Pengembangan Sistem Manajemen Termal Baterai Kendaraan Listrik berbasis Dual Evaporator Loop Heat Pipe = Development of a Battery Thermal Management System for Electric Vehicles Based on a Dual-Evaporator Loop Heat Pipe

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Abstrak

Penelitian ini menginvestigasi performa termal single evaporator loop heat pipe (SE-LHP) dan dual evaporator loop heat pipe (DE-LHP) pada sistem manajemen termal baterai kendaraan listrik dengan banyak sumber panas. Eksperimen dilakukan untuk menganalisis pengaruh filling ratio, parameter cairan pendingin, dan orientasi terhadap performa termal, serta untuk mengamati fenomena dua-fasa secara real-time menggunakan radiografi neutron. Hasil menunjukkan bahwa SE-LHP mencapai efisiensi termal tertinggi 81% dan resistensi minimum 0,22 °C/W pada filling ratio 40% dan beban panas 120 W. Untuk DE-LHP, orientasi 10° menghasilkan resistensi termal rendah (0,24 °C/W) dengan distribusi cairan yang terbantu gravitasi. Orientasi -10° menunjukkan flooding di evaporator 2, sedangkan orientasi 60° menghasilkan resistensi termal tinggi (0,45 °C/W) akibat distribusi cairan yang tidak efektif. Radiografi neutron juga mengungkap peningkatan distribusi cairan di kondensor seiring kenaikan beban panas, serta membantu mengidentifikasi fenomena seperti vapor backflow dan liquid carryover. Selain pendekatan eksperimental, penelitian ini juga mengembangkan model prediksi fraksi uap menggunakan artificial neural network (ANN) berbasis data temperatur dari 11 titik ukur. Model ini mampu memprediksi fraksi uap yang sudah dikuantifikasi secara akurat. Hasil ini menegaskan pentingnya sinergi antara optimasi parameter operasional (seperti filling ratio 40% dan temperatur cairan pendingin 30°C) dan pendekatan berbasis kecerdasan buatan untuk memahami dan memprediksi perilaku termal LHP multi-evaporator secara komprehensif.
......This study investigates the thermal performance of a single evaporator loop heat pipe (SE-LHP) and a dual evaporator loop heat pipe (DE-LHP) applied to the thermal management system of electric vehicle batteries with multiple heat sources. Experiments were conducted to analyze the effects of filling ratio, coolant parameters, and orientation on thermal performance, as well as to observe two-phase flow phenomena in real-time using neutron radiography. Results show that the SE-LHP achieved the highest thermal efficiency of 81% and the lowest thermal resistance of 0.22°C/W at a 40% filling ratio and a heat load of 120W. For the DE-LHP, a 10° orientation yielded the best performance with a thermal resistance of 0.24°C/W, aided by gravity-enhanced liquid distribution. A -10° orientation led to flooding in evaporator 2, while a 60° orientation resulted in high thermal resistance (0.45°C/W) due to ineffective liquid distribution. Neutron radiography also revealed an increase in liquid distribution within the condenser as the heat load increased, and it effectively captured phenomena such as vapor backflow and liquid carryover. In addition to the experimental approach, this study developed a vapor fraction prediction model using an artificial neural network (ANN) based on temperature data from 11 measurement points. The model accurately predicted the quantified vapor fraction. These findings emphasize the importance of combining optimal operational parameters (e.g., 40% filling ratio and 30°C coolant temperature) with artificial intelligence approaches to comprehensively understand and predict the thermal behavior of multi-evaporator LHP systems.