of this application can be used to achieve a large-circulating battery hydrothermal operating mode when the temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger is higher than the battery pack temperature, to be specific, to achieve a heat transfer from the heating apparatus to the battery pack so as to increase the temperature of the battery pack.

(22) In some embodiments, when temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger, measured by the medium outlet temperature sensor of heating apparatus heat exchanger, is not higher than the battery pack temperature measured by the battery management module, the controller turns on the first pump, turns off the second pump, controls the first three-way valve to make only the second valve port communicate with the common valve port, controls the second three-way valve to make only the first valve port communicate with the common valve port, and turns off the cooling module so as to transfer heat from the heating apparatus to the heat exchange medium in the pipeline subsystem. In this case, the thermal management system according to this embodiment of this application can be used to achieve a small-circulating rapid hydrothermal operating mode when the temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger is not higher than the battery pack temperature, to be specific, to rapidly heat the heat exchange medium and rapidly increase the

temperature of the heat exchange medium.

(23) In some embodiments, under the condition that the heating apparatus is not in operating state, when the battery pack temperature measured by the battery management module is higher than a first battery pack temperature threshold, the controller turns off the first pump, turns on the second pump, controls the first three-way valve to make only the second valve port communicate with the common valve port, controls the second three-way valve to make only the second valve port communicate with the common valve port, and turns off the cooling module so as to cool the battery pack. In this case, the thermal management system according to this embodiment of this application can be used to cool the battery when the battery pack temperature is relatively high, to be specific, to cool the battery pack and reduce the battery pack temperature.

(24) In some embodiments, when the battery pack temperature measured by the battery management module is higher than a second battery pack temperature threshold, the controller turns off the first pump, turns on the second pump, controls the first three-way valve to make only the second valve port communicate with the common valve port, controls the second three-way valve to make only the second valve port communicate with the common valve port, and turns on the cooling module so as to cool the battery pack. In this case, the thermal management system according to this embodiment of this application can be used to rapidly cool the battery when the battery pack temperature is too high, to be specific, to rapidly cool the battery pack and rapidly reduce the battery pack temperature.

(25) The foregoing description is merely an overview of the technical solution of this application. For a better understanding of the technical means in this application such that they can be implemented according to the content of the specification, and to make the above and other objectives, features and advantages of this application more obvious and easier to understand, the following describes specific embodiments of this application.

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## Description

### BRIEF DESCRIPTION OF DRAWINGS

(1) Persons of ordinary skill in the art can clearly understand various other advantages and benefits by reading the detailed description of the preferred embodiments below. The accompanying drawings are merely intended to illustrate the preferred embodiments and are not intended to limit this application. Moreover, throughout the accompanying drawings, the same reference signs represent the same parts. In the accompanying drawings:

(2) FIG. 1 is a schematic diagram of a thermal management system according to some embodiments of this application;

(3) FIG. 2 is a schematic connection diagram of a pipeline subsystem of a thermal management system according to some embodiments of this application;

(4) FIG. 3 is a schematic control diagram of a thermal management system according to some embodiments of this application;

(5) FIG. 4 is a schematic diagram of a first operating mode of a thermal management system according to some embodiments of this application;

(6) FIG. 5 is a schematic diagram of a second operating mode of a thermal management system according to some embodiments of this application;

(7) FIG. 6 is a schematic diagram of a third operating mode of a thermal management system according to some embodiments of this application;

(8) FIG. 7 is a schematic diagram of a fourth operating mode and a fifth operating mode of a thermal management system according to some embodiments of this application;

(9) FIG. 8 is a flowchart of a thermal management method according to some embodiments of this application;



(10) FIG. 9 is a flowchart of a thermal management method according to some embodiments of this application for implementing some of operating modes; and

(11) FIG. 10 is a flowchart of a thermal management method according to some embodiments of this application for implementing some of operating modes.

(12) Reference signs in the specific embodiments are described as follows: battery pack **100**; heating apparatus **200**; pipeline subsystem **300**; controller **400**; battery pack heat exchanger **110**; heating apparatus heat exchanger **210**; battery management module **101**; heating apparatus control unit **201**; voltage regulator module **203**; switch module **205**; energy storage unit **207**; cooling unit **209**; first pump **301**; second pump **302**; first three-way pipe **303**; second three-way pipe **304**; first three-way valve **305**; second three-way valve **306**; heat exchanger **307**; expansion tank **308**; medium outlet temperature sensor of battery pack heat exchanger **111**; medium inlet temperature sensor of battery pack heat exchanger **112**; medium outlet temperature sensor of heating apparatus heat exchanger **211**; and cooling module **311**.

#### DETAILED DESCRIPTION

(13) The following describes in detail the embodiments of technical solutions of this application with reference to the accompanying drawings. The following embodiments are merely intended for a clearer description of the technical solutions of this application and therefore are used as just examples which do not constitute any limitations on the protection scope of this application.

(14) Unless otherwise defined, all technical and scientific terms used herein shall have the same meanings as commonly understood by those skilled in the art to which this application relates. The terms used herein are intended to merely describe the specific embodiments rather than to limit this application. The terms “include”, “comprise”, and “have” and any other variations thereof in the specification, claims and brief description of drawings of this application are intended to cover non-exclusive inclusions.

(15) In the description of the embodiments of this application, the terms “first”, “second”, and the like are merely intended to distinguish between different objects, and shall not be understood as any indication or implication of relative importance or any implicit indication of the number, sequence or primary-secondary relationship of the technical features indicated. In the description of this application, “a plurality of” means at least two unless otherwise specifically stated.

(16) In this specification, reference to “embodiment” means that specific features, structures or characteristics described with reference to the embodiment may be incorporated in at least one embodiment of this application. The word “embodiment” appearing in various places in the specification does not necessarily refer to the same embodiment or an independent or alternative embodiment that is exclusive of other embodiments. It is explicitly or implicitly understood by persons skilled in the art that the embodiments described herein may be combined with other embodiments.

(17) In the description of the embodiments of this application, the term “and/or” is only an associative relationship for describing associated objects, indicating that three relationships may be present. For example, A and/or B may indicate the following three cases: presence of only A, presence of both A and B, and presence of only B. In addition, the character “/” in this specification generally indicates an “or” relationship between contextually associated objects.

(18) In the description of the embodiments of this application, the term “a plurality of” means more than two (inclusive). Similarly, “a plurality of groups” means more than two (inclusive) groups, and “a plurality of pieces” means more than two (inclusive) pieces.

(19) In the description of the embodiments of this application, the orientations or positional relationships indicated by the technical terms “center”, “longitudinal”, “transverse”, “length”, “width”, “thickness”, “upper”, “lower”, “front”, “rear”, “left”, “right”, “perpendicular”, “horizontal”, “top”, “bottom”, “inside”, “outside”, “clockwise”, “counterclockwise”, “axial”, “radial”, “circumferential”, and the like are based on the orientations or positional relationships as shown in the accompanying drawings. These terms are merely for ease and brevity of the

description of the embodiments of this application rather than indicating or implying that the apparatuses or components mentioned must have specific orientations, or must be constructed or manipulated according to specific orientations, and therefore shall not be construed as any limitations on embodiments of this application.

(20) In the description of the embodiments of this application, unless otherwise specified and defined explicitly, the terms “mount”, “connect”, “join”, and “fasten” should be understood in their general senses. For example, they may refer to a fixed connection, a detachable connection, or an integral connection, may refer to a mechanical connection or an electrical connection, and may refer to a direct connection, an indirect connection via an intermediate medium, an internal communication between two elements, or an interaction between two elements. Persons of ordinary skill in the art can understand specific meanings of these terms in this application as appropriate to specific situations.

(21) With the development of new energy technologies, the battery pack as a power source is more widely used. The performance of the battery pack is affected by the use environment, especially by the ambient temperature. For example, in a low temperature environment (for example,  $-10^{\circ}\text{C}$ .,  $-20^{\circ}\text{C}$ ., or below  $-20^{\circ}\text{C}$ .), the performance of the battery pack may be reduced to some degree relative to that in a room temperature environment (for example,  $20^{\circ}\text{C}$ .). For example, the maximum usable capacity of the battery pack may drop by 10% to 20%.

(22) To overcome the adverse effects of the low temperature environment on the battery pack, various technologies can be used to heat the battery pack.

(23) For example, the battery pack can be heated by using an external heating method (for example, a hydrothermal method using a heating film). The external heating method requires heat transfer among a heat source, a medium, and a heating target, resulting in a long transfer process, great loss, and low overall efficiency.

(24) Alternatively, the battery pack can be heated by using an internal heating method (for example, producing heat directly inside the battery pack by placing an impedance element in the battery pack structure). The internal heating method requires current to flow through conductors and impedance elements inside the battery pack, resulting in great heat loss, and as a duration becomes longer, greater heat loss is produced, resulting in heat waste.

(25) In addition, heating the battery pack also has energy consumption problems. In other words, the energy consumed for heating the battery pack comes directly or indirectly from the power of the battery pack. If the energy consumed for heating the battery pack can be reduced, it means that more energy can be used for driving the electric vehicle, and thus the range of the electric vehicle can be increased.

(26) In addition, improving the heating effect on the battery pack and improving the heating efficiency will inevitably lead to an increase in cost, and this increase in cost usually does not match the improvement in heating effect and the increase in heating efficiency, in other words, the heating gain does not match the cost input. Therefore, from the cost perspective, it may be more reasonable to allow some of the heating heat to be dissipated.

(27) Based on the foregoing considerations, to overcome or alleviate the problems of low efficiency and high costs of thermal management, the inventors, after research, have proposed a thermal management system including a battery pack, a heating apparatus, and a pipeline subsystem, where the heating apparatus is electrically connected to the battery pack, and the heating apparatus and the battery pack are both in thermal contact with the pipeline subsystem including a heat exchange medium. Such thermal management system can implement heat transfer from the heating apparatus to the battery pack.

(28) In such thermal management system, on the one hand, the heating apparatus is electrically connected to the battery pack such that the heating apparatus can heat the battery pack by applying current to the battery pack, and on the other hand, the battery pack and the heating apparatus are in thermal contact with the pipeline subsystem such that heat transfer from the heating apparatus to

the battery pack can be implemented by using the heat exchange medium in the pipeline subsystem. Therefore, based on the heat transfer from the heating apparatus to the battery pack implemented by using the pipeline subsystem, the thermal management system according to the embodiments of this application can utilize the heat that may be dissipated by the heating apparatus in different thermal management modes, thereby improving the thermal management efficiency and reducing the thermal management costs.

(29) The thermal management system according to the embodiments of this application can be applied to various electric apparatuses, for example, but not limited to, cell phones, tablets, notebook computers, electric toys, electric tools, battery bicycles, electric vehicles, ships, and spacecraft. Electric vehicles include battery electric vehicles, hybrid electric vehicles utilizing electric power, extended-ranged electric vehicles, and the like. The thermal management system according to the embodiments of this application can improve the thermal management efficiency and reduce the thermal management costs of the electric apparatus.

(30) FIG. 1 is a schematic diagram of a thermal management system according to some embodiments of this application.

(31) An embodiment of this application provides a thermal management system. The thermal management system includes a battery pack **100**, a heating apparatus **200**, and a pipeline subsystem **300**. The heating apparatus **200** is electrically connected to the battery pack **100**, such that the heating apparatus **200** is capable of heating the battery pack **100** by applying current to the battery pack **100**. The pipeline subsystem **300** includes a heat exchange medium capable of flowing therein. The pipeline subsystem **300** is in thermal contact with the heating apparatus **200** and the battery pack **100**, such that the heating apparatus **200** can transfer heat to the battery pack **100** through the heat exchange medium.

(32) In this embodiment of this application, the thermal management system is formed by the battery pack **100**, the heating apparatus **200**, and the pipeline subsystem **300**.

(33) Examples of the battery pack **100** include a traction battery pack provided in an electric vehicle, where the traction battery pack is capable of supplying energy to the electric vehicle. The heating apparatus **200** is electrically connected to the battery pack **100**, for example, electrically connected to positive and negative electrodes of the battery pack **100**, such that the battery pack **100** can be heated by applying current to the battery pack **100** by using various components of the heating apparatus **200** (see details below). Examples of the heating apparatus **200** include a heating box electrically connected to the battery pack **100**, and also include other forms of heating apparatus capable of heating the battery pack **100**. The pipeline subsystem **300** is in thermal contact with both the heating apparatus **200** and the battery pack **100**.

(34) A voltage used for the electrical connection between the heating apparatus **200** and the battery pack **100** may be hundreds of volts of direct current. It should be understood by those skilled in the art that this is merely an exemplary description of the electrical connection and does not constitute any limitation on the present invention, and that other forms of voltage capable of heating the battery pack **100** are within the scope of the present invention.

(35) Through the thermal contact between the battery pack **100** and the pipeline subsystem **300** and the thermal contact between the heating apparatus **200** and the pipeline subsystem **300**, the heat exchange between the heating apparatus **200** and the battery pack **100**, for example, heat transfer from the heating apparatus **200** to the battery pack **100**, can be implemented using the heat exchange medium flowing in the pipeline subsystem **300**. In this way, the heat that may be dissipated by the heating apparatus **200** can be utilized, thereby improving the thermal management efficiency.

(36) For the purposes of this specification, thermal contact is a state of contact in which two components or two apparatuses can adequately transfer heat. For example, in the embodiments described below, the battery pack **100** is in thermal contact with the battery pack heat exchanger **110** (for example, the heat exchanger may be a heat exchanger plate or the like depending on an

actual application scenario) of the pipeline subsystem **300**, thereby enabling adequate heat transfer therebetween.

(37) In addition, depending on an actual application scenario, the heat exchange medium flowing in the pipeline subsystem **300** can be heated or cooled, for example, by the heating apparatus **200** or the cooling module **311** described below, such that the heat exchange efficiency can be improved.

(38) According to some embodiments of this application, optionally, still referring to FIG. 1, the heating apparatus **200** includes a switch module **205**, an energy storage unit **207**, and a cooling unit **209**. The switch module **205** and the energy storage unit **207** are electrically connected to each other, and the switch module **205** and the energy storage unit **207** are both in thermal contact with the cooling unit **209**, thereby enabling both the switch module **205** and the energy storage unit **207** to transfer heat to the cooling unit **209**.

(39) In these embodiments of this application, the switch module **205** may include a semiconductor switch device (for example, an insulated gate bipolar transistor IGBT), and the energy storage unit **207** may include an inductor, where the inductor is electrically connected to the semiconductor switch device. The heating apparatus **200** includes a heating apparatus control unit **201** (see description below) for controlling the switch module **205**, for example, controlling the on/off of the semiconductor switch device, so as to control a current applied to the battery pack **100** from the energy storage unit **207**, and thus control the heating of the battery pack **100** by the heating apparatus **200**.

(40) The thermal contact between the cooling unit **209** and the switch module **205** and the thermal contact between the cooling unit **209** and the energy storage unit **207** may be direct contact or may be indirect contact through a heat conducting component and/or a heat conducting medium. The cooling unit **209** can be used to provide effective heat dissipation for the switch module **205** and the energy storage unit **207** through the thermal contact between the switch module **205** and the cooling unit **209** and the thermal contact between the energy storage unit **207** and the cooling unit **209**.

(41) According to some embodiments of this application, optionally, still referring to FIG. 1, the heating apparatus **200** further includes a voltage regulator module **203**. The voltage regulator module **203** is electrically connected to the switch module **205** and is in thermal contact with the cooling unit **209**, such that the voltage regulator module **203** can transfer heat to the cooling unit **209**.

(42) The voltage regulator module **203** may include a capacitor. In these embodiments of this application, the voltage regulator module **203** is electrically connected to the battery pack **100**, for example, electrically connected to positive and negative electrodes of the battery pack **100**, thereby regulating the voltage output from the heating apparatus **200** to the battery pack **100**. In addition, the cooling unit **209** can be used to provide effective heat dissipation for the voltage regulator module **203** through the thermal contact between the voltage regulator module **203** and the cooling unit **209**.

(43) FIG. 2 is a schematic connection diagram of a pipeline subsystem of a thermal management system according to some embodiments of this application.

(44) According to some embodiments of this application, optionally, referring to FIG. 2, the pipeline subsystem includes a battery pack heat exchanger **110**, a heating apparatus heat exchanger **210**, a first pump **301**, a second pump **302**, a first three-way pipe **303**, a second three-way pipe **304**, a first three-way valve **305**, a second three-way valve **306**, and a heat exchanger **307**. The battery pack heat exchanger **110** is in thermal contact with the battery pack **100**, and the heating apparatus heat exchanger **210** is in thermal contact with the heating apparatus **200**; the first three-way pipe **303** and the second three-way pipe **304** each include a first port, a second port, and a third port, and the first three-way valve **305** and the second three-way valve **306** each include a common valve port O, a first valve port A, and a second valve port B; a medium outflow port of the heating apparatus heat exchanger **210** is connected to an input port of the first pump **301**, an output port of

the first pump **301** is connected to the first port of the first three-way pipe **303**, the second port of the first three-way pipe **303** is connected to a port of the heat exchanger **307**, another port of the heat exchanger **307** is connected to the common valve port of the second three-way valve **306**, the second valve port of the second three-way valve **306** is connected to an input port of the second pump **302**, an output port of the second pump **302** is connected to a medium inflow port of the battery pack heat exchanger **110**, a medium outflow port of the battery pack heat exchanger **110** is connected to the first port of the second three-way pipe **304**, and the second port of the second three-way pipe **304** is connected to a medium inflow port of the heating apparatus heat exchanger **210**; and the third port of the first three-way pipe **303** is connected to the second valve port of the first three-way valve **305**, the third port of the second three-way pipe **304** is connected to the common valve port of the first three-way valve **305**, and the first valve port of the second three-way valve **306** is connected to the first valve port of the first three-way valve **305**.

(45) In these embodiments of this application, the battery pack heat exchanger **110** and the heating apparatus heat exchanger **210** are in thermal contact with the battery pack **100** and the heating apparatus **200**, respectively. Depending on an actual application scenario of this application, the battery pack heat exchanger **110** and the heating apparatus heat exchanger **210** each may be a heat exchanger plate. For example, the heat exchanger plate is provided above or below the battery pack **100** in close contact with the upper or lower surface of the battery pack **100**, thereby enabling adequate heat transfer between the heat exchanger plate and the battery pack **100**.

(46) It should be understood by those skilled in the art that the heat exchanger plate described herein is merely an example and does not constitute any limitation on the scope of the present invention. Depending on an actual application scenario of the present invention, those skilled in the art may use any other heat exchangers in other forms that implement the conception of the present invention, such as a heat exchanger that wraps all or part of the battery pack **100** (or the heating apparatus **200**).

(47) In these embodiments of this application, the first pump **301** and the second pump **302** may be pumps capable of using energy (for example, using energy from the battery pack) to drive the heat exchange medium in the pipeline subsystem **300**, for example, water pumps.

(48) In these embodiments of this application, the first three-way pipe **303** and the second three-way pipe **304** are disposed in the pipeline subsystem **300**, and the first three-way pipe **303** and the second three-way pipe **304** each have the same three ports.

(49) In these embodiments of this application, the first three-way valve **305** and the second three-way valve **306** are both electronic three-way valves, and the first three-way valve **305** and the second three-way valve **306** each include a common valve port, a first valve port, and a second valve port. Both the first three-way valve **305** and the second three-way valve **306** are controlled by the controller **400** described below, such that the first three-way valve **305** and the second three-way valve **306** each can switch between a first state and a second state based on a control signal from the controller **400**. In the first state, the common valve port is connected to the first valve port, and the second valve port is disconnected from both the common valve port and the first valve port; and in the second state, the common valve port is connected to the second valve port, and the first valve port is disconnected from both the common valve port and the first valve port. In other words, based on the control signal from the controller **400**, the first three-way valve **305** can switch between the first state in which its common valve port is only in contact with its first valve port and the second state in which its common valve port is only in contact with its second valve port. Similarly, the second three-way valve **306** can also switch between the first state in which its common valve port is only in contact with its first valve port and the second state in which its common valve port is only in contact with its second valve port.

(50) It should be understood by those skilled in the art that the first three-way valve **305** and the second three-way valve **306** each including a common valve port, a first valve port, and a second valve port described herein are merely examples and do not constitute any limitation on the scope

of the present invention. Depending on an actual application scenario of the present invention, those skilled in the art may use any other three-way valves in other forms that implement the conception of the present invention.

(51) In these embodiments of this application, the heat exchanger **307** can enable the heat exchange medium in the pipeline subsystem **300** to transfer heat and exchange heat with the external environment or other components (for example, the cooling module described below).

(52) It should be understood by those skilled in the art that the connection forms of the heat exchanger, the pumps, the three-way pipes, the three-way valves, and the heat exchanger in the foregoing embodiments are only examples and do not constitute any limitation on the scope of the present invention. Depending on an application scenario of the present invention, those skilled in the art may use any other components and connection forms thereof that implement the conception of the present invention.

(53) By providing the pipeline subsystem **300** including the heat exchanger, the pumps, the three-way pipes, the three-way valves, and the heat exchanger, a set of pipelines for implementing different thermal management modes for different application scenarios can be formed, thereby reducing thermal management costs.

(54) According to some embodiments, optionally, the pipeline subsystem **300** includes a heat exchange medium circulating therein, where the heat exchange medium is a mixed solution of ethylene glycol and water; and the pipeline subsystem **300** further includes an expansion tank **308** disposed between the first three-way pipe **303** and the heat exchanger **307** for storing and replenishing the mixed solution.

(55) In these embodiments of this application, the expansion tank **308** is configured to accommodate the heat exchange medium such as the mixed solution of ethylene glycol and water. By providing an expansion tank **308** in the pipeline subsystem **300**, the heat exchange medium can be stored under the condition that there is too much heat exchange medium, and the heat exchange medium can be replenished under the condition that there is not enough heat exchange medium, as needed. The position of the expansion tank **308** disposed in the pipeline subsystem **300** is merely an example and does not constitute any limitation on the present invention.

(56) In these embodiments of this application, the heat exchange medium is used for implementing heat exchange between the battery pack **100** and the heating apparatus **200** and between other components. The inventors have found that using the mixed solution of ethylene glycol and water as the heat exchange medium can balance the cost, heat exchange performance, maintainability, and the like. However, it should be understood by those skilled in the art that the foregoing composition of the heat exchange medium is merely an example and does not constitute any limitation on the present invention. By using the mixed solution of ethylene glycol and water as the heat exchange medium, effective heating or cooling of the heat exchange medium can be achieved, and the heat exchange efficiency between the heating apparatus and the battery pack is improved.

(57) According to some embodiments of this application, optionally, referring to FIG. 2, the thermal management system further includes: a medium outlet temperature sensor of heating apparatus heat exchanger **211**, where the medium outlet temperature sensor of heating apparatus heat exchanger **211** is disposed at the medium outflow port of the heating apparatus heat exchanger **210** to measure temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger **210**; and a cooling module **311**, where the cooling module **311** is connected to the heat exchanger **307** to cool the heat exchanger **307**.

(58) In these embodiments of this application, the medium outlet temperature sensor of heating apparatus heat exchanger **211** may be a sensor capable of sensing temperature and converting the sensed temperature into an output signal, for example, a contact temperature sensor (resistance temperature sensor and the like) and a non-contact temperature sensor (radiation temperature sensor and the like). In these embodiments of this application, the cooling module **311** may be a cooling component of an automotive air conditioning system, and thus is able to take away heat

from the heat exchanger **307** after start-up. Therefore, using the cooling component of the automotive air conditioning system as the cooling module **311** can reduce the thermal management costs.

(59) By providing a temperature sensor at the medium outflow port of the heating apparatus heat exchanger **210**, the temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger **210** can be measured, and measuring results can then be used for implementing different thermal management modes for different application scenarios. The heat exchanger **307** can be cooled by using the cooling module **311** connected to the heat exchanger **307**.

(60) FIG. **3** is a schematic control diagram of a thermal management system according to some embodiments of this application.

(61) According to some embodiments of this application, optionally, referring to FIG. **3**, the thermal management system further includes a controller **400**, the battery pack **100** includes a battery management module **101**, the heating apparatus **200** includes a heating apparatus control unit **201**, and the controller **400**, the battery management module **101**, and the heating apparatus control unit **201** are connected to each other via a controller area network (CAN); the medium outlet temperature sensor of heating apparatus heat exchanger **211**, the first pump **301**, the second pump **302**, the first three-way valve **305**, the second three-way valve **306**, and the cooling module **311** are connected to the controller **400**; the battery management module **101** measures the battery pack temperature; and the heating apparatus control unit **201** measures temperature of at least one of the switch module **205** and energy storage unit **207** in the heating apparatus **200**; where the controller **400** controls at least one of the first pump **301**, the second pump **302**, the first three-way valve **305**, the second three-way valve **306**, and the cooling module **311** based on data from the medium outlet temperature sensor of heating apparatus heat exchanger **211**, the battery management module **101**, and the heating apparatus control unit **201**, so as to implement at least one operating mode of the thermal management system.

(62) In these embodiments of this application, the controller **400** may be a separate controller or may be integrated into the system of the vehicle. The battery management module **101** may be the battery management system (BMS) or a component of the vehicle. The heating apparatus control unit **201** is configured to detect and control the components (for example, the voltage regulator module **203**, the switch module **205**, and the energy storage unit and cooling unit **209** that integrally disposed) of the heating apparatus **200**. It should be understood by those skilled in the art that the CAN is merely an example of the form of connection among the controller **400**, the battery management module **101**, and the heating apparatus control unit **201** and does not constitute any limitation on the present invention. Depending on an actual application scenario, other wired/wireless connection networks or protocols can also be used.

(63) The battery management module **101** can measure the temperature associated with the battery pack **100**, the heating apparatus control unit **201** can measure the temperatures associated with components of the heating apparatus **200**, and in turn, all the pumps, all the three-way valves, and the cooling module can be controlled by the controller **400** connected to the battery management module **101** and the heating apparatus control unit **201**, thereby implementing different thermal management modes for different application scenarios.

(64) FIG. **4** is a schematic diagram of a first operating mode of a thermal management system according to some embodiments of this application.

(65) According to some embodiments of this application, optionally, referring to FIG. **4**, under the condition that the heating apparatus **200** is in operating state, when the temperature of the energy storage unit **207** measured by the heating apparatus control unit **201** is higher than an energy storage unit temperature threshold or when the temperature of the switch module **205** is higher than a switch module temperature threshold, the controller **400** turns on the first pump **301**, turns off the second pump **302**, controls the first three-way valve **305** to make only the first valve port communicate with the common valve port, controls the second three-way valve **306** to make only

the first valve port communicate with the common valve port, and turns on the cooling module **311** so as to cool the heating apparatus **200**.

(66) In these embodiments of this application, the heating apparatus **200** being in operating state or not can be determined by measuring current or voltage of the heating apparatus **200** by the heating apparatus control unit **201**. Specifically, when the heating apparatus control unit **201** detects that the current or the voltage of the heating apparatus **200** is not zero, it is determined that the heating apparatus **200** is in operating state. Conversely, when the heating apparatus control unit **201** detects that the current and the voltage of the heating apparatus **200** are zero, it is determined that the heating apparatus **200** is not in operating state.

(67) In these embodiments of this application, if the heating apparatus **200** and components thereof are overheated, cooling is required to prevent damage.

(68) In this case, the thermal management system according to these embodiments of this application can be used to cool the heating apparatus **200** when temperature of a component of the heating apparatus **200** is relatively high to reduce the temperature of the heating apparatus **200**, so as to implement the first operating mode, that is, the “cooling the heating apparatus” operating mode.

(69) For example, the energy storage unit temperature threshold may be 140° C., and the switch module temperature threshold may be 100° C.; when the temperature of the energy storage unit **207** measured by the heating apparatus control unit **201** is higher than 140° C. or the temperature of the switch module **205** is higher than 100° C., the controller **400** controls to enter the “cooling the heating apparatus” operating mode.

(70) In these embodiments of this application, alternatively, the temperature of the voltage regulator module **203** can be measured. For example, under the condition that a temperature threshold of the voltage regulator module is 85° C., when the temperature of the voltage regulator module **203** measured by the heating apparatus control unit **201** is higher than 85° C., the controller **400** can control to enter the “cooling the heating apparatus” operating mode.

(71) In addition, under the condition that the heating apparatus **200** is in operating state, when the temperature of the energy storage unit **207** measured by the heating apparatus control unit **201** is not higher than an energy storage unit temperature threshold and the temperature of the switch module **205** is not higher than a switch module temperature threshold, the controller **400** further controls at least one of the first pump **301**, the second pump **302**, the first three-way valve **305**, the second three-way valve **306**, and the cooling module **311** based on data from the medium outlet temperature sensor of heating apparatus heat exchanger **211** and the battery management module **101**.

(72) FIG. 5 is a schematic diagram of a second operating mode of a thermal management system according to some embodiments of this application.

(73) According to some embodiments of this application, optionally, referring to FIG. 5, when temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger **210**, measured by the medium outlet temperature sensor of heating apparatus heat exchanger **211**, is higher than the battery pack temperature measured by the battery management module **101**, the controller **400** turns on the first pump **301**, turns on the second pump **302**, controls the first three-way valve **305** to make only the first valve port communicate with the common valve port, controls the second three-way valve **306** to make only the second valve port communicate with the common valve port, and turns off the cooling module **311** so as to transfer heat from the heating apparatus **200** to the battery pack **100**.

(74) In these embodiments of this application, when the ambient temperature is low in winter, the performance of the battery pack **100** may be decreased to some extent and therefore the battery pack **100** needs to be heated. If the temperature of the heat exchange medium is appropriate, for example, the temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger **210** is higher than the temperature of the battery pack **100**, the heat transfer from the



heating apparatus **200** to the battery pack **100** can be implemented using the heat exchange medium in the pipeline subsystem **300**.

(75) In this case, the thermal management system according to these embodiments of this application can be used to make the heat exchange medium pass through both the battery pack heat exchanger **110** and the heating apparatus heat exchanger **210** when the battery pack **100** needs to be heated, such that the heat transfer from the heating apparatus **200** to the battery pack **100** can be carried out with a relatively large medium circulation loop, so as to increase the temperature of the battery pack **100**, implementing the second operating mode, that is, the “large-circulating battery hydrothermal” operating mode.

(76) FIG. **6** is a schematic diagram of a third operating mode of a thermal management system according to some embodiments of this application.

(77) According to some embodiments of this application, optionally, referring to FIG. **6**, when temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger **210**, measured by the medium outlet temperature sensor of heating apparatus heat exchanger **211**, is not higher than the battery pack temperature measured by the battery management module **101**, the controller **400** turns on the first pump **301**, turns off the second pump **302**, controls the first three-way valve **305** to make only the second valve port communicate with the common valve port, controls the second three-way valve **306** to make only the first valve port communicate with the common valve port, and turns off the cooling module **311** so as to transfer heat from the heating apparatus **200** to the heat exchange medium in the pipeline subsystem **300**.

(78) In these embodiments of this application, when heating of the battery pack **100** is required, if the temperature of the heat exchange medium is not appropriate, for example, the temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger **210** is not higher than the temperature of the battery pack **100**, the efficiency of heat transfer from the heating apparatus **200** to the battery pack **100** is severely reduced, thus reducing the thermal management efficiency.

(79) In this case, the thermal management system according to these embodiments of this application can be used to make the heat exchange medium not pass through the battery pack heat exchanger **110** when the battery pack **100** needs to be heated but the temperature of the heat exchange medium is not appropriate, such that the heat exchange medium can be heated with a relatively small medium circulation loop, so as to increase the temperature of the heat exchange medium, implementing the third operating mode, that is, the “small-circulating hydrothermal” operating mode.

(80) FIG. **7** is a schematic diagram of a fourth operating mode and a fifth operating mode of a thermal management system according to some embodiments of this application.

(81) According to some embodiments of this application, optionally, referring to FIG. **7**, under the condition that the heating apparatus **200** is not in operating state, when the battery pack temperature measured by the battery management module **101** is higher than a first battery pack temperature threshold, the controller **400** turns off the first pump **301**, turns on the second pump **302**, controls the first three-way valve **305** to make only the second valve port communicate with the common valve port, controls the second three-way valve **306** to make only the second valve port communicate with the common valve port, and turns off the cooling module **311** so as to cool the battery pack **100**.

(82) In these embodiments of this application, when the ambient temperature is high in summer, the battery pack **100** needs to be cooled to ensure the safety of the battery pack.

(83) In this case, the thermal management system **10** according to these embodiments of this application can be used to cool the battery pack **100** when the battery pack temperature is relatively high, so as to reduce the temperature of the battery pack **100**, implementing the fourth operating mode, that is, the “battery cooling” operating mode. In this mode, the heat exchange medium does not pass through the heating apparatus heat exchanger **210**.

(84) For example, the first battery pack temperature threshold may be 30° C., and when the battery pack temperature measured by the battery management module **101** is higher than the controller **400** controls to enter the “battery cooling” operating mode.

(85) According to some embodiments of this application, optionally, still referring to FIG. 7, when the battery pack temperature measured by the battery management module **101** is higher than a second battery pack temperature threshold (the second battery pack temperature threshold is higher than the first battery pack temperature threshold), the controller **400** turns off the first pump **301**, turns on the second pump **302**, controls the first three-way valve **305** to make only the second valve port communicate with the common valve port, controls the second three-way valve **306** to make only the second valve port communicate with the common valve port, and turns on the cooling module **311** so as to cool the battery pack **100**.

(86) In these embodiments of this application, when the temperature of the battery pack **100** is higher, the battery pack **100** needs to be cooled rapidly to ensure the safety of the battery pack.

(87) In this case, the thermal management system according to this embodiment of this application can be used to implement the fifth operating mode, that is, the “rapid battery cooling”, when the battery pack temperature is higher, so as to rapidly cool the battery pack **100** and rapidly reduce the temperature of the battery pack **100**. The difference from the fourth operating mode is that in the fifth operating mode, the controller **400** also turns on the cooling module **311** for cooling, and the cooling module **311** removes heat from the heat exchanger **307**, thereby improving the heat exchange efficiency.

(88) For example, the second battery pack temperature threshold may be 40° C., and when the battery pack temperature measured by the battery management module **101** is higher than 40° C., the controller **400** controls to enter the “rapid battery cooling” operating mode.

(89) In addition, according to some embodiments of this application, the thermal management system may further include a medium outlet temperature sensor of battery pack heat exchanger **111** and a medium inlet temperature sensor of battery pack heat exchanger **112**, which are disposed at a medium outflow port and medium inflow port of the battery pack heat exchanger **110**, respectively, as shown in FIG. 2. The medium outlet temperature sensor of battery pack heat exchanger **111** and the medium inlet temperature sensor of battery pack heat exchanger **112** each may be connected to the battery management module **101**, such that the measured temperature of the heat exchange medium flowing out of the battery pack heat exchanger **110** and the measured temperature of the heat exchange medium flowing into the battery pack heat exchanger **110** are sent to the battery management module **101**. Persons skilled in the art may understand that any one of the temperature of the heat exchange medium flowing out of the battery pack heat exchanger **110** and the temperature of the heat exchange medium flowing into the battery pack heat exchanger **110** may be used to substitute for the battery pack temperature, depending on an actual application scenario.

(90) FIG. 8 is a flowchart of a thermal management method according to some embodiments of this application.

(91) These embodiments of this application provide a thermal management method. Referring to FIG. 8, the thermal management method includes the following steps: S1: Measure temperature of a heating apparatus and battery pack temperature of a battery pack under the condition that the heating apparatus is in operating state, and S2: Transfer heat from the heating apparatus to the battery pack via a pipeline subsystem under the condition that the temperature of the heating apparatus is higher than the battery pack temperature.

(92) In these embodiments of this application, an example of a battery pack is a traction battery pack installed in an electric vehicle for providing energy for the electric vehicle, and the heating apparatus is, for example, electrically connected to the positive and negative electrodes of the battery pack so as to heat the battery pack by applying current to the battery pack. The pipeline subsystem is in thermal contact with both the heating apparatus and the battery pack such that, for example, heat transfer from the heating apparatus to the battery pack can be implemented by using

the heat exchange medium flowing in the pipeline subsystem. In this way, the heat that may be dissipated by the heating apparatus can be utilized, thereby improving the thermal management efficiency.

(93) FIG. 9 is a flowchart of a thermal management method according to some embodiments of this application for implementing some of operating modes.

(94) According to some embodiments of this application, in step **S100**, it is determined whether a heating apparatus is in operation or not. Determining whether the heating apparatus is in operation or not can be done by measuring a voltage and/or current of the heating apparatus. For example, if the current or voltage of the heating apparatus is not zero, it is determined that the heating apparatus is in operating state, and step **S200** is performed.

(95) In step **S200**, it is determined whether temperature of the heating apparatus is higher than a first heating apparatus temperature threshold. Measuring the temperature of the heating apparatus can be achieved by measuring temperature of one or more components of the heating apparatus, for example, by measuring temperature of one or more of a voltage regulator module, a switch module, and an energy storage unit of the heating apparatus. When the temperature of the heating apparatus is higher than the first heating apparatus temperature threshold, the temperature of the heating apparatus may be considered high enough and there is an internal heat loss of the heating apparatus. Therefore, the heat from the heating apparatus can be transferred to the heat exchange medium in the pipeline subsystem, such that the heat inside the heating apparatus can be fully used, improving the thermal management efficiency. If the temperature of the heating apparatus is higher than the first heating apparatus temperature threshold, step **S300** is performed.

(96) In step **S300**, medium circulation is started to transfer the heat from the heating apparatus to the heat exchange medium. The heat exchange medium in the pipeline subsystem may circulate in a manner of avoiding a battery pack heat exchanger. This can be implemented by using a controller to control pumps and three-way valves in the pipeline subsystem, which corresponds to the “small-circulating hydrothermal” operating mode described above. Preventing the heat of the heat exchange medium from being transferred to the battery pack can allow the heat from the heating apparatus to be fully transferred to the heat exchange medium, rapidly increasing the temperature of the heat exchange medium and improving the thermal management efficiency.

(97) In step **S400**, it is determined whether temperature at an outflow port of the heating apparatus is higher than the battery pack temperature. To facilitate measurement, the temperature at the outflow port of the heating apparatus, that is, the temperature of the heating apparatus, may be measured at a medium outflow port of the heating apparatus heat exchanger. The battery pack temperature can be measured by the battery management module of the battery pack. If the temperature at the outflow port of the heating apparatus is higher than the battery pack temperature, step **S500** is performed; otherwise, step **S300** is performed again.

(98) In step **S500**, the heat is transferred from the heating apparatus to the battery pack via the pipeline subsystem. This step can be implemented by using a controller to control pumps and three-way valves in the pipeline subsystem, which corresponds to the “large-circulating battery hydrothermal” operating mode described above. For heat transfer from the heating apparatus to the battery pack, the heat from the heating apparatus that is possible to be dissipated can be used to heat the battery pack so as to reduce thermal management costs.

(99) In step **S600**, it is determined whether the temperature of the heating apparatus is higher than a second heating apparatus temperature threshold, where the second threshold may be higher than the first threshold. Measuring the temperature of the heating apparatus can be achieved by measuring temperature of one or more components of the heating apparatus, for example, by measuring temperature of one or more of a voltage regulator module, a switch module, and an energy storage unit of the heating apparatus. When the temperature of the heating apparatus is higher than the second heating apparatus temperature threshold, the temperature of the heating apparatus may be considered to be too high, and thus the heating apparatus needs to be cooled so as to ensure the

safety of the heating apparatus. If the temperature of the heating apparatus is higher than the second heating apparatus temperature threshold, step **S700** is performed.

(100) In step **S700**, a cooling apparatus is turned on and the heat transfer between the heating apparatus and the battery pack is stopped. In this step, the heat exchange medium in the pipeline subsystem may circulate in a manner of avoiding the battery pack heat exchanger, and the cooling module connected to the pipeline subsystem is turned on to cool the heat exchange medium. This can be implemented by using a controller to control pumps, three-way valves, and cooling module in the pipeline subsystem, which corresponds to the “cooling the heating apparatus” operating mode described above. In this way, the heat is prevented from transferring from the battery pack to the heat exchange medium, and the heat exchange medium is cooled, such that the heat exchange medium can be fully cooled so as to rapidly reduce the temperature of the heating apparatus, improving the thermal management efficiency.

(101) FIG. **10** is a flowchart of a thermal management method according to some embodiments of this application for implementing some of operating modes.

(102) According to some embodiments of this application, optionally, in step **S10**, temperature of an energy storage unit and temperature of a semiconductor switch module are measured by using a heating apparatus control unit and sent to a CAN bus; and temperature of a battery pack is measured by using a battery management module and sent to the CAN bus.

(103) In step **S20**, the heating apparatus control unit is used to detect whether a current or voltage of the heating apparatus is zero or not. If the current and voltage of the heating apparatus are zero, it is determined that the heating apparatus is not in operating state, and step **S31** is performed. If the current or voltage of the heating apparatus is not zero, it is determined that the heating apparatus is in operating state, and step **S32** is performed.

(104) Under the condition that the heating apparatus is in operating state, in step **S42**, a controller is used to determine whether the temperature of the energy storage unit is higher than a first energy storage unit temperature threshold or whether the temperature of the switch module is higher than a first switch module temperature threshold. If a determining result of step **S42** is no, step **S43** is performed, in which a pipeline subsystem of a thermal management system is out of operation. If a determining result of step **S42** is yes, step **S52** is performed, in which the controller is used to control pump **1** to turn on so as to ensure that cooling water flows through the heating apparatus.

(105) After the cooling water flows through the heating apparatus, in step **S62**, the controller is used to determine whether the temperature of the energy storage unit is higher than a second energy storage unit temperature threshold or whether the temperature of the switch module is higher than a second switch module temperature threshold. The second energy storage unit temperature threshold is higher than the first energy storage unit temperature threshold, and the second switch module temperature threshold is higher than the first switch module temperature threshold. If a determining result of step **S62** is yes, step **S72** is performed, in which the controller controls to enter a first operating mode, that is, the “cooling the heating apparatus” operating mode. In this case, in step **S82**, a first pump is turned on, a second pump is turned off, a first three-way valve is controlled to make only a first valve port communicate with a common valve port, a second three-way valve is controlled to make only a first valve port communicate with a common valve port, and a cooling module is turned on so as to cool the heating apparatus.

(106) If a determining result of step **S62** is no, step **S63** is performed, in which the controller is used to determine whether temperature at an outflow port of the heating apparatus is higher than the battery pack temperature. If a determining result of step **S63** is yes, step **S73** is performed, in which the controller controls to enter a second operating mode, that is, the “large-circulating battery hydrothermal” operating mode. In this case, in step **S83**, a first pump is turned on, a second pump is turned on, a first three-way valve is controlled to make only a first valve port communicate with a common valve port, a second three-way valve is controlled to make only a second valve port communicate with a common valve port, and the cooling module is turned off, such that the heat

from the heating apparatus can be transferred to the battery pack, and the heat transfer from the heating apparatus to the battery pack is carried out with a relatively large medium circulation loop. (107) If a determining result of step **S63** is no, step **S74** is performed, in which the controller controls to enter a third operating mode, that is, the “small-circulating hydrothermal” operating mode. In this case, in step **S84**, a first pump is turned on, a second pump is turned off, a first three-way valve is controlled to make only a second valve port communicate with a common valve port, a second three-way valve is controlled to make only a first valve port communicate with a common valve port, and the cooling module is turned off, such that the heat from the heating apparatus can be transferred to the heat exchange medium in the pipeline subsystem, and the heat exchange medium can be heated with a relatively small medium circulation loop.

(108) In the first, second, and third operating modes, the controller is used for performing circulation determining for step **S62**, to be specific, determining whether the temperature of the energy storage unit is higher than the second energy storage unit temperature threshold or whether the temperature of the switch module is higher than the second switch module temperature threshold, and performing a corresponding process based on a determining result. Therefore, the thermal management system can be kept in an appropriate operating mode, thereby improving the thermal management efficiency.

(109) In addition, under the condition that the heating apparatus is not in operating state, in step **S41**, the controller turns off the first pump. Then, in step **S51**, the controller is used to determine whether the battery pack temperature is higher than a first battery pack temperature threshold. If a determining result of step **S51** is no, step **S43** is performed, in which a pipeline subsystem of a thermal management system is out of operation.

(110) If a determining result of step **S51** is yes, step **S61** is performed, in which the controller controls to enter a fourth operating mode, that is, the “battery cooling” operating mode. In this case, in step **S71**, a first pump is turned off, a second pump is turned on, a first three-way valve is controlled to make only a second valve port communicate with a common valve port, a second three-way valve is controlled to make only a second valve port communicate with a common valve port, and a cooling module is turned off, such that the heating apparatus is cooled by using the heat exchange medium under the condition that no heat exchange medium passes through the heating apparatus heat exchanger.

(111) After entering in the fourth operating mode, in step **S81**, the controller is used to determine whether the battery pack temperature is higher than a second battery pack temperature threshold. The second battery pack temperature threshold is higher than the first battery pack temperature threshold. If a determining result of step **S81** is no, still stay in the fourth operating mode, that is, the “battery cooling” operating mode. If a determining result of step **S81** is yes, step **S91** is performed, in which the controller controls to enter a fifth operating mode, that is, the “rapid battery cooling” operating mode. In this case, in step **S101**, a first pump is turned off, a second pump is turned on, a first three-way valve is controlled to make only a second valve port communicate with a common valve port, a second three-way valve is controlled to make only a second valve port communicate with a common valve port, and a cooling module is turned on, such that the heating apparatus is cooled by using the heat exchange medium under the condition that no heat exchange medium passes through the heating apparatus heat exchanger and that the cooling module is turned on.

(112) The difference from the fourth operating mode is that in the fifth operating mode, the controller also turns on the cooling module for cooling, and the cooling module removes heat from the heat exchanger, thereby improving the heat exchange efficiency.

(113) In the fifth operating mode, the controller is used for performing circulation determining for step **S51**, to be specific, determining whether the battery pack temperature is higher than a temperature threshold D, and performing a corresponding process based on a determining result. Therefore, the thermal management system can be kept in an appropriate operating mode, thereby

improving the thermal management efficiency.

(114) Persons skilled in the art can understand that the specific values (for example, temperature values) described above are merely examples and do not constitute any limitation on the scope of the present invention. Depending on an actual application scenario of the present invention, the specific values can be determined based on test data.

(115) Therefore, according to some embodiments of this application, different thermal management modes for different application scenarios are implemented with a set of pipelines, thus reducing thermal management costs.

(116) In conclusion, it should be noted that the above embodiments are merely intended for describing the technical solutions of this application but not for limiting this application. Although this application is described in detail with reference to the foregoing embodiments, persons of ordinary skill in the art should understand that they may still make modifications to the technical solutions described in the foregoing embodiments or make equivalent replacements to some or all technical features thereof without departing from the scope of the technical solutions of the embodiments of this application. They should all be covered in the scope of the claims and specification of this application. In particular, as long as there is no structural conflict, the various technical features mentioned in the embodiments can be combined in any manner. This application is not limited to the specific embodiments disclosed in this specification but includes all technical solutions falling within the scope of the claims.

## Claims

1. A thermal management method, applied to a thermal management system which comprises a heating apparatus, a battery pack, a cooling module and a pipeline subsystem, the pipeline subsystem being in thermal contact with the heating apparatus, the battery pack and the cooling module; wherein the heating apparatus comprises a switch module, an energy storage unit, and a cooling unit, the switch module and the energy storage unit are electrically connected to each other, both the switch module and the energy storage unit are in thermal contact with the cooling unit, and both the switch module and the energy storage unit are capable of transferring heat to the cooling unit; wherein the thermal management method comprises measuring a temperature of the battery pack and a temperature of a heat exchange medium of the pipeline subsystem; and under the condition that the temperature of the battery pack and the temperature of the heat exchange medium are under a low temperature threshold, operating the pipeline subsystem such that the heat exchange medium is circulated in the pipeline subsystem to exchange heat with the heating apparatus but not with the cooling module or the battery pack, until the temperature of the heat exchange medium reaches a predetermined threshold and the pipeline subsystem is operated such that the heat exchange medium is circulated in the pipeline subsystem to exchange heat with the battery pack and the heating apparatus; and under the condition that the temperature of the battery pack is higher than a high temperature threshold, operating the pipeline subsystem such that the heat exchange medium is circulated in the pipeline subsystem to exchange heat with the cooling module and the battery pack but not with the heating apparatus.

2. The thermal management method according to claim 1, wherein the pipeline subsystem further comprises a battery pack heat exchanger in thermal contact with the battery pack to allow the heat exchange medium to exchange heat with the battery pack and a heating apparatus heat exchanger in thermal contact with the heating apparatus to allow the heat exchange medium to exchange heat with the heating apparatus.

3. The thermal management method according to claim 2, wherein the temperature of the heating apparatus is measured at a medium outflow port of the heating apparatus heat exchanger.

4. The thermal management method according to claim 2, wherein the thermal management method further comprises: measuring the temperature of the heating apparatus; and under the

condition that the measured temperature of the heating apparatus is higher than a first heating apparatus temperature threshold, causing the heat exchange medium in the pipeline subsystem to circulate in a manner of avoiding the battery pack heat exchanger.

5. The thermal management method according to claim 2, wherein the thermal management method further comprises: measuring the temperature of the heating apparatus; and under the condition that the measured temperature of the heating apparatus is higher than a second heating apparatus temperature threshold, causing the heat exchange medium in the pipeline subsystem to circulate in a manner of avoiding the battery pack heat exchanger, and turning on a cooling module connected to the pipeline subsystem to cool the heat exchange medium.

6. A thermal management system, comprising: a battery pack; a heating apparatus, a cooling apparatus; and a pipeline subsystem, wherein the pipeline subsystem is in thermal contact with the heating apparatus, the battery pack and the cooling module; wherein the heating apparatus comprises a switch module, an energy storage unit, and a cooling unit, the switch module and the energy storage unit are electrically connected to each other, both the switch module and the energy storage unit are in thermal contact with the cooling unit, and both the switch module and the energy storage unit are capable of transferring heat to the cooling unit; wherein the thermal management system is arranged to measure a temperature of the battery pack and a temperature of a heat exchange medium of the pipeline subsystem; and under the condition that the temperature of the battery pack and the temperature of the heat exchange medium are under a low temperature threshold, to operate the pipeline subsystem such that the heat exchange medium is circulated in the pipeline subsystem to exchange heat with the heating apparatus but not with the cooling module or the battery pack, until the temperature of the heat exchange medium reaches a predetermined threshold and to operate the pipeline subsystem such that the heat exchange medium is circulated in the pipeline subsystem to exchange heat with the battery pack and the heating apparatus; and under the condition that the temperature of the battery pack is higher than a high temperature threshold, to operate the pipeline subsystem such that the heat exchange medium is circulated in the pipeline subsystem to exchange heat with the cooling module and the battery pack but not with the heating apparatus.

7. The thermal management system according to claim 6, wherein the heating apparatus further comprises a voltage regulator module, wherein the voltage regulator module is electrically connected to the switch module and is in thermal contact with the cooling unit, wherein the voltage regulator module is capable of transferring heat to the cooling unit.

8. The thermal management system according to claim 6, wherein the pipeline subsystem comprises a battery pack heat exchanger, a heating apparatus heat exchanger, a first pump, a second pump, a first three-way pipe, a second three-way pipe, a first three-way valve, a second three-way valve, and a cooling apparatus heat exchanger; the battery pack heat exchanger is in thermal contact with the battery pack, and the heating apparatus heat exchanger is in thermal contact with the heating apparatus; the first three-way pipe and the second three-way pipe each comprise a first port, a second port, and a third port, and the first three-way valve and the second three-way valve each comprise a common valve port, a first valve port, and a second valve port; a medium outflow port of the heating apparatus heat exchanger is connected to an input port of the first pump, an output port of the first pump is connected to the first port of the first three-way pipe, the second port of the first three-way pipe is connected to a port of the cooling apparatus heat exchanger, another port of the cooling apparatus heat exchanger is connected to the common valve port of the second three-way valve, the second valve port of the second three-way valve is connected to an input port of the second pump, an output port of the second pump is connected to a medium inflow port of the battery pack heat exchanger, a medium outflow port of the battery pack heat exchanger is connected to the first port of the second three-way pipe, and the second port of the second three-way pipe is connected to a medium inflow port of the heating apparatus heat exchanger; and the third port of the first three-way pipe is connected to the second valve port of the first three-way

valve, the third port of the second three-way pipe is connected to the common valve port of the first three-way valve, and the first valve port of the second three-way valve is connected to the first valve port of the first three-way valve.

9. The thermal management system according to claim 8, wherein the heat exchange medium is a mixed solution of ethylene glycol and water; and the pipeline subsystem further comprises an expansion tank disposed between the first three-way pipe and the heat exchanger for storing and replenishing the mixed solution.

10. The thermal management system according to claim 8, wherein the thermal management system further comprises: a medium outlet temperature sensor of heating apparatus heat exchanger, wherein the medium outlet temperature sensor of heating apparatus heat exchanger is disposed at the medium outflow port of the heating apparatus heat exchanger to measure the temperature of the heating apparatus.

11. The thermal management system according to claim 10, wherein the thermal management system further comprises a controller, the battery pack comprises a battery management module, the heating apparatus comprises a heating apparatus control unit, and the controller, the battery management module, and the heating apparatus control unit are connected to each other via a controller area network (CAN); the medium outlet temperature sensor of heating apparatus heat exchanger, the first pump, the second pump, the first three-way valve, the second three-way valve, and the cooling module are connected to the controller; the battery management module measures the battery pack temperature; and the heating apparatus control unit measures temperature of at least one of the switch module and energy storage unit in the heating apparatus; wherein the controller controls at least one of the first pump, the second pump, the first three-way valve, the second three-way valve, and the cooling module based on data from the medium outlet temperature sensor of heating apparatus heat exchanger, the battery management module, and the heating apparatus control unit, so as to implement at least one operating mode of the thermal management system.

12. The thermal management system according to claim 11, wherein under the condition that the heating apparatus is in operating state, when the temperature of the energy storage unit measured by the heating apparatus control unit is higher than an energy storage unit temperature threshold or when the temperature of the switch module is higher than a switch module temperature threshold, the controller turns on the first pump, turns off the second pump, controls the first three-way valve to make only the first valve port communicate with the common valve port, controls the second three-way valve to make only the first valve port communicate with the common valve port, and turns on the cooling module so as to cool the heating apparatus.

13. The thermal management system according to claim 11, wherein under the condition that the heating apparatus is in operating state, when the temperature of the energy storage unit measured by the heating apparatus control unit is not higher than an energy storage unit temperature threshold and the temperature of the switch module is not higher than a switch module temperature threshold, the controller further controls at least one of the first pump, the second pump, the first three-way valve, the second three-way valve, and the cooling module based on data from the medium outlet temperature sensor of heating apparatus heat exchanger and the battery management module.

14. The thermal management system according to claim 13, wherein when temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger, measured by the medium outlet temperature sensor of heating apparatus heat exchanger, is higher than the battery pack temperature measured by the battery management module, the controller turns on the first pump, turns on the second pump, controls the first three-way valve to make only the first valve port communicate with the common valve port, controls the second three-way valve to make only the second valve port communicate with the common valve port, and turns off the cooling module so as to transfer heat from the heating apparatus to the battery pack.



15. The thermal management system according to claim 13, wherein when temperature of the heat exchange medium flowing out of the heating apparatus heat exchanger, measured by the medium outlet temperature sensor of heating apparatus heat exchanger, is not higher than the battery pack temperature measured by the battery management module, the controller turns on the first pump, turns off the second pump, controls the first three-way valve to make only the second valve port communicate with the common valve port, controls the second three-way valve to make only the first valve port communicate with the common valve port, and turns off the cooling module so as to transfer heat from the heating apparatus to the heat exchange medium in the pipeline subsystem.
16. The thermal management system according to claim 11, wherein under the condition that the heating apparatus is not in operating state, when the battery pack temperature measured by the battery management module is higher than a first battery pack temperature threshold, the controller turns off the first pump, turns on the second pump, controls the first three-way valve to make only the second valve port communicate with the common valve port, controls the second three-way valve to make only the second valve port communicate with the common valve port, and turns off the cooling module so as to cool the battery pack.
17. The thermal management system according to claim 16, wherein when the battery pack temperature measured by the battery management module is higher than a second battery pack temperature threshold, the controller turns off the first pump, turns on the second pump, controls the first three-way valve to make only the second valve port communicate with the common valve port, controls the second three-way valve to make only the second valve port communicate with the common valve port, and turns on the cooling module so as to cool the battery pack.
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