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HYBRID ENERGY STORAGE SYSTEMS UTILIZING REDOX ACTIVE ORGANIC COMPOUNDS

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with Government support under Contract DE-AC0576RLO1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

BACKGROUND

Redox flow batteries (RFB) have attracted considerable research interests primarily due to their ability to store large amounts of power and energy, up to multi-MW and multi-MWh, respectively. RFB systems are considered one of the most promising technologies to be utilized not only for renewable energy resources integration, but also to improve the efficiency of grid transmission and distribution. With the energy supplied from externally stored electrolytes, the dissociation of energy capacity and power capability offers unique design latitude for RFBs to be sized for a wide spectrum of power and energy storage applications. Other advantages of RFBs include high safety, quick response, long service life, deep discharge ability, etc.

Due to limits of the water electrolysis potential window and the solubility of the active materials in water, traditional aqueous RFBs are typically considered to be low energy density systems (<25 Wh/L in most true flow battery systems). While significant progress has been made to improve the energy density, aqueous RFB systems can still be severely hindered by the poor solubility and stability of the active materials in the solutions. In this regard, a non-aqueous energy storage system that utilizes at least some aspects of RFB systems is attractive because it offers the expansion of the operating potential window, which can have a direct impact on the system energy and power densities.

SUMMARY

This document describes energy storage systems having a separator separating first and second electrodes. The first electrode comprises a first current collector and a first volume containing a first active material. The second electrode comprises a second current collector and a second volume containing a second active material. The energy storage systems are characterized, during operation, by a first source operably connected to the first volume and configured to provide a flow of first active material, wherein the first active material comprises a redox active organic compound dissolved in a non-aqueous, liquid electrolyte and the second active material comprises a redox active metal.

The second active material can be a solid, a liquid, or a mixture of solid and non-aqueous liquid materials. In one embodiment, the second active material comprises lithium. An example of a mixture of solid and liquid materials includes, but is not limited to a flowable suspension. An example of a liquid includes, but is not limited to, a non-aqueous solution. In one embodiment, the second active material comprises redox active metal ions dissolved in a non-aqueous liquid. Preferably, the redox active metal ions comprise ions of transition metals. Particular examples can include, but are not limited to, titanium ions, zinc ions, chromium ions, manganese ions, iron ions, nickel ions, and copper ions. In some embodiments, wherein the second active mate-

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rial comprises liquid and is flowable, the energy storage systems can comprise a second source operably connected to the second volume and configured to provide a flow of second active material.

In one embodiment, the first active material has a concentration of redox active organic compound that is greater than, or equal to 0.1 M. In another embodiment, the concentration is greater than, or equal to, 0.2 M. A redox active organic compound, as used herein, can refer to a compound comprising at least a bond between a carbon and a hydrogen atom. Examples can include, but are not limited to, organic-soluble derivatives of anthraquinone (AQ) and 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO). One instance of an organic-soluble derivative of AQ is 1,5-bis(2-(2-(2-methoxyethoxy)ethoxy)anthracene-9,10-dione (15D3GAQ).

In one embodiment, the energy storage system is configured such that the first electrode functions as a cathode and the second cathode functions as an anode. The embodiments described herein are not limited to primary cells, but can encompass secondary (i.e., rechargeable) cells. In such cases, the mode of operation (i.e., charging or discharging) can determine the function of the electrodes. For example, the cathode might be considered to be the negative electrode and the anode might be considered the positive electrode during recharging. While discharging, the functions would be reversed.

Another embodiment described herein is an energy storage system having a separator separating a cathode and an anode. The cathode comprises a positive current collector and a cathode volume containing a cathode active material. The anode comprises a negative current collector and an anode volume containing an anode active material. The energy storage system is characterized during operation by a source operably connected to the cathode volume and configured to provide a flow of cathode active material, wherein the cathode active material comprises TEMPO or an organic-soluble derivative of AQ dissolved in a non-aqueous electrolyte and the anode active material comprises lithium metal. In a preferred embodiment, the concentration of the TEMPO or the organic-soluble derivative of AQ is greater than, or equal to, 0.2 M. In another embodiment, the anode active material is a solid. One instance of an organic-soluble derivative of AQ is 1,5-bis(2-(2-(2-methoxyethoxy)ethoxy)ethoxy)anthracene-9,10-dione (15D3GAQ).

In yet another embodiment, the energy storage system is characterized during operation by a first source operably connected to the cathode volume and configured to provide a flow of cathode active material and by a second source operably connected to the anode volume and configured to provide a flow of anode active material, wherein the cathode active material comprises a redox active organic compound dissolved in a non-aqueous electrolyte at a concentration of at least 0.1 M, and the anode active material comprises a redox active metal. The anode active material can comprise a solid and flowable liquid materials. Preferably, the anode active material comprises redox active transition metal ions dissolved in a non-aqueous liquid.

The purpose of the foregoing abstract is to enable the United States Patent and Trademark Office and the public generally, especially the scientists, engineers, and practitioners in the art who are not familiar with patent or legal terms or phraseology, to determine quickly from a cursory inspection the nature and essence of the technical disclosure of the application. The abstract is neither intended to define the invention of the application, which is measured by the claims, nor is it intended to be limiting as to the scope of the invention in any way.