A Versatile Simulator for the Analysis and Design of Thermal Batteries

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Thermal Batteries are primary, one-shoot high-power batteries consisting of serial-connected thermal cells. These unique batteries are typically used as short time power sources for many autonomous systems. Due to their high operational temperature (400-600°C), heat loss is crucial to the operation of the battery, determining the operation time in which power can be supplied. Thermal design is therefore of utmost importance, involving optimization of the geometrical structure, cell structure and insulation materials. Developing a specific battery, to meet desired performance specifications, using experience together with experimental trial and error is an expensive and time-consuming process. It is however possible to improve the design process, using battery performance simulations based on a reliable calibrated mathematical model.

Battery performance simulation efforts have mostly been invested in single cell modeling. Initial models involved the analysis of a cell of certain materials at a certain temperature [1]. More complex models of heat and mass transfer, together with the resulting electrical performance of a single cell were later developed [2,3] and recently improved [4]. Most recently, a product level thermal simulation with better consideration of electrochemical reactions has been attempted [5]. However, a complete and detailed simulation from each cell level up to the entire battery has yet to be presented.

In this contribution, we present our efforts in developing a comprehensive two-dimensional mathematical model of Thermal Batteries as a versatile and robust simulation and design tool. This thermal model enables detailed simulation from the level of a single cell up to the entire product, considering different aspects of heat transfer, including phase-change and Joule-Heating in each cell. The simulator could be used to examine worthwhile R&D directions (e.g., developing materials with desired physical properties), in addition to achieving better understanding of underlying physical processes. As a result, significant cost and time savings could be achieved during the development of each new battery, since all primary tests will involve computer-conducted simulations. Hopefully, this will also be the appropriate tool to design the next line of products, capable of significantly longer operation times

A leading characteristic of our simulator is its capacity for enabling flexibility in the design. For example, the geometrical model is easily built (Fig. 1a) using a supported Graphic User Interface, enabling the easy construction of a variety of different batteries (e.g. Fig. 2a), to be numerically analyzed *via* the Finite Element Method (sample meshes depicted in Figs. 1b, 2b). The geometrical model allows the user to define the inner structure with great flexibility; this includes specifying the cell ingredients, the number of cells, and details of the insulation layers. As the geometrical model is built, it is supported by a material property library, which can be updated by the user with new materials characterized by a set of temperature dependent physical properties. Thus far, the flexible geometrical model and material library includes batteries developed and manufactured in the RAFAEL Thermal Battery Plant.

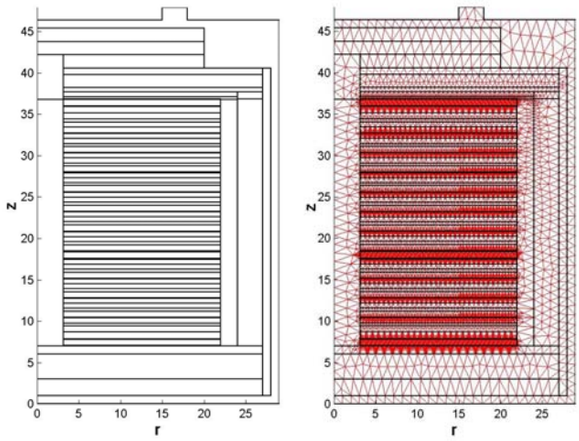

Fig 1: *Battery I, (a) Structure (b) Finite Element mesh*

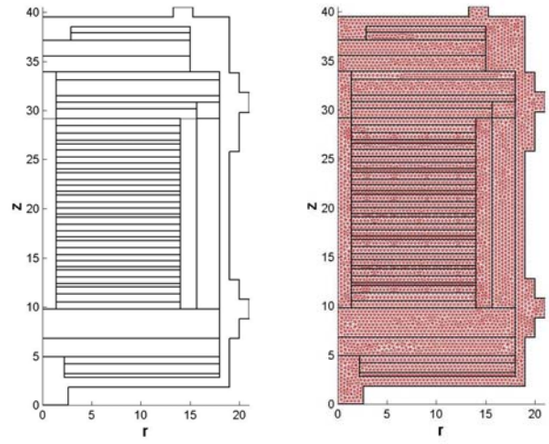

Fig 2: *Battery II, (a) Structure (b) Finite Element mesh*

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