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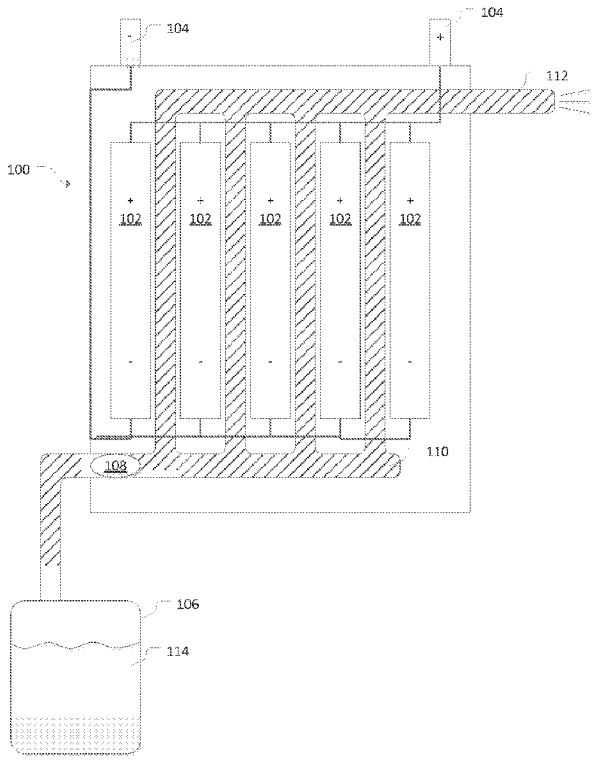
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(54) Title: FAST THERMAL DUMPING FOR BATTERIES

FIG. 1



(57) Abstract: A cooling system includes a fluid delivery system configured to bring a working liquid (such as water) into thermal contact with a battery where it vaporizes into an exhaust gas, and an exhaust system configured to vent the exhaust gas.

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Fast Thermal Dumping for Batteries

If an Application Data Sheet (ADS) has been filed on the filing date of this application, it is incorporated by reference herein. Any applications claimed on the ADS for priority under 35 U.S.C. §§ 119, 120, 121, or 365(c), and any and all parent, grandparent, great-grandparent, etc. applications of such applications, are also incorporated by reference, including any priority claims made in those applications and any material incorporated by reference, to the extent such subject matter is not inconsistent herewith.

SUMMARY

In one aspect, a system for cooling thermal runaway in a batter includes a fluid delivery system configured to transport a working liquid (*e.g.*, water, a CFC, an HFC, an HCFC, a BCFC, or a mixture thereof) into thermal contact with the battery and further configured to permit the working liquid to vaporize to form an exhaust gas, and an exhaust system configured to vent the exhaust gas. The system may include a storage tank for the working liquid, and may be configured to work without a connection to an external source of working liquid. The system may include a structure configured to route the working liquid through the battery interior, for example multiple channels that bring working liquid through a plurality of locations within the battery. These may be configured to cool the battery at different cooling rates in different locations, for example separately controlling the cooling rate of each cell of a multi-cell battery. The fluid delivery system may include a pump, a valve, or a pressurization source (*e.g.*, a source pressurized by a portion of the exhaust gas). The system may further include triggering circuitry configured to activate the cooling system in response to a battery condition (*e.g.*, temperature, current, rate of change of temperature, acceleration, acceleration history, speed, speed history, internal pressure of the battery, or structural integrity of the battery), and optionally a memory configured to store a record of the battery condition or a record of the cooling system activation. The system may include a heat transfer structure (*e.g.*, including a heat

pipe, a coolant flow conduit, or a thermal conductor) configured to transport heat from the interior of the battery to an external heat exchanger, where the fluid delivery system is configured to route the working liquid into thermal contact with the external heat exchanger. The system may include triggering circuitry configured to activate the cooling system in response to an external command, or flow rate circuitry configured to control a flow rate of the working liquid within the fluid delivery system in response to a battery condition (*e.g.*, battery temperature profile). The system may be configured to deliver working liquid to different cells of the battery at different rates.

In another aspect, a method of cooling a battery includes bringing a working liquid (*e.g.*, water, a CFC, an HFC, an HCFC, a BCFC, or a mixture thereof) into thermal contact with the battery, allowing the working liquid to vaporize to form an exhaust gas, and venting the exhaust gas. The method may include storing the working liquid the working liquid in a storage tank, and bringing it from the tank without an existing connection to an external liquid supply. The method may include routing the working liquid through the battery interior, for example via multiple channels that bring working liquid to a plurality of locations within the battery. These may be configured to cool the battery at different cooling rates in different locations, for example separately controlling the cooling rate of each cell of a multi-cell battery. The method may include pumping the working liquid. The method may further include activating the cooling system in response to a battery condition (*e.g.*, temperature, current, rate of change of temperature, acceleration, acceleration history, speed, speed history, internal pressure of the battery, or structural integrity of the battery), and optionally storing a record of the battery condition or a record of the cooling system activation in a memory. The method may include transporting heat via a heat transfer structure (*e.g.*, a heat pipe, a coolant flow conduit, or a thermal conductor) from the interior of the battery to an external heat exchanger, and placing the working liquid into thermal contact with the external heat exchanger. The method may include activating the cooling system in response to an external command, or adjusting a flow rate of the working liquid within the fluid delivery system in

response to a battery condition (*e.g.*, battery temperature profile). The method may include delivering working liquid to different cells of the battery at different rates.

In still another aspect, a system for cooling a battery includes means for bringing a working liquid (*e.g.*, water, a CFC, an HFC, an HCFC, a BCFC, or a mixture thereof) into thermal contact with the battery, means for allowing the working liquid to vaporize to form an exhaust gas, and means for venting the exhaust gas. The system may include a storage tank that stores the working liquid, and means for bringing it from the tank without an existing connection to an external liquid supply. The system may include means for routing the working liquid through the battery interior, for example via multiple channels that bring working liquid to a plurality of locations within the battery. These may be configured to cool the battery at different cooling rates in different locations, for example separately controlling the cooling rate of each cell of a multi-cell battery. The means for bringing the working liquid into thermal contact with at least a portion of the battery may include a pump, a valve, or a pressurization source. The system may further include means for activating the cooling system in response to a battery condition (*e.g.*, temperature, current, rate of change of temperature, acceleration, acceleration history, speed, speed history, internal pressure of the battery, or structural integrity of the battery), and optionally means for storing a record of the battery condition or a record of the cooling system activation in a memory. The system may include means for transporting heat via a heat transfer structure (*e.g.*, a heat pipe, a coolant flow conduit, or a thermal conductor) from the interior of the battery to an external heat exchanger, and means for placing the working liquid into thermal contact with the external heat exchanger. The system may include means for activating the cooling system in response to an external command, or means for adjusting a flow rate of the working liquid within the fluid delivery system in response to a battery condition (*e.g.*, battery temperature profile). The system may include means for delivering working liquid to different cells of the battery at different rates.

The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features

described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a battery cooling system.

FIG. 2 is a flow chart of a method of operating the battery cooling system of **FIG. 1**.

FIG. 3 is a detail of a battery having separate flow control in different cells.

FIG. 4 is a detail of a battery having valves to control routing of exhaust gas.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here.

The term "circulated," as it is used herein, includes flowing a fluid through a pipe, channel, or conduit, or through an indeterminate path such as through an open-cell foam, either once or multiple times. The term "recirculated," as it is used herein, includes circulating a fluid in a configuration in which it passes through the same portion of an apparatus more than once.

FIG. 1 is a schematic drawing illustrating a cooling system for a battery **100**, such as an auto battery. Battery **100** includes multiple cells **102**, each with a positive and negative terminal as shown. Cells **102** are wired in parallel and connected to positive and negative battery terminals **104** in a conventional manner. A fluid delivery system includes reservoir **106**, pump **108**, heat exchanger pipes **110**, and exhaust **112**. Reservoir **106** holds a working liquid **114**. Any convenient working liquid that may be circulated through the battery at its working temperature and that may be vaporized as described below may be used. It is expected that water will represent a good working liquid in many embodiments, since it has a relatively high

heat of vaporization and is innocuous when vented to the atmosphere, but in some embodiments, more exotic working liquids may be appropriate, such as chlorofluorocarbons (CFCs, *e.g.*, FREON™), hydrofluorocarbons (HFCs), hydrofluorochlorocarbons (HCFCs), bromochlorofluorocarbons (BCFCs), or mixtures of any of the preceding compounds, which may, for example, be azeotropic mixtures.

Heat exchanger pipes **110** are provided that allow working liquid **114** from reservoir **106** to be circulated through the battery, either by free convection or assisted by one or more pumps **108**. (One pump is illustrated in **FIG. 1**, but in other embodiments, pumps **108** may be provided throughout the system, which may be jointly or separately controlled, as further discussed below in connection with **FIG. 3**. Alternatively, instead of a pump, the system may harness pressure generated by vaporization of working fluid **114** or the energy of a catastrophic event precipitating rapid cooling, as further discussed below.) In the embodiment shown in **FIG. 1**, the system includes defined pipes in thermal communication with the battery cells **102**, but in other embodiments, fluid may be circulated around or even through the cells in any convenient configuration. For example, cells **102** may be embedded in an open-cell foam through which the working liquid **114** circulates, or there are may be perforations in cells **102** that are designed to permit working fluid **114** to exchange heat with cells **102** without unacceptably degrading the electrical performance of the cells. In some embodiments, solid heat pipes or similar structures (not shown) conduct heat out of the cells to the heat exchanger pipes **110**. The illustrated heat exchanger pipes **110** are connected to exhaust **112** that allows vaporized working liquid to be vented, for example to the atmosphere or to a sealed balloon or the like (not shown) where it can be subsequently harvested for reuse.

FIG. 2 is a flow chart illustrating steps of one method of using the cooling system illustrated in **FIG. 1**. In normal operation, working liquid **114** circulates **202** through battery **100** to cool it, either through free convection or assisted by pump **108**. However, upon experiencing a precipitating event **204**, system **100** shifts to an irreversible cooling mode designed to cool the battery as fast as possible, before thermal runaway can occur. In some embodiments, precipitating events may include

temperature exceeding a threshold, rate of temperature change exceeding a threshold, rapid acceleration of the system (*e.g.*, an impact), internal pressure of the battery, compromise of the integrity of one or more cells **102**, or a received command such as a wireless command. In the embodiment shown in **FIG. 1**, working liquid **114** is pumped through the system by pump(s) **108** to cool the battery **206**, and is allowed to vaporize **208** to absorb as much heat as possible via evaporative cooling, and is vented to the atmosphere through exhaust **112**.

FIG. 3 is a schematic showing the interior of a battery equipped to individually control the cooling rate for each cell. Each cell **302** has an associated heat exchanger pipe **310**, each with its own pump **308**. The schematic illustration shows each heat exchanger pipe **310** as a loop around cell **302**, but it will be understood that the path of each pipe **310** may vary from this configuration, and should be designed to efficiently remove heat from cell **302**. Thermocouple **304** is positioned to measure the temperature of cell **302**, and to provide a feedback signal to pump **308**. The speed of pump **308** is controlled relative to the temperature measured by thermocouple **304** so that cell **302** is cooled at a controlled rate, which can be independently controlled for each cell **302**. For example, more cooling may be needed for cells in the center of the battery than for cells at the periphery.

Thermocouple **304** and pump **308** may also be connected to circuitry for measuring and recording the temperature and cooling rate of the battery. In some embodiments, such a record may include time-stamping or place-stamping (*e.g.*, via GPS), so that the performance of the battery can be reconstructed, for example for forensic purposes after an accident.

In other embodiments, rather than directly routing the working liquid through the battery, the battery may include thermal conductors (heat pipes) configured to transport heat to a heat exchanger. In some embodiments, a single or a few heat pipes may serve the whole battery, which is others, individual heat pipes may be provided for each cell or other region of the battery interior. In embodiments in which heat pipes are provided to transport heat to a heat exchanger, the working liquid is brought into thermal contact with the heat pipes, which in some embodiments may be outside of the main battery compartment. Those of skill in the art will recognize that this

design may facilitate the construction of batteries that need not be able to tolerate working liquid in the battery interior, but that this advantage must be balanced against possible inefficiencies in transporting heat to the working liquid (instead of transporting the working liquid to the heat source).

Pressures generated by vaporization of a working liquid in a battery can be quite high if the fluid is not adequately vented. Plumbing in the battery should generally be designed with an eye to managing pressures to avoid rupturing a heat exchanger pipe within the battery, although in some embodiments, planned rupture may be used to improve heat transfer within the battery. However, such pressures can also be leveraged to increase fluid flow, in some embodiments even to the point where pump **108** can be omitted from the system. In some embodiments, liquid recirculates around the battery (with or without a pump), until the cooling system is activated (for example, by a substantial temperature excursion within the battery, or by a detected rapid deceleration indicative of an impact).

FIG. 4 shows an exhaust system that uses internal pressure to reroute the path of the exhaust gas. Working liquid **414** is stored in reservoir **406** and circulated through battery **416**, absorbing heat from the battery and vaporizing to form exhaust gas. Exhaust port **418** for the vaporized exhaust gas leads to a chamber **420** having two one-way, pressure activated, valves. Recirculation valve **422** opens at a first pressure P_1, thereby allowing pressurization of the reservoir **406**. If the pressure reaches a greater pressure P_2, exhaust valve **424** opens, allowing excess exhaust gas to be vented through exhaust pipe **412**.

While the novel batteries presented herein may be used in stationary applications, they are particularly well-suited for use in vehicles or other devices that move independently (*e.g.*, robots or autonomous vehicles). In such embodiments, the vehicle or other device typically carries a tank of working liquid that may be vented in the case of a battery failure. For example, currently used electric vehicle batteries usually store about 15-60 kW-h of electrochemical energy. Water absorbs about 2.3 kJ/g when vaporized, so it would require about 22-87 kg of water to be vaporized to dissipate all of the electrochemical energy in the battery (neglecting energy used to heat the water to the boiling point and any possible parasitic losses), a reasonable

amount to carry with the battery in a dedicated storage tank or the like (22 kg of water occupies less than a cubic foot of space). (Dichlorodifluoromethane (FREON-12) is much less efficient with a latent heat of vaporization of 0.17 kJ/g, but may nevertheless be preferable in some embodiments.) Those of skill in the art will understand that these numbers are estimates used to demonstrate feasibility of the concept and are not intended to be limiting. In some embodiments, slower cooling or incomplete cooling may be tolerable, in which case less working liquid may be carried. In other embodiments, speed of cooling may be paramount, in which case pumping must be faster and thermal transfer to the working liquid made as efficient as possible to optimize performance.

Various embodiments of electrochemical devices and methods have been described herein. In general, features that have been described in connection with one particular embodiment may be used in other embodiments, unless context dictates otherwise. For example, the individual cell cooling described in connection with **FIG. 3** may be employed in the devices described in connection with **FIG. 4**, or with any of the embodiments described herein. For the sake of brevity, descriptions of such features have not been repeated, but will be understood to be included in the different aspects and embodiments described herein.

It will be understood that, in general, terms used herein, and especially in the appended claims, are generally intended as "open" terms (*e.g.*, the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of introductory phrases such as "at least one" or "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the

introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (*e.g.*, "a cell" should typically be interpreted to mean "at least one cell"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation *is* explicitly recited, it will be recognized that such recitation should typically be interpreted to mean *at least* the recited number (*e.g.*, the bare recitation of "two heat pipes," or "a plurality of heat pipes," without other modifiers, typically means *at least* two heat pipes). Furthermore, in those instances where a phrase such as "at least one of A, B, and C," "at least one of A, B, or C," or "an [item] selected from the group consisting of A, B, and C," is used, in general such a construction is intended to be disjunctive (*e.g.*, any of these phrases would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, or A, B, and C together, and may further include more than one of A, B, or C, such as A_1, A_2, and C together, A, B_1, B_2, C_1, and C_2 together, or B_1 and B_2 together). It will be further understood that virtually any disjunctive word or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the possibilities of "A" or "B" or "A and B."

While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

CLAIMS

1. A cooling system for cooling thermal runaway in a battery, the system comprising:
   a fluid delivery system configured to transport a working liquid into thermal contact with the battery and further configured to permit the working liquid to vaporize to form an exhaust gas; and
   an exhaust system configured to vent the exhaust gas.

2. The system of claim 1, wherein the working liquid includes water.

3. The system of claim 1, wherein the working liquid includes a chlorofluorocarbon, hydrofluorocarbon, hydrofluorochlorocarbon, bromochlorofluorocarbon, or a mixture of any of the preceding compositions.

4. The system of claim 1, further comprising a storage tank for the working liquid, wherein the system is configured to cool thermal runaway without a present connection to an external source of working liquid.

5. The system of claim 1, wherein the fluid delivery system includes a structure configured to route the working liquid through the battery interior.

6. The system of claim 5, wherein the fluid delivery system includes a plurality of channels configured to route the working liquid through a plurality of locations within the battery.

7. The system of claim 6, wherein the fluid delivery system includes a structure configured to separately control a flow rate through the plurality of channels, wherein the fluid delivery system is configured to cool different portions of the battery at different cooling rates.

8. The system of claim 7, wherein the battery includes a plurality of cells, and further comprising a control system configured to direct the fluid delivery system to cool each cell separately.

9. The system of claim 1, wherein the fluid delivery system includes a pump.

10. The system of claim 1, wherein the fluid delivery system includes a valve.

11. The system of claim 1, wherein the fluid delivery system includes a pressurization source.

12. The system of claim 11, wherein the pressurization source includes at least a portion of the exhaust gas.

13. The system of claim 1, further comprising triggering circuitry configured to activate the cooling system in response to a battery condition.

14. The system of claim 13, wherein the battery condition is temperature.

15. The system of claim 13, wherein the battery condition is current.

16. The system of claim 13, wherein the battery condition is rate of change of temperature.

17. The system of claim 13, wherein the battery condition is acceleration, acceleration history, speed, or speed history of the battery.

18. The system of claim 13, wherein the battery condition is internal pressure of the battery.

19. The system of claim 13, wherein the battery condition is structural integrity of the battery.

20. The system of claim 13, further comprising a memory configured to store a record of the battery condition.

21. The system of claim 13, further comprising a memory configured to store a record of the cooling system activation.

22. The system of claim 1, wherein the battery includes a heat transfer structure configured to transport heat from the interior of the battery to an external heat

exchanger, and wherein the fluid delivery system is configured to route the working liquid into thermal contact with the external heat exchanger.

23. The system of claim 22, wherein the heat transfer structure includes a heat pipe.

24. The system of claim 22, wherein the heat transfer structure includes a coolant flow conduit.

25. The system of claim 22, wherein the heat transfer structure includes a thermal conductor.

26. The system of claim 1, further comprising triggering circuitry configured to activate the cooling system in response to an external command.

27. The system of claim 1, further comprising flow rate circuitry configured to control a flow rate of the working liquid within the fluid delivery system, wherein the flow rate circuitry is configured to respond to a battery condition by adjusting the flow rate of working liquid delivered to the battery.

28. The system of claim 27, wherein the flow rate circuitry is configured to deliver the working liquid to the battery in response to a battery temperature profile.

29. The system of claim 1, wherein the battery includes a plurality of cells, and wherein the fluid delivery system is configured to deliver working liquid to individual cells at different rates.

30. A method of cooling a battery, comprising:
bringing a working liquid into thermal contact with at least a portion of the battery;
allowing heat from the battery to vaporize the working liquid; and
venting the vaporized working liquid.

31. The method of claim 30, wherein the working liquid includes water.

32. The method of claim 30, wherein the working liquid includes a chlorofluorocarbon, hydrofluorocarbon, hydrofluorochlorocarbon, bromochlorofluorocarbon, or a mixture of any of the preceding compositions.

33. The method of claim 30, wherein bringing the working liquid into thermal contact with at least a portion of the battery includes bringing the working liquid from a storage tank without an existing connection to an external liquid supply.

34. The method of claim 30, wherein bringing the working liquid into thermal contact with at least a portion of the battery includes routing working liquid through the battery interior.

35. The method of claim 34, wherein bringing the working liquid into thermal contact with at least a portion of the battery includes routing the working liquid through a plurality of locations within the battery.

36. The method of claim 35, wherein bringing the working liquid into thermal contact with at least a portion of the battery includes cooling different portions of the battery at different cooling rates.

37. The method of claim 36, wherein the battery includes a plurality of cells, and wherein bringing the working liquid into thermal contact with at least a portion of the battery includes separately cooling each cell of the battery.

38. The method of claim 30, wherein bringing the working liquid into thermal contact with at least a portion of the battery includes pumping the working liquid.

39. The method of claim 30, wherein bringing the working liquid into thermal contact with at least a portion of the battery includes activating the cooling system in response to a battery condition.

40. The method of claim 39, wherein the battery condition is temperature.

41. The method of claim 39, wherein the battery condition is current.

42. The method of claim 39, wherein the battery condition is rate of change of temperature.

43. The method of claim 39, wherein the battery condition is acceleration, acceleration history, speed, or speed history of the battery.

44. The method of claim 39, wherein the battery condition is internal pressure of the battery.

45. The method of claim 39, wherein the battery condition is structural integrity of the battery.

46. The method of claim 39, further comprising storing a record of the battery condition in a memory.

47. The method of claim 39, further comprising storing a record of the cooling system activation in a memory.

48. The method of claim 30, further comprising transporting heat from the interior of the battery to an external heat exchanger, wherein bringing the working liquid into thermal contact with at least a portion of the battery includes bringing the working liquid into thermal contact with the external heat exchanger.

49. The method of claim 48, wherein transporting heat from the interior of the battery to an external heat exchanger includes transporting heat from the interior of the battery to the external heat exchanger via a heat pipe.

50. The method of claim 48, wherein transporting heat from the interior of the battery to an external heat exchanger includes transporting heat from the interior of the battery to the external heat exchanger via a coolant flow conduit.

51. The method of claim 48, wherein transporting heat from the interior of the battery to an external heat exchanger includes transporting heat from the interior of the battery to the external heat exchanger via a thermal conductor.

52. The method of claim 30, wherein bringing the working liquid into thermal contact with at least a portion of the battery includes activating the cooling system in response to an external command.

53. The method of claim 30, further comprising responding to a battery condition by adjusting a flow rate of working liquid delivered to the battery.

54. The method of claim 53, wherein the adjusting a flow rate of working liquid delivered to the battery includes adjusting the flow rate of working liquid in response to a battery temperature profile.

55. The method of claim 30, wherein the battery includes a plurality of cells, and wherein bringing the working liquid into thermal contact with at least a portion of the battery includes delivering liquid to individual cells at different rates.

56. A system for cooling a battery, comprising:
means for bringing a working liquid into thermal contact with at least a portion of the battery;
means for allowing heat from the battery to vaporize the working liquid; and
means for venting the vaporized working liquid.

57. The system of claim 56, wherein the working liquid includes water.

58. The system of claim 56, wherein the working liquid includes a chlorofluorocarbon, hydrofluorocarbon, hydrofluorochlorocarbon, bromochlorofluorocarbon, or a mixture of any of the preceding compositions.

59. The system of claim 56, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes means for bringing the working liquid from a storage tank without an existing connection to an external liquid supply.

60. The system of claim 56, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes means for routing working liquid through the battery interior.

61. The system of claim 60, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes means for routing the working liquid through a plurality of locations within the battery.

62. The system of claim 61, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes means for cooling different portions of the battery at different cooling rates.

63. The system of claim 62, wherein the battery includes a plurality of cells, and wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes means for separately cooling each cell of the battery.

64. The system of claim 56, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes a pump.

65. The system of claim 56, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes a valve.

66. The system of claim 56, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes a pressurization source.

67. The system of claim 66, wherein the pressurization source includes at least a portion of the exhaust gas.

68. The system of claim 56, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes means for activating the cooling system in response to a battery condition.

69. The system of claim 68, wherein the battery condition is temperature.

70. The system of claim 68, wherein the battery condition is current.

71. The system of claim 68, wherein the battery condition is rate of change of temperature.

72. The system of claim 68, wherein the battery condition is acceleration, acceleration history, speed, or speed history of the battery.

73. The system of claim 68, wherein the battery condition is internal pressure of the battery.

74. The system of claim 68, wherein the battery condition is structural integrity of the battery.

75. The system of claim 68, further comprising means for storing a record of the battery condition in a memory.

76. The system of claim 68, further comprising means for storing a record of the cooling system activation in a memory.

77. The system of claim 56, further comprising means for transporting heat from the interior of the battery to an external heat exchanger, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes means for bringing the working liquid into thermal contact with the external heat exchanger.

78. The system of claim 77, wherein the means for transporting heat from the interior of the battery to an external heat exchanger include a heat pipe.

79. The system of claim 77, wherein the means for transporting heat from the interior of the battery to an external heat exchanger include a coolant flow conduit.

80. The system of claim 77, wherein the means for transporting heat from the interior of the battery to an external heat exchanger include a thermal conductor.

81. The system of claim 56, wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes means for activating the cooling system in response to an external command.

82. The system of claim 56, further comprising means for responding to a battery condition by adjusting a flow rate of working liquid delivered to the battery.

83. The system of claim 82, wherein the means for responding to a battery condition by adjusting a flow rate of working liquid delivered to the battery include means for adjusting the flow rate of working liquid in response to a battery temperature profile.

84. The system of claim 56, wherein the battery includes a plurality of cells, and wherein the means for bringing the working liquid into thermal contact with at least a portion of the battery includes means for delivering liquid to individual cells at different rates.

FIG. 1

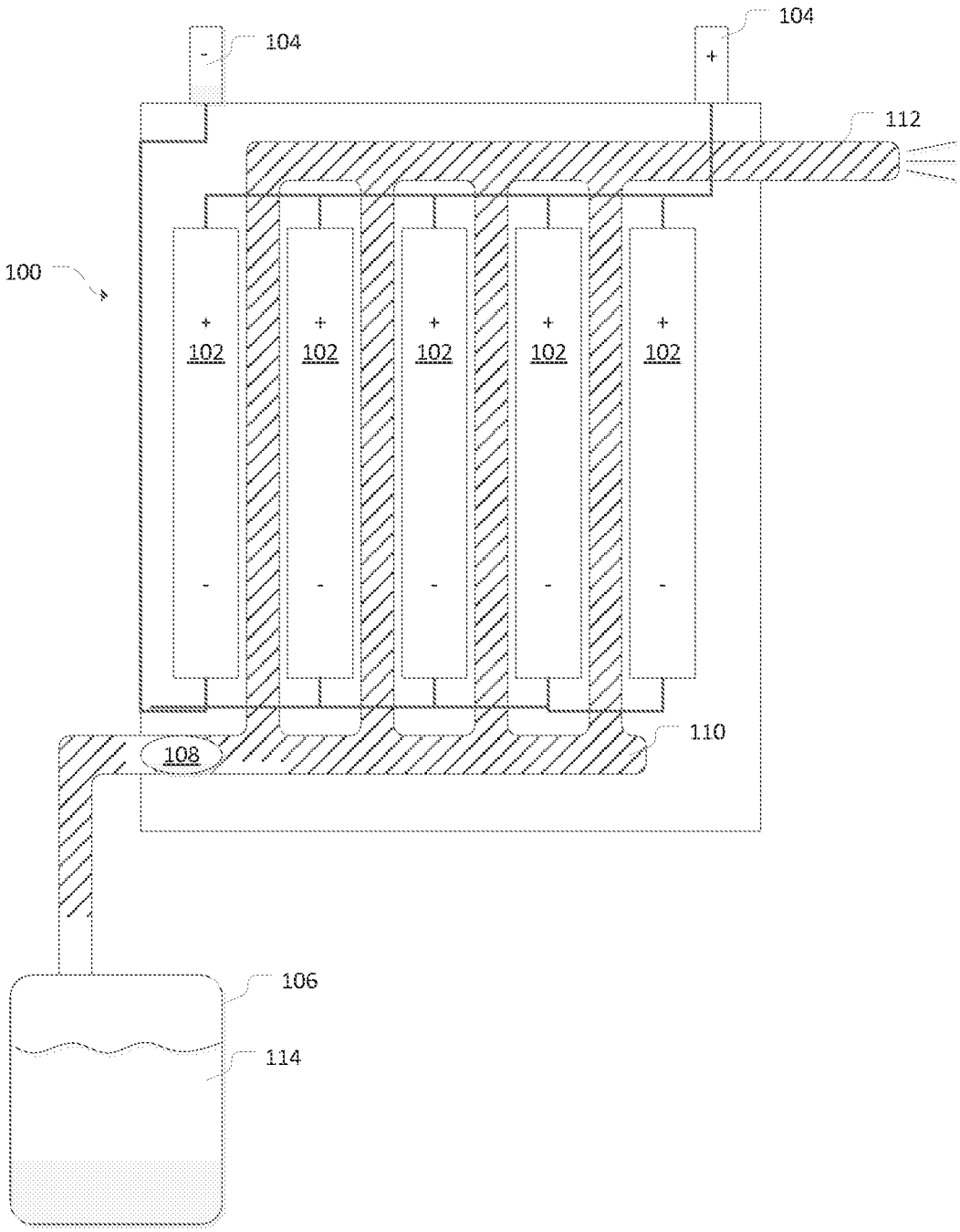


FIG. 2

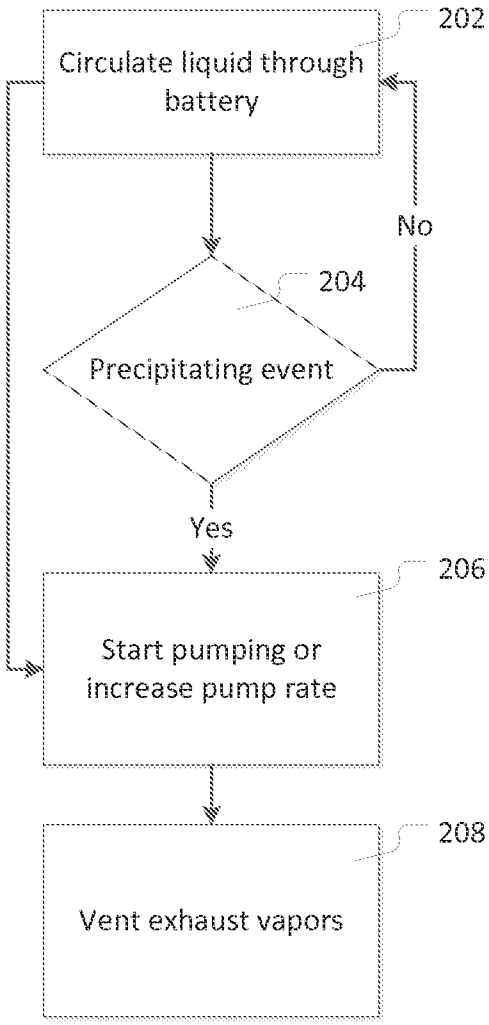

202
Circulate liquid through battery
No
204
Precipitating event
Yes
206
Start pumping or increase pump rate
208
Vent exhaust vapors

FIG. 3

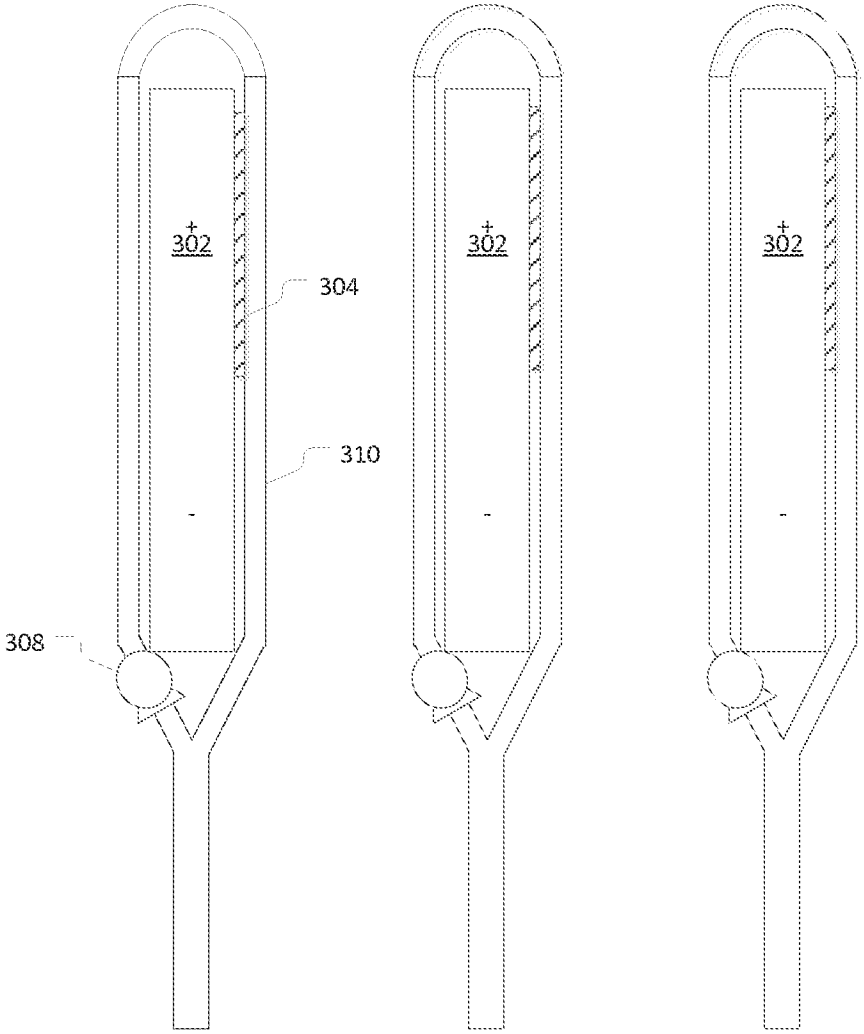
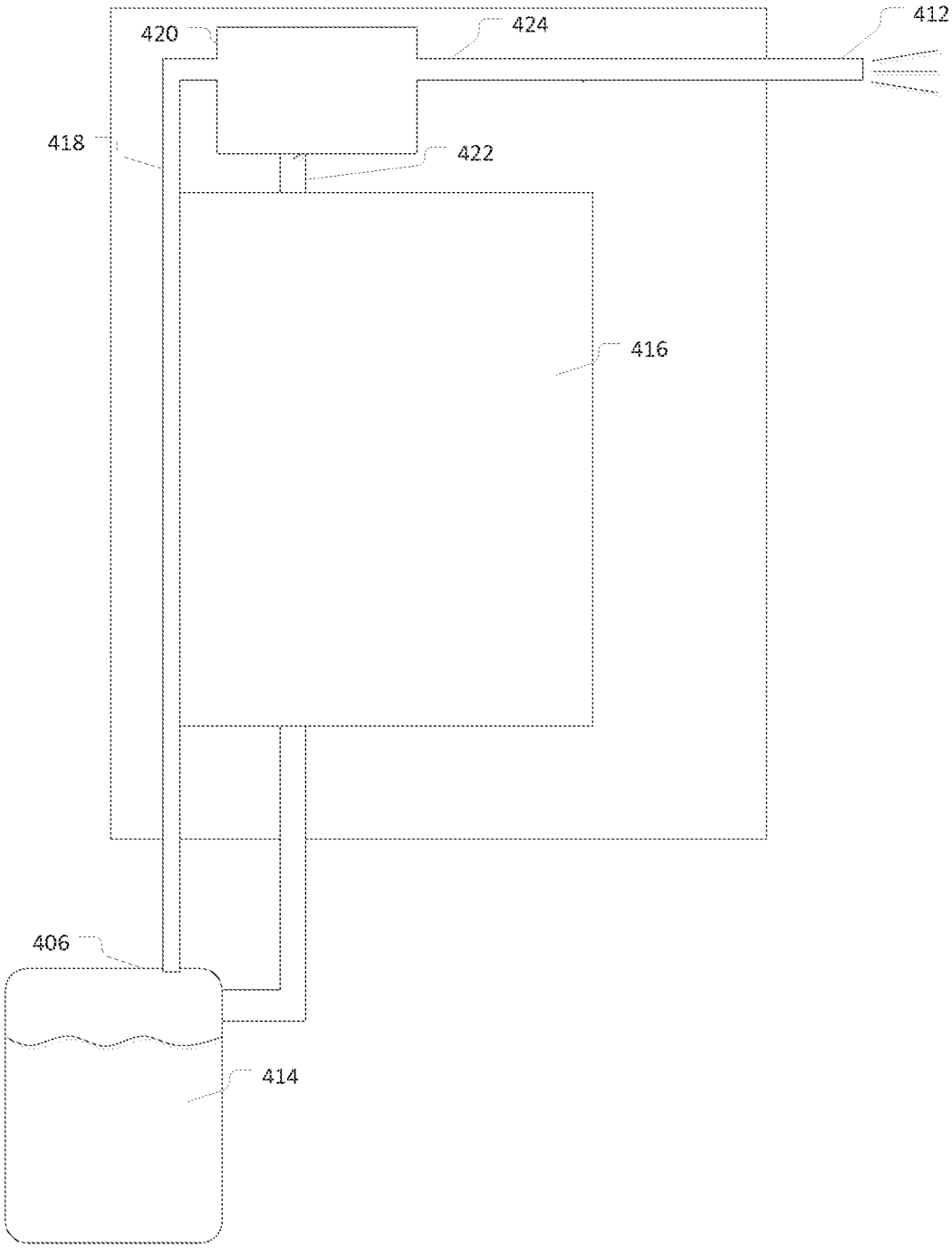


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/039008

A. CLASSIFICATION OF SUBJECT MATTER

H01M 10/60(2014.01)i, H01M 10/65(2014.01)i, H01M 10/656(2014.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01M 10/60; F25D 3/00; H01M 10/6569; F28D 15/00; H01M 10/6571; F25D 23/12; H01M 10/50; F25B 49/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: cooling, battery, liquid, contact, vaporizing, venting

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	KR 10-2010-0041727 A (RIM, JAE HYEON) 22 April 2010 See abstract; paragraphs [0007]-[0009]; claims 1-11; and figures 1-3, 7.	1-3,10,30-32,56-58,65 4-9,11-29,33-55,59-64,66-84
Y	JP 2010-277767 A (NISSAN MOTOR CO., LTD. et al.) 9 December 2010 See abstract; paragraphs [0011]-[0020]; and figures 1-2.	4,11-12,33,59,66-67
Y	JP 2013-062207 A (NISSAN MOTOR CO., LTD.) 4 April 2013 See abstract; paragraphs [0028]-[0044]; claims 1-6; and figures 3-7.	5-9,13-29,34-55,60-64,68-84
A	US 2013-0074525 A1 (JOHNSTON, VINCENT GEORGE et al.) 28 March 2013 See abstract; paragraphs [0022]-[0035]; claims 1-22; and figures 1-7.	1-84
A	US 2004-0163398 A1 (MORISHITA, YUSUKE et al.) 26 August 2004 See paragraphs [0025]-[0034], [0051]-[0053]; claims 1-4; and figures 1, 3.	1-84

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
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"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 September 2014 (12.09.2014)	**12 September 2014 (12.09.2014)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2014/039008

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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