Three-Dimensional Model of a New Thin-Plate Lead-Acid Battery

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Abstract

Introduction: The drawbacks of most commercial "advanced battery" solutions are high price, danger, and low recyclability. The most cost efficient, environmental-friendly, and safest solutions so far is based on lead-acid electrochemistry, a proven technology for more than 150 years. Key problems of this technology are however the limited cyclability which results in a reduced lifetime and high costs of ownership, as well as the low charge acceptance. The latter decreases the system efficiency and impedes its integration in systems requiring high specific power of the installed storage. To overcome this bottleneck, we at CEA are currently using advanced functional materials as current collectors and additives combined with lead-acid electrochemistry in order to enhance the performance of lead-acid batteries in several different energy storage applications.

Use of COMSOL Multiphysics®: The new materials that have been selected to design this new cell prototype are implemented in COMSOL Multiphysics® software to test them. The cell design has been exactly drawn in 3D thanks to the numerous components available in the geometry node. Of course, some hypotheses have been made to speed up the computation time. They mostly concern the current collector of the positive electrode. This model was derived from the seminal paper published by Bernardi et al. [1]. Some of the variables and parameters come from a more recent work [2].

The unique ability of COMSOL to deal with multiple physics has been fully tried out through the Electric Currents, Transport of Species, and Heat Transfer interfaces. Finally the validation of our model simulations with experimental data has been successfully done with some cut-planes, isosurfaces, and other easy-to-handle tools available in the Results node.

Results: The three-dimensional model of our new thin-plate lead-acid battery allows to test the impact of the cell design on the overall cell performance. It has already helped us improving the current collector of the positive electrode. The concentration of sulfuric acid in the electrolyte is also one of our concern, particularly at high rate of discharge. Passivation of the positive electrode has not been yet included inside the model, but we know that acid concentration affects it. Porosity change during discharge squeezes the electrolyte out of the electrodes, which in turn modify the transport of species.

Figure 1 shows isosurfaces of the liquid phase potential inside the electrolyte filling the pores of the electrodes and the separator, one minute after the beginning of a 20h-discharge. There is no such a model of lead-acid cell available in the literature to date. We thus believe that our study will bring attention on the interest of working again on lead-acid batteries, a technology that still weighs 35 billion USD today [3].

Conclusion: Multiphysics-based models are particularly useful in the field of electrochemical storage systems. The latter are energy converters, and as such, they involve many physics. The unique ability of COMSOL to compute fully coupled PDE offers a new way to understand the behavior of batteries and to continuously improve their performance.

Reference

[1] D. M. Bernardi et. al. Two-dimensional mathematical model of a lead-acid cell. J. Electrochem. Soc. 140, 2250-2258 (1993)

[2] M. Cugnet et. al. A mathematical model for the simulation of new and aged automotive lead-acid batteries, J. Electrochem. Soc., 156, A974-A985.(2009)

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Figures used in the abstract

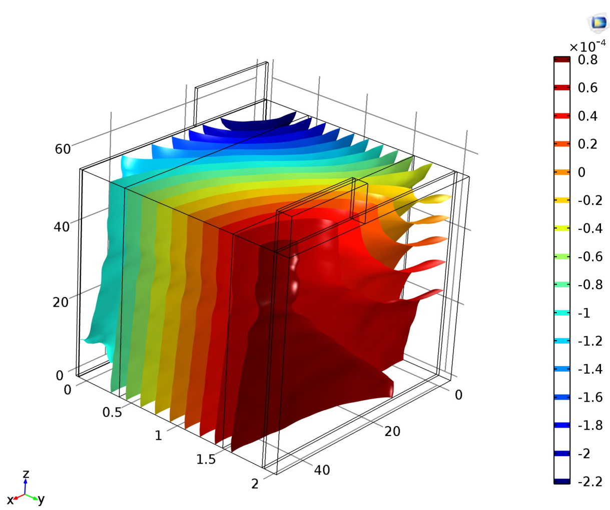

Figure 1: Liquid phase potential (V) 1 min after the beginning of discharge at C/20