NUMERICAL ANALYSIS ON THE TEMPERATURE DISTRIBUTION IN THE MOLTEN SODIUM-SULFUR BATTERY MODULE

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ABSTRACT

The sodium-sulfur battery cell operates at a high-temperature condition of 290 °C to 350 °C to use molten-liquid-state electrodes. The battery module consists of multiple cells and the corresponding thermal management system such as heaters and insulations. The optimal design of the thermal management system is essential in order to achieve uniform temperature distribution inside the module, and the overall energy efficiency of the module is directly dependent on the heat dissipation of the casing. In the present study, a new numerical model for the thermal analysis of sodium-sulfur battery module has been suggested. The heat generation of the cell was modeled based on the electrochemical reaction process of the battery. The thermal properties of the cell such as thermal conductivity and thermal capacity were also modeled by using the one-dimensional thermal network analysis and available test results. Using these equivalent thermal models of the cell, the three-dimensional temperature distribution inside the battery module could be predicted by solving the thermal energy conservation equation numerically. The distribution of temperature and the thermal energy efficiency of the battery module for different arrangements of the cells and heaters are summarized.

Keywords: sodium-sulfur battery, thermal management, numerical analysis

INTRODUCTION

It is well known that the sodium-sulfur battery has a high energy density, high efficiency of charge/discharge, and long cycle life. In 1960s, studies on this battery for the application to the electric car were carried out. Since the 1980s, this battery has been a promising candidate for the stationary energy storage. Great achievements have been made for this application, especially in Japan and Europe [1].

The sodium-sulfur battery operates at a high-temperature condition of 290 °C to 350 °C to use molten-liquid-state electrodes. The battery module, which contains multiple unitary cells, uses the thermal management system such as the heater and the insulation casing. This thermal management system should be able to heat the battery to desired temperature and maintain an even temperature distribution in all operating conditions [2]. The heat dissipation from the module is also important since it is directly related to the module efficiency [3]. As a result, the optimal design of the thermal management system for the battery module is essential.

In the present study, the numerical prediction model of the sodium-sulfur battery module has been suggested. Even with the rapidly growing computer capability, the direct prediction of thermal performance of the battery is too complicated. To overcome this complexity, a multi-level approach has been adopted by evaluating equivalent thermal properties of the cell. Furthermore, a multi-fidelity approach that incorporates zero- and three-dimensional analyses has also been developed.

NUMERICAL APPROACH

Cell Model

Figure 1 represents the typical configuration of a sodium-sulfur cell. The purpose of cell model analysis is to get equivalent thermal properties such as the thermal conductivity, specific heat, and density in order to use in the module-level analysis. From the geometric configuration of the cell, the thermal conductivity of the cell should have different values in the horizontal and vertical directions, respectively. For a numerical thermal analysis, hexahedral mesh was generated inside the half model of the cell. Figure 2 shows the temperature distributions inside the cell when it is under temperature difference. As a result, the equivalent anisotropic thermal conductivities in each direction can be evaluated by solving the Fourier's law using the calculated heat transfer rate Q. The other properties are calculated considering the volume fractions of each component inside the cell.

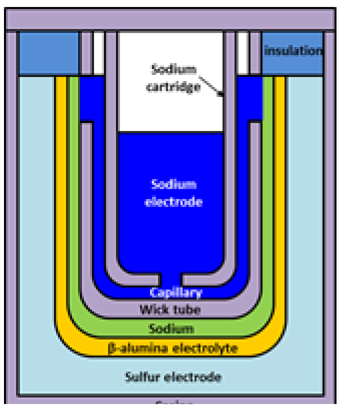

Fig. 1. Schematic of a sodium-sulfur cell.

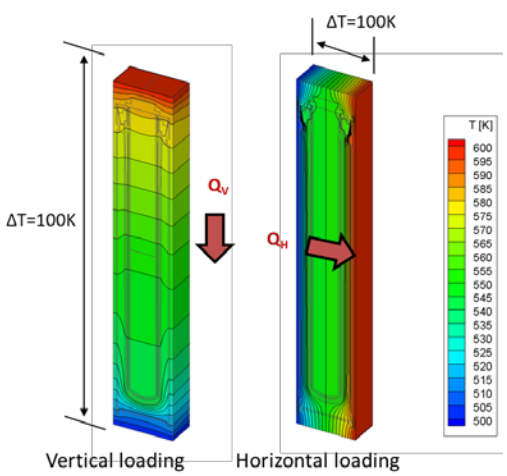

Fig. 2. Temperature distribution inside the cell.

Module Analysis

Figure 3 shows the quarter model of sodium-sulfur battery module. In the module analysis the cell is assumed to have equivalent thermal properties evaluated in the cell model. The gap between the cells is filled with the industrial sand. It is known that the heat generation inside the cell can be represented by the following equation.

$$Q = I\left(\eta - T\frac{dE}{dT}\right) \quad (1)$$

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 Koendler [4] has been used in the calculation. Using computational mesh generated inside the module, the unsteady heat conduction equation is solved to get the temperature distribution.

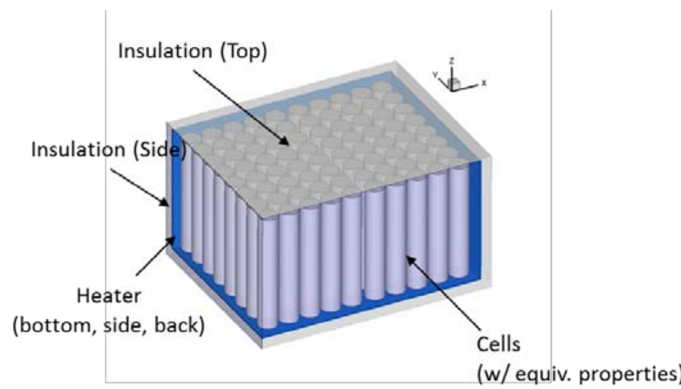

Fig. 3. Solid model of a battery module (1/4).

RESULTS

In Figure 4, the temperature distribution inside the battery module is depicted at the end of discharge period. In the calculation, it is assumed only the heaters at the side and bottom walls were working. It can be seen that the cells near the heater have higher temperature and the non-uniformity of temperature can be precisely evaluated quantitatively. Due to the heat generation inside the cell, the cell shows relatively higher temperature compared to the surrounding sand region. Figure 5 shows the variations of average, maximum, and minimum temperatures for module operation. It is expected that the optimal design of the thermal management system for the sodium-sulfur battery module can be carried out numerically by using the suggested procedure.

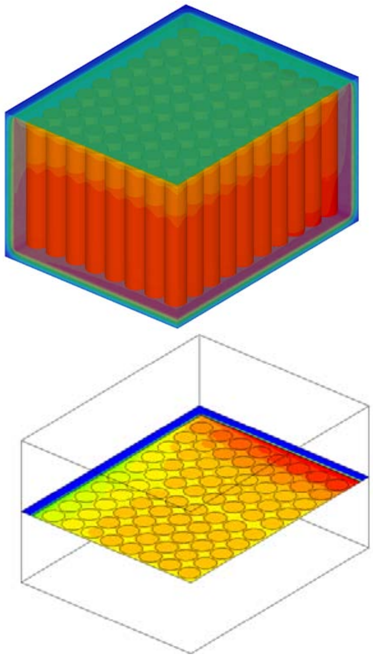

Fig. 4. Temperature distribution inside the module.

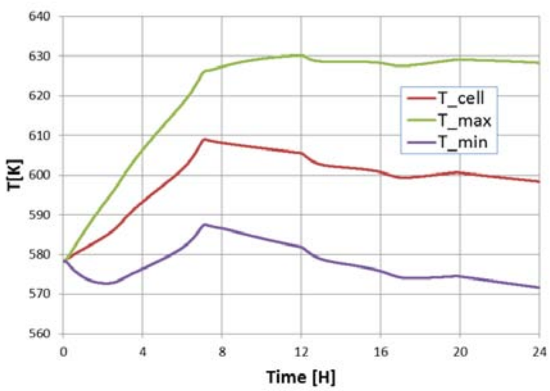

Fig. 5. Temperature variation inside the module.

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BIOGRAPHICAL NOTE

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