CASCADE HEAT EXCHANGER AND GAS KNOCKOUT FOR METAL AIR BATTERY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to, and is a non-provisional of U.S. Patent Application 63/501,090 (filed May 9, 2023), the entirety of which is incorporated herein by reference.

BACKGROUND

[0002] Metal air batteries provide a high energy density power source that shows promising applications for mobile and stationary distributed power sources. They have the potential to replace the internal combustion engines found in hybrid cars, locomotives, ships and aircraft since the energy density and efficiency of conversion approach those of hydrocarbon fuels.

[0003] Metal air batteries suffer from a number of problems that have, to date, excluded them from use in the aforementioned areas. The distance between the oxygen reduction reaction (ORR) material and charge-collecting screens cause electrical resistance losses during operation. Since the metal anode is consumed during the discharge of the battery the distance between the cathode and anode increases over time. This change in electrode spacing increases the I^2R (electrical resistance) lowering the power output over time. Furthermore, when the batteries are run open circuit or without load they rapidly produce hydrogen gas in the electrolyte that further increases I^2R losses and prevents return to full power when connected to a closed electrical circuit again.

[0004] A number of attempts have been made to resolve the aforementioned problems. There has been much research into the chemistry of electrolyte additives that can inhibit the production of hydrogen gas without much success. Some removable electrode designs have been tested that incorporate protection of the edges of the anode from corrosion and gas production with limited success. Other designs have attempted to mount the anode on a moving apparatus to reduce the increase in resistance by altering the space between the anode and cathode. These have been shown to be mechanically complicated and limit the

ability to load the metal air battery with fresh metal anodes quickly. None of these solutions have been applied in combination with success, leaving the metal air battery as a one-use item and difficult to use for intermittent power applications.

SUMMARY

[0005] This disclosure provides a metal air battery with a heat exchanger. The heat exchanger has air-side fins directly connected to a backplate and liquid-side fins thermally connected to the backplate. The liquid-side fins receive liquid electrolyte from an overflow port, pass the liquid electrolyte over the liquid-side fins and into a liquid electrolyte compartment. The liquid-side fins have alternating, adjacent fins that are at an angle (θ) to one another and are separated by a gap such that liquid electrolyte cascades over adjacent fins. The heat exchanger simultaneously degasses the electrolyte and removes excess heat therefrom.

[0006] This disclosure provides a metal air battery. The metal air battery comprising: a metal air battery comprising a liquid electrolyte compartment and a chamber with an anode, a cathode, an overflow port and a liquid electrolyte input that introduces liquid electrolyte from the liquid electrolyte compartment to the chamber wherein the liquid electrolyte input is disposed at a lower end of the chamber and the overflow port is disposed at an upper end of the chamber; a heat exchanger comprising: a plurality of air-side fins directly connected to a backplate; a plurality of liquid-side fins thermally connected to the backplate, the plurality of liquid-side fins being disposed in an overflow path positioned to receive liquid electrolyte from the overflow port, pass the liquid electrolyte over the plurality of liquid-side fins and into the liquid electrolyte compartment; and the plurality of liquid-side fins consisting of alternating, adjacent first fins and second fins that are at an angle (θ) greater than 0° and less than 135° to one another and separated by a gap such that liquid electrolyte cascades from a distal end of the first fins, through the gap and to a proximal end of the second fins.

[0007] This brief description of the invention is intended only to provide a brief overview of subject matter disclosed herein according to one or more illustrative embodiments, and does not serve as a guide to interpreting the claims or to define or limit

the scope of the invention, which is defined only by the appended claims. This brief description is provided to introduce an illustrative selection of concepts in a simplified form that are further described below in the detailed description. This brief description is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter. The claimed subject matter is not limited to implementations that solve any or all disadvantages noted in the background.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] So that the manner in which the features of the invention can be understood, a detailed description of the invention may be had by reference to certain embodiments, some of which are illustrated in the accompanying drawings. It is to be noted, however, that the drawings illustrate only certain embodiments of this invention and are therefore not to be considered limiting of its scope, for the scope of the invention encompasses other equally effective embodiments. The drawings are not necessarily to scale, emphasis generally being placed upon illustrating the features of certain embodiments of the invention. In the drawings, like numerals are used to indicate like parts throughout the various views. Thus, for further understanding of the invention, reference can be made to the following detailed description, read in connection with the drawings in which:

[0009] FIG. 1 depicts a perspective view of a heat exchanger.

[0010] FIG. 2 illustrates a metal air battery that uses the heat exchanger.

[0011] FIG. 3 depicts the flow path of liquid electrolyte through the metal air battery.

[0012] FIG. 4 depicts the flow path of hydrogen gas through the metal air battery.

[0013] FIG. 5A is a plan view of air-side fins of the heat exchanger.

[0014] FIG. 5B is a plan view of liquid-side fins of the heat exchanger.

[0015] FIG. 5C is a side-view showing the air-side fins and the liquid-side fins attached with fasteners.

[0016] FIG. 6 is a detailed view of the liquid-side fins.

[0017] FIG. 7 depicts an alternate embodiment wherein the liquid-side fins directly contact the first and second sidewall of the heat exchanger.

DETAILED DESCRIPTION

[0018] Referring to FIG. 1, a heat exchanger 100 is shown. The heat exchanger 100 comprises a plurality of air-side fins 102 that are directly connected to a backplate 104. Each air-side fin extends outwardly from the backplate 104 in direction 106 by a depth 108 over a length 110 of the backplate 104.

[0019] The heat exchanger 100 further comprises a plurality of liquid-side fins 112 that are thermally connected to the backplate 104. In the embodiment of FIG. 1, liquid-side fins 112 are directly connected to a mounting plate 114 which, in turn, is directly connected to the backplate 104. Both the plurality of air-side fins 102 and the plurality of liquid-side fins 112 are formed of thermally conductive material which thereby places the components in thermal contact with one another. Each liquid-side fin extends outwardly from the backplate 104 in direction 116 by a depth 118. Each liquid-side fin also has a width 120. In the embodiment of FIG. 1, direction 106 and direction 116 are opposite.

[0020] FIG. 2 depicts one embodiment of the heat exchanger 100 in use. A metal air battery 200 is shown in bisected cross section. An anode 202 and cathode 204 are disposed in an electrolyte-filled chamber 206. As shown in further detail in FIG. 3, the liquid electrolyte flows from electrolyte-filled chamber 206, over the liquid-side fins 112, into electrolyte compartment 208 for subsequent reuse.

[0021] FIG. 3 depicts the flow path of liquid electrolyte through the metal air battery 200. Liquid electrolyte is introduced into chamber 206 at a liquid electrolyte input 300 using an electrolyte fluid pump 302 which pulls liquid electrolyte from electrolyte compartment 208. Chamber 206 fills with liquid electrolyte until it reaches overflow port

304. The liquid electrolyte input 300 is disposed at a lower end of the chamber 206 whereas the overflow port 304 is disposed at an upper end of the chamber, thereby permitting the chamber to be filled with liquid electrolyte and submerge the anode 202 and cathode 204. Overflowing liquid electrolyte is carried by gravity through an overflow path 306 that is positioned to receive the liquid electrolyte and pass it over the liquid-side fins 112. The liquid-side fins 112 thermally conduct heat away from the liquid electrolyte and to the air-side fins 112, thereby cooling the liquid electrolyte before it is returned to electrolyte chamber 208 for reuse. Because the electrolyte chamber 208 is disposed below the overflow path 306, the cooling of the liquid electrolyte is gravity driven and minimizes the use of pumps. As described in detail elsewhere in this specification, the hydrogen gas that is generated by the electrolysis reaction is knocked out of the liquid electrolyte due to the configuration of the liquid-side fins 112.

[0022] FIG. 4 depicts the flow path of hydrogen gas through the metal air battery 200. Hydrogen gas that is knocked out of the liquid electrolyte by liquid-side fins 112 rises in the direction of arrow 400 where it contacts mist eliminator 402. The lower surface of mist eliminator 402 is slanted such that any condensed liquids flow back into the overflow path 306. Gases, such as hydrogen gas, continue until they exit gas outlet 404. The hydrogen gas itself carries heat away from the metal air battery 200 and the increased knockout therefore contributes to the cooling. The released hydrogen may be burned with an external combustion apparatus using ambient air. In one embodiment, the external combustion apparatus is located directly above the air-side fins 102 such that the combustion causes a thermal siphon that draws air upward, through the air-side fins 102 and thereby increases the efficiency of the cooling.

[0023] FIG. 5A is a plan view of the air-side fins 102. The air-side fins 102 are parallel one another along their lengths 110 such that they provide elongated, parallel air flow paths. In the embodiment of FIG. 5A, the air flow paths are disposed vertically such that thermal convections carry the heat upward and away from the metal air battery system 200. In one embodiment, forced air is passed over the air-side fins 102 to provide enhanced cooling. The air-side fins 102 have at least one hole 500 in the backplate 104 for

subsequent attachment to liquid-side fins 112. In one embodiment, the air-side fins 102 and the backplate 104 are monolithic.

[0024] FIG. 5B is a plan view of liquid-side fins 112. The liquid-side fins 112 also have at least one hole 502 in mounting plate 114 for subsequent attachment to air-side fins 102. In one embodiment, the liquid-side fins 112 and the mounting plate 114 are monolithic.

[0025] FIG. 5C is a side-view showing air-side fins 102 and liquid-side fins 112 attached with fasteners 504 (e.g. bolts, screws, etc.). In one embodiment, air-side fins 102, backplate 104 and liquid-side fins 112 are monolithic. In another embodiment, the liquid-side fins 112 are directly attached to the backplate 104 without an intervening mounting plate 114 by, for example, welding. A sealant (e.g. a silicone sealant) may be used at junction 506 of the backplate 104 and the mounting plate 114 to prevent liquid electrolyte from escaping the overflow path 306.

[0026] In one embodiment, the heat exchanger 100 is made of a thermally conductive metal (e.g. brass, copper, etc.) that is stable in the alkaline environment of common electrolytes. In one embodiment, the liquid-side fins 112 are nickel plated to provide further corrosion protection. In those embodiments where air-side fins 102 and liquid-side fins 112 are fabricated separately, dissimilar materials may be used. Such a configuration permits the air-side fins 102 to be formed from a first material (e.g. aluminum) while the liquid-side fins 112 are formed from a second material (e.g. copper, brass, etc.). This permits the use of aluminum in the ambient air while keeping aluminum (which is a common anode material) out of contact with the liquid electrolyte.

[0027] FIG. 6 is a detailed view of liquid-side fins 112. The liquid-side fins 112 consists of a plurality of first fins 601 (which are proximate a first sidewall 600) and a plurality of second fins 602 (which are proximate a second sidewall 603). The first sidewall 600 and the second sidewall 603 define the overflow path 306 (also see FIG. 3). The first fins 601 and the second fins 602 are present in an alternating pattern over the overflow path 306 and are at an angle (θ) to one another. The angle (θ) is measured relative to the width 120 (see FIG. 1) of each adjacent fin of the angle that faces inwardly. In one embodiment,

the angle (θ) is greater than 0° and less than 135°. In another embodiment, the angle (θ) is at least 45° and less than 120°. In one such embodiment, the angle (θ) is between 80° and 100°. In another embodiment, the angle (θ) is 90°.

[0028] In FIG. 6, the first fins 601 have been bisected into proximal sections 601a and distal sections 601b. Likewise, the second fins 602 have been bisected into proximal sections 602a and distal sections 602b. The distal end (e.g. distal end 601b) of each fin terminates over the proximal end (e.g. proximal end 602a) of the adjacent, lower fin. Such a configuration permits liquid electrolyte to cascade over the sequential, slanted surfaces of the fins and pass through gaps 604 before returning to electrolyte compartment 208 (see FIG. 3). Without wishing to be bound to any particular theory, the liquid electrolyte is believed to thin as it contacts the high surface area of the liquid-side fins 112. This is believed to be responsible for the high degree of hydrogen gas knockout that occurs.

[0029] FIG. 7 depicts an alternate embodiment wherein the first fins 601 directly contact the first sidewall 600 and the second fins 602 directly contact the second sidewall 603.

[0030] While the invention has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof to adapt to particular situations without departing from the scope of the disclosure. Therefore, it is intended that the claims not be limited to the particular embodiments disclosed, but that the claims will include all embodiments falling within the scope and spirit of the appended claims.

What is claimed is:

1. A metal air battery comprising:

a liquid electrolyte compartment and a chamber with an anode, a cathode, an overflow port and a liquid electrolyte input that introduces liquid electrolyte from the liquid electrolyte compartment to the chamber wherein the liquid electrolyte input is disposed at a lower end of the chamber and the overflow port is disposed at an upper end of the chamber;

a heat exchanger comprising:

a plurality of air-side fins directly connected to a backplate;

a plurality of liquid-side fins thermally connected to the backplate, the plurality of liquid-side fins being disposed in an overflow path positioned to receive liquid electrolyte from the overflow port, pass the liquid electrolyte over the plurality of liquid-side fins and into the liquid electrolyte compartment; and

the plurality of liquid-side fins consisting of alternating, adjacent first fins and second fins that are at an angle (θ) greater than 0° and less than 135° to one another and separated by a gap such that liquid electrolyte cascades from a distal end of the first fins, through the gap and to a proximal end of the second fins.

2. The metal air battery as recited in claim 1, wherein the angle (θ) is between 45° and 120°.

3. The metal air battery as recited in claim 1, wherein the angle (θ) is between 80° and 100°.

4. The metal air battery as recited in claim 1, wherein the angle (θ) is 90°.

5. The metal air battery as recited in claim 1, wherein each air-side fin in the plurality of air-side fins is parallel one another along their length to provide elongated, parallel air flow paths that are arranged vertically.

6. The metal air battery as recited in claim 1 , wherein each liquid-side fin extends in a first direction outwardly from the backplate to provide a first fin depth and each air-side fin

extends in a second direction to provide a second fin depth, wherein the second direction is opposite the first direction.

7. The metal air battery as recited in claim 1, wherein the plurality of air-side fins and the backplate are monolithic.

8. The metal air battery as recited in claim 1, wherein the plurality of liquid-side fins are directly attached to a mounting plate, the mounting plate being directly attached to the backplate.

9. The metal air battery as recited in claim 8, wherein the plurality of liquid-side fins and the mounting plate are monolithic.

10. The metal air battery as recited in claim 1, wherein the plurality of liquid-side fins are directly attached to the backplate.

11. The metal air battery as recited in claim 1, wherein the plurality of air-side fins, the plurality of liquid-side fins and the backplate are monolithic.

12. The metal air battery as recited in claim 1, wherein the air-side fins and the liquid-side fins are formed of different metals.

13. The metal air battery as recited in claim 1, wherein the air-side fins consist of aluminum and the liquid-side fins are aluminum- free.

14. The metal air battery as recited in claim 1, wherein the distal end of the first fins terminate directly above the proximal end of the second fins.