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Experimental research on heat transfer characteristics of a battery liquid-cooling system with ⊥-shaped oscillating heat pipe under pulsating flow

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ABSTRACT

After a comprehensive review of oscillating heat pipe (OHP) based on battery thermal management system (BTMS), a novel battery liquid-cooling system with a ⊥-shaped OHP is presented to increase the volume utilization efficiency of battery module and the total amount of heat dissipation. The new system retains the heat transfer path of the OHP while incorporating an additional heat dissipation route where the liquid cooling plate is in direct contact with the cells. In this paper, pulsating flow is used to tackle the problem of the OHP failing to operate stably due to the insufficient heat load achieved in the new system. The parametric effects of pulsating flow frequencies, cooling initiation temperatures, and duty cycles on the operational performance of the OHP and the average surface temperature of the battery module ($\boldsymbol{T_b}$) within the new system were investigated. The results indicate that pulsating flow periodically elevates the heat load on the battery surface, enhancing the OHP working properly. The smaller the pulsating flow frequency, the greater the impact on the temperature fluctuations of the new system. The $\boldsymbol{T_b}$ is lowest when the pulsating flow frequencies range from 0.03 Hz to 0.05 Hz. Beyond a frequency of 0.06 Hz, the OHP cannot operate stably. Additionally, moderately increasing the cooling initiation temperature is beneficial for enhancing the average temperature oscillation amplitude of the OHP. The cooling initiation temperature between 45 °C and 47 °C results in a better $\boldsymbol{T_b}$. Both pulsating flow duty cycles of 38% and 62% contribute to OHP running effectively. The new system with OHP under optimum pulsating flow condition has the optimal $\boldsymbol{T_b}$, eventually rising by 17.5 °C, which is a 9.8% decrease in temperature rise compared to the system without OHP. And the battery module's surface temperature uniformity has been improved through a reduction of 1.3 °C in the maximum temperature difference ($\boldsymbol{\Delta T_{max}}$), amounting to a 17.8% decrease. It has been proved that the improved thermal performance of the new system under pulsating flow is attributed to the stable operation of the OHP.

1. Introduction

Lithium-ion batteries, serving as electric vehicles' primary power source, possess obvious performance benefits [1–2]. However, significant heat is generated during the charging and discharging processes [3]. Inadequate temperature control can result in irreversible physical and chemical reactions within the battery, leading to reduced operational performance, a shorter cycle life, and the risk of fire hazards [4–5]. Consequently, Implementing the highly efficient battery thermal management (BTM) technologies is pivotal in mitigating thermal runaway in automotive lithium-ion batteries [6–9].

Among the prevalent battery cooling strategies are air cooling, liquid cooling, phase-change material (PCM) cooling, and heat pipe cooling, with air and liquid cooling systems being commonly utilized in electric vehicles [10–17]. Air-cooled systems exhibit a lower cost, leveraging optimized air duct designs to curtail energy consumption, diminish maximum battery temperatures, and enhance temperature uniformity within battery module [18–19]. However, owing to the low density, thermal conductivity, specific heat, and other thermal physical parameters, air-cooled systems yield an inadequate cooling effect and necessitate substantial spatial occupation [20]. In comparison to air-cooled systems, water-cooled systems typically boast higher heat transfer coefficients and superior cooling capacities [21]. Studies have

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