Optimal Phase-Change-Material Properties for Battery Thermal Management: A Multi-objective Design Optimization Approach

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Highlights

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Abstract

Keywords

Battery thermal management; battery cooling; design optimization

Contents

1 Introduction

BATTERY PERFORMANCE AT LOW TEMPERATURES

BATTERY PERFORMANCE AT HIGH TEMPERATURES

PCM SYSTEMS FOR COOLING

PCM SYSTEMS FOR HEATING/HEAT RETENTION

OPTIMIZED PCM SYSTEMS A PCM's melting process absorbs heat and can be applied to cool batteries at elevated temperatures [1]. The PCM solidification process releases heat and can be applied to keep batteries warm at low temperatures [1].

Passive cooling: High latent heat per unit mass, high thermal conductivity, and high specific heat [2]. Should match operating temperature of the heating or cooling ot the PCM transition temperature [2].

Passive heating: to delay a PCM solidification process it is desirable to have lower thermal conductivity, greater latent heat, and higher environmental temperature. However, larger latent heat resulted in more less uniform cell temperatures [3].

Important to balance PCM's ability to keep batteries warm during short stops, ensure temperature uniformity, and allow for fast battery temperature rise after long stops [1].

Low thermal conductivity PCMs result in larger temperature gradients, while higher thermal conductivities allow for faster heat transfer to batteries reducing warm up times [1].

Soaking period in cold conditions impacts the performance of PCM systems [4]. For a short soaking time the PCM keeps batteries warm, while after a long soaking time the extra thermal mass of the PCM prevents the battery from self-heating as quickly [4]. In the long term, PCM was found to reduce capacity loss for cold temperature operation, increasing the average temperature compared to systems without PCM [4].

2 Modeling

PCM MODELS

COMSOL IMPLEMENTATION (BCs, initial conditions, mesh details, mesh independence, etc.)

Assumptions:

- One way coupling of flow and heat generation - the change in temperature is assumed to have no effect on the flow field
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3 Optimization

Consider a fixed volume of PCM and the thermal material properties as the design variables (latent heat, thermal conductivity, specific heat, phase-change temperature). Consider bounds on the design variables rooted in reality, based on maximum and minimum property quantities of available PCMs. Need to consider specific objective functions and properly formulate:

1. Heat up time (time in seconds to reach certain temperature)

2. Cooling performance (maximum temperature, average temperature)
3. Temperature uniformity (cell temperature difference, cell temperature standard deviation)
4. Battery heat retention time (starting after running to the maximum temperature, how long do batteries stay warm for)

The optimization problem is thus formulated as shown in Figure 1.

$$\begin{aligned}
\text{minimize} \quad & f(\mathbf{x}) \\
\text{with respect to} \quad & \mathbf{x} \\
\text{subject to} \quad & h_i(\mathbf{x}) = 0; \qquad i = 1 \text{ to } p \\
& g_j(\mathbf{x}) \leq 0; \qquad j = 1 \text{ to } m
\end{aligned} \tag{1}$$

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