A Multiphysics Study to Improve Specific Energy of Primary Batteries for Low Temperature Operation for Deep Space Missions

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Several lander missions on the outer planets such as Europa, Enceladus, and Titan require electrical power to operate scientific and communication equipment. The traditional power generation methods, such as a photovoltaic array, are not feasible as their efficiency drops significantly at these vast distances. The novel radioisotope power systems are not practical today based on current lander designs and the effectiveness of these systems. To perform in situ science on distant planets, a high specific energy battery (>700 Wh/kg) needs to operate for about 480 hours under cold temperatures (-40^{o}C or 0^{o}C) [1].

While a primary battery such as Li-CF_x can provide high specific energy at room temperature, its specific capacity decreases significantly at low temperatures. One of the causes for this drop is low ion and electrical conductivity, and slower reaction kinetics. Slower transport and facile kinetics lead to an increase in the battery's resistance and higher voltage drops during the cell operation, thus reducing specific capacity. Both the transport and kinetics show a strong dependence on temperature. Thus, a small temperature rise can lead to an increase in the reaction rate and ion conductivity; since the temperature, cell resistance, and specific capacity are interdependent. A conventional battery model accounts for ohmic, thermodynamic, and, electrochemical, and chemical decomposition heating. The ohmic heating can be controlled by designing a resistive microstructure and varying the ratios of the active materials [2]. The kinetics can be improved by increasing the surface area, reducing the particle size, or adding a catalyst. These parameters are often optimized to achieve high specific energy at room temperatures. A similar optimization study is not available at low temperatures and for a primary (high specific energy) battery. For this presentation, we will explore the effect of geometrical, microstructural, and material properties on optimal specific capacity at low temperatures through multiphysics simulations. The ion transport resistance depends on the porosity and the tortuosity of an electrode and the separator.

References:

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2. Mistry, Aashutosh N., Kandler Smith, and Partha P. Mukherjee (2018). ACS Applied Materials & Interfaces, 10 (34), 28644-55.