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Research Paper

Parametric investigation of battery thermal management system with phase change material, metal foam, and fins; utilizing CFD and ANN models

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ABSTRACT

The focus on developing an effective battery thermal management system (BTMS) to maintain optimal temperatures for lithium-ion batteries (LIBs), especially in electric vehicle (EV) applications, has grown significantly. The effective BTMS not only enhances the cooling performance of LIBs but also contributes to increased passenger safety and mileage of EVs. This study investigates BTMS configurations with fins, metal foam, and phase change material (PCM) to minimize temperature of battery during 3C discharging in varying conditions. Additionally, the study explores the impact of different BTMS material combinations and various fins lengths on system performance as a parametric investigation. Moreover, to streamline the analysis process and introduce novelty, artificial intelligence is explored as an alternative to computational fluid dynamics for predicting liquid fraction of PCM and temperature of battery, enhancing the innovative aspect of this study. Numerical simulations, using a non-equilibrium thermal model for metal foam modeling, reveal that the fourth case, integrating all three passive approaches, maintains the lowest temperature and enhances LIB cooling. The optimum BTMS shows a reduction of 3 K compared to BTMS utilizing pure PCM. During discharge process, the temperature difference in the battery decreases by approximately 75 % and 66 % in the fourth case compared to the first case (with pure PCM) under normal and harsh environmental conditions, respectively. Applying copper metal foam and copper fins yields the best results in reducing battery temperature. Increasing the length of fins and adding more fins effectively lower the battery temperature. Finally, an artificial neural network model is developed using the backpropagation learning technique coupled with the gradient descent optimization algorithm. The model exhibits excellent predictive capabilities, achieving high R-squared values of 0.98 for PCM liquid fraction and 0.99 for battery temperature.

1. Introduction

In recent decades, there has been growing concern about environmental pollution and the limited availability of fossil fuels. Out of all the machines and technologies, vehicles are considered the largest consumers of petrol. Consequently, the industry of automotive is actively seeking another fuel that offers high energy output and produces minimal CO_2 emissions. Rechargeable lithium-ion batteries (LIBs) are highly promising substitutes for fossil fuels due to their high specific energy and operating voltage. Therefore, car manufacturers have been producing electric vehicles (EVs) and hybrid electric vehicles (HEVs) that rely on LIBs in recent years. However, since the performance of EVs and HEVs largely depends on the capabilities of their LIBs, several challenges need to be addressed in terms of their performance. One of the challenges is controlling the temperature of LIBs with a suitable thermal management system (TMS) [1].

According to research findings, it is generally recommended that the suitable operating temperature range for LIBs should be between 15 °C and 35 °C [2], or alternatively, between 20 °C and 40 °C [3–5]. Consequently, researchers have proposed various methods to regulate the temperature of LIBs, known as battery thermal management systems

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