EXPERIMENTAL APPROACH FOR THERMAL MODELING OF SODIUM-SULFUR BATTERY BASED ON ISOTHERMAL CHAMBER TEST

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ABSTRACT

In order to design the efficient system of the sodium-sulfur battery, the optimization of the thermal management system is essential because the cell is operating above 300 ^{o}C with the high-temperature condition. To figure out the thermal management of the system or battery module, the thermal modeling of the unit cell is a very basic and important step by observing the heat generation under the cyclic operation of the sodium-sulfur system. Basically, the reaction of the sodium-sulfur battery is quite complex during the charge and discharge of the cell. With the thermal system viewpoint, the reaction between sodium and sulfur is simplified to exothermic reaction when the cell is discharged and endothermic when it is charged. However, the thermal capacity of the cell needs to be clarified because the reaction of the cell is quite inhomogeneous along the cell. In this paper, the thermal properties of the cell such as thermal conductivity and thermal capacity were analyzed by the isothermal chamber experiment during the cyclic performance test in a certain range of operation. An experimental setup was developed that allows the investigation of the temperature response of the cell by using the calorimeter concepts. To get the accurate response, the thermal loss should be minimized throughout the whole experiment. Based on the research, the sodium-sulfur cell can be modeled by the heat source with various thermal capacities by the operation schedule.

Keywords: sodium-sulfur battery, thermal modeling, isothermal chamber test

INTRODUCTION

Nowadays, the sodium-sulfur batteries operated on high temperature are widely spread on load leveling applications based on their high energy density, high efficiency of charge/discharge, and long cycle life. In an earlier stage of development of sodium-sulfur batteries, most of the applications were diverged to the electric vehicle. However, since the 1980s, this battery has been a promising candidate for stationary energy storage. Moreover, this is one of the great successes that has been made for this application, especially in Japan and Europe [1].

Similar to all other battery systems, thermal management is very important to manage safe system operation. Moreover, high-temperature sodium-sulfur batteries are more important to predict their thermal response during their cyclic operation because of their temperature-sensitive characteristics in efficiency and the safety point of view. During the operation of sodium-sulfur batteries, the batteries evolve the irreversible heat losses due to cell polarization, and the reversible losses due to its entropy change.

From the previous research [2, 3], most of the research was focused on the determination of the heat capacity and the heat generation rate of sodium-sulfur cells. In the cyclic operation of those cells, the adiabatic and isothermal procedure was applied to figure out their thermal characteristics. However, those cells are relatively low-capacity with small dimension compare to the recently developed higher-capacity cells, so the developed heat generation model has the fundamental limitation on their practical application for recently developed sodium-sulfur systems.

In the present study, the experimental approach to determine the heat generation of the recently developed sodium-sulfur battery has been suggested. The recently developed battery is designed to the higher capacity along with a bigger dimension. Figure 1 shows that the cell has higher length-to-diameter ratio in its geometrical characteristics; therefore, compared to the smaller cell, the longitudinal deviation must be considered when the cell is characterized in its thermal and electrical properties.

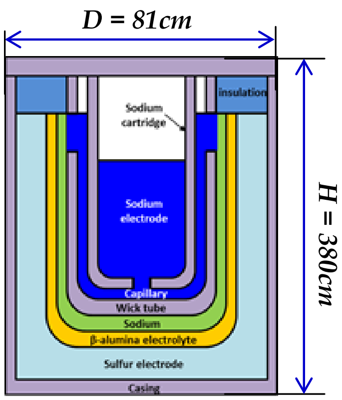

Fig. 1. Schematic and major dimension of the cell.

EXPERIMENTAL APPROACH

Cyclic Testing of The Cell

Figure 2 represents the experimental setup of charge/discharge cyclic operation of the sodium-sulfur cell. The purpose of the cyclic testing is to figure out the short-term electrical performance of the sodium-sulfur cell. During the cyclic testing, the cell temperature of the sodium and sulfur side was also recorded; the chamber is controlled by three-zone controllers.

For the cyclic testing, the cell is operated between 8 to 85% of its depth of discharge (DOD). The cell has the minimum resistance as 4.2 milliohms under 40 amperes current load.

Thermal Analysis

Generally, the heat generation rate $\dot{Q}$ can be calculated as the product of heat capacity and temperature change per unit time:

$$\dot{Q} = mc\frac{dT}{dt} \qquad (1)$$

If the measuring time and thus the temperature rise were kept low, dT/dt will be constant and $\dot{Q}$ can be determined rather precisely. In this experiment, measurements on the test cell are made using the above procedure.

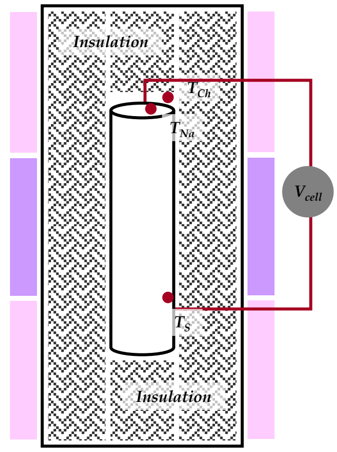

Fig. 2. Schematic of the cyclic testing of the cell.

Moreover, the thermodynamic equation for the heat generation $\dot{Q}$ in the electrochemical cell is:

$$\dot{Q} = I\left(\eta - T\frac{dE}{dT}\right) \qquad (2)$$

In the above equation, the first term represents the joule heating due to the electric resistance of the cell and the second term is an entropy term that represents the heat of reaction. The chemical reaction of the sodium-sulfur cell is exothermic for discharge and endothermic for the charge process. In the present study, the experimental correlation of the entropy generation by Knoedler [2, 3] has been compared with the experimental result.

RESULTS

In Figure 3, the tested results with entropy calculation were compared with the previous research of Knoedler and Sudworth [3, 4]. The experimental result is well matched considering the phase change at 60% DOD; however, the variable resistance by DOD change should be more discussed with more experimentation and proper modeling.

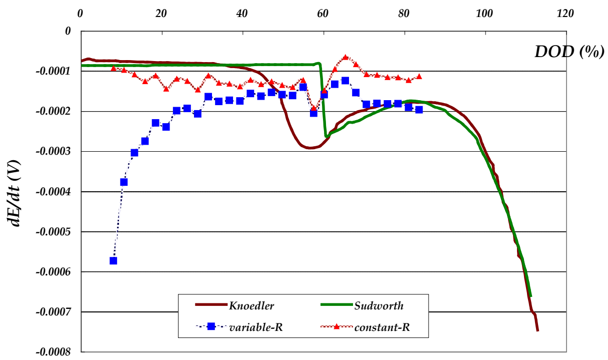

Fig. 3. Comparison of the calculated entropy variation by DOD.

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BIOGRAPHICAL NOTE

Conference presenter: Dr. Lee is a senior researcher of RIST, South Korea. She is now involved in the assessment and analysis department considering reliability issues. She studied at the Korea Advanced Institute of Science and Technology (KAIST) for her Ph.D., M.S., and B.S. degrees. Before she joined RIST, she worked for Samsung Electronics as a senior engineer in the home appliance division for more than five years. Her research interests mainly focus on product and technology development, considering the reliability concerns in the advanced energy storage system.