IRON-SULFIDE REDOX FLOW BATTERIES

CROSS-REFERENCE TO RELATED APPLICATIONS

This invention claims priority from and is a continuation of currently pending U.S. patent application Ser. No. 13/071, 688, filed Mar. 25, 2011, which is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with Government support under Contract DE-AC0576RL01830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

BACKGROUND

A redox flow battery (RFB) stores electrical energy in reduced and oxidized species dissolved in two separate electrolyte solutions. The negative electrolyte and the positive electrolyte circulate through cell electrodes separated by an ion exchange membrane or a separator. Redox flow batteries are advantageous for energy storage because they are capable of tolerating fluctuating power supplies, repetitive charge/discharge cycles at maximum rates, overcharging, overdischarging, and because cycling can be initiated at any state of charge.

However, among the many redox couples upon which redox flow batteries are based, a number of disadvantages exist. For example, many systems utilize redox species that are unstable, are highly oxidative, are difficult to reduce or oxidize, precipitate out of solution, and/or generate volatile gases. In many ways, the existing approaches to addressing these disadvantages have been ad hoc and can include the imposition of restrictive operating conditions, the use of expensive membranes, the inclusion of catalysts on the electrodes, and/or the addition of external heat management devices. These approaches can significantly increase the complexity and the cost of the total system. While some redox couples, such as those involving vanadium, can eliminate the need for some of these ad hoc approaches, they often utilize highly acidic solutions and/or expensive materials. Therefore, a need for improved redox flow battery systems exists.

SUMMARY

The present invention includes iron-sulfide redox flow battery systems for energy storage. The systems demonstrate excellent energy conversion efficiency and stability and utilize low-cost materials that are relatively safer and more environmentally friendly. One embodiment of the redox flow battery systems is characterized by a positive electrolyte that comprises Fe(III) and/or Fe(II) in a positive electrolyte supporting solution, a negative electrolyte that comprises S^{2-} and/or S in a negative electrolyte supporting solution, and a membrane, or a separator, that separates the positive electrolyte and electrode from the negative electrolyte and electrode. An exemplary membrane, or separator, can include, but is not limited to, a sulfonate tetrafluoroethylene-based fluoropolymer-copolymer. Alternatively, the membrane, or separator, can comprise a hydrocarbon.

In preferred embodiments, the concentrations of the Fe(II), the Fe(III), or both are greater than 0.2M and/or the concentrations of the S^{2-}, at the S, or both are greater than 0.1M.

The positive and negative electrolyte supporting solutions preferably have pH values greater than or equal to 6. The use of supporting solutions that are basic can be advantageous because they will not corrode components of the battery system in which they are utilized. Exemplary supporting solutions can comprise alkali metal hydroxides, ammonium hydroxide, or both. In a particular embodiment, the positive electrolyte can comprise potassium ferricyanide, potassium ferrocyanide, or both. The negative electrolyte can comprise a polysulfide compound.

Embodiments of the RFB systems can further include electrodes comprising carbon. Preferably, the carbon electrodes comprise graphite felt. The electrodes can also comprise a partial or complete coating having a catalyst such as Ni and/or Co. Alternatively, the electrodes can comprise noble metals. Exemplary noble metal electrodes include any form of Ni, Co, Au, Pt, and stainless steels.

In preferred embodiments, the cell temperature of the system is between between −10° C. and 60° C. during operation. Furthermore, during operation, the state-of-charge condition is greater than 0% and less than 100%.

In a particular embodiment, the redox flow battery system is characterized by a positive electrolyte comprising $K_4F(CN)_6$, $K_3F(CN)_6$, or both and NaOH. The negative electrolyte comprises S^{2-}, S, or both and NaOH. A membrane, or a separator, separates the positive electrolyte and negative electrolyte. At least a portion of the S is arranged as sodium polysulfide.

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.

Various advantages and novel features of the present invention are described herein and will become further readily apparent to those skilled in this art from the following detailed description. In the preceding and following descriptions, the various embodiments, including the preferred embodiments, have been shown and described. Included herein is a description of the best mode contemplated for carrying out the invention. As will be realized, the invention is capable of modification in various respects without departing from the invention. Accordingly, the drawings and description of the preferred embodiments set forth hereafter are to be regarded as illustrative in nature, and not as restrictive.

DESCRIPTION OF DRAWINGS

Embodiments of the invention are described below with reference to the following accompanying drawings.

FIG. **1** is a diagram depicting one embodiment of a redox flow battery system according to the present invention.

FIG. **2** depicts the simplified redox reaction and their corresponding standard potentials according to one embodiment of the present invention.

FIG. **3** is a graph of cell voltage and individual electrode potential (vs. 1M Ag/AgCl reference electrode) during charge-discharge cycles for one embodiment of a Fe-polysulfide RFB.