INTISARI

Kendaraan listrik (EV) menjadi alternatif populer terhadap kendaraan bermotor berbahan bakar fosil yang semakin menipis dan pencemaran lingkungan. Baterai *lithium-ion* (*Li-ion*) menjadi pilihan utama saat ini untuk EV karena efisiensi tinggi dan umur pakai yang panjang. Namun, kinerja dan keamanan baterai ini sangat dipengaruhi oleh temperatur, di mana kisaran temperatur operasional idealnya adalah 25-40 °C. Penyimpangan dari kisaran ini dapat mengurangi kapasitas dan kinerja baterai secara drastis. Oleh karena itu, sistem manajemen termal baterai (BTMS) yang dapat menstabilkan temperatur sangat vital untuk memaksimalkan kinerja dan memperpanjang usia baterai. BTMS efektif harus bisa mengatur temperatur baterai dalam kondisi apapun, memastikan bahwa baterai selalu beroperasi dalam rentang temperatur yang aman dan meningkatkan kinerja serta umur baterai.

Penelitian ini melakukan investigasi eksperimental tentang karakteristik pelepasan dan perpindahan panas baterai lithium-ion dengan pendinginan cairan langsung untuk manajemen termal. Paket baterai *Li-ion* tipe LFP 18650 yang dirangkai seri sebanyak 24 buah. Penelitian dilakukan mencelupkan secara simetris ke dalam cairan dielektrik Tipe A (berbasis *hydrocarbon*) dan Tipe B (berbasis *hydrofluoroether*) menggunakan fasilitas *immersion cooling test* dengan desain 6 *channel*. Temperatur maksimum, temperatur rata-rata, *absorbed heat*, dan *heat transfer coefficient* diselidiki di bawah berbagai kondisi laju pengosongan, dan laju aliran volume cairan pendingin.

Hasil penelitian menunjukan bahwa temperatur rata-rata dan temperatur maksimum baterai meningkat dengan seiring meningkatnya laju pengosongan (*C-rate*), dan menurun seiring meningkatnya laju aliran volume fluida pendingin. Nilai *heat transfer coefficient* meningkat seiring dengan meningkatnya laju pengosongan dan laju aliran. *Heat transfer coefficient* rata-rata untuk *flow immersion cooling* dengan aliran 0,25 LPM, 0,50 LPM, dan 0,75 LPM, sebesar 163,22 $W/m^2 \cdot K$, 169,46 $W/m^2 \cdot K$, dan 173,65 $W/m^2 \cdot K$, pada *discharge rate* 2,5C. Peningkatan laju aliran volume akan menyebabkan peningkatan *pressure drop.* Fluida pendingin Tipe B (berbasis *hydrofluoroether*) lebih unggul dibandingkan Tipe A (berbasis *hydrocarbon*) dalam mempertahankan temperatur yang lebih rendah. Pada akhir pelepasan untuk *immersion cooling* fluida Tipe A (berbasis *hydrocarbon*), *immersion cooling* fluida Tipe B (berbasis *hydrofluoroether*), *flow immersion cooling* fluida Tipe A (berbasis *hydrocarbon*) dengan aliran 0,50 LPM, dan *flow immersion cooling* fluida Tipe B (berbasis *hydrofluoroether*) dengan aliran 0,50 LPM, temperatur rata-rata akhir sebesar 35,3 °C, 29,5 °C, 30,4 °C, dan 28,0 °C, pada *discharge rate* 2,5C.

Kata Kunci: *Immersion cooling, dielectric fluid, thermal management, lithium-ion battery, heat transfer coefficient, thermal runaway.*

ABSTRACT

Electric vehicles (EVs) are becoming a popular alternative to fossil fuel motorised vehicles that are depleting and polluting the environment. Lithium-ion (Li-ion) batteries are the current top choice for EVs due to their high efficiency and long lifespan. However, the performance and safety of these batteries are greatly affected by temperature, where the ideal operating temperature range is 25-40°C. Deviations from this range can drastically reduce battery capacity and performance. Therefore, a battery thermal management system (BTMS) that can stabilise the temperature is vital to maximise performance and extend battery life. An effective BTMS should be able to regulate the battery temperature under any conditions, ensuring that the battery always operates within a safe temperature range and improving the performance and lifespan of the battery.

This study conducted an experimental investigation on the discharge and heat transfer characteristics of lithium-ion batteries with direct liquid cooling for thermal management. There were 24 LFP 18650 type Li-ion battery packs assembled in series. The study was conducted symmetrically dipping into Type A (hydrocarbon-based) and Type B (hydrofluoroether-based) dielectric fluids using an immersion cooling test facility with a 6-channel design. The maximum temperature, average temperature, absorbed heat, and heat transfer coefficient were investigated under various conditions of discharge rate, and coolant volume flow rate.

The results show that the average temperature and maximum temperature of the battery increase with increasing discharge rate (C-rate), and decrease with increasing coolant volume flow rate. The heat transfer coefficient value increases with increasing discharge rate and flow rate. The average heat transfer coefficient for flow immersion cooling with flows of 0.25 LPM, 0.50 LPM, and 0.75 LPM, is 163.22 W/m2·K, 169.46 W/m2·K, and 173.65 W/m2·K, at a discharge rate of 2.5C. An increase in volume flow rate will lead to an increase in pressure drop. Type B (hydrofluoroether-based) cooling fluid is superior to Type A (hydrocarbon-based) in maintaining lower temperatures. At the end of discharge for immersion cooling fluid Type A (hydrocarbon-based), immersion cooling fluid Type B (hydrofluoroether-based), flow immersion cooling fluid Type A (hydrocarbon-based) with a flow of 0.50 LPM, and flow immersion cooling fluid Type B (hydrofluoroether-based) with a flow of 0.50 LPM, the final average temperatures were 35.3 °C, 29.5 °C, 30.4 °C, and 28.0 °C, at a discharge rate of 2.5C.

Keywords: Immersion cooling, dielectric fluid, thermal management, lithium-ion battery, heat transfer coefficient, thermal runaway.