

INTISARI

Baterai lithium-ion (Li-ion) memainkan peran yang sangat penting dalam kendaraan listrik dan sistem penyimpanan energi, namun rentan terhadap penurunan performa dan risiko *thermal runaway* akibat panas berlebih saat proses pengosongan daya laju tinggi. Sistem pendingin konvensional seperti pendingin udara dinilai kurang efektif untuk mengatasi beban termal yang tinggi ini. Oleh karena itu, penelitian ini memiliki tujuan untuk mengkaji secara eksperimental performa sistem pendinginan *immersion cooling* satu fase dengan menggunakan fluida kerja dielektrik berbasis hidrokarbon (Shell S3 X) dalam meregulasi temperatur dan mendongkrak keandalan baterai Li-ion.

Penelitian eksperimental ini dilakukan menggunakan fasilitas *Battery Immersion Cooling Test* pada dua jenis kemasan baterai Li-ion yang dirangkai seri (4S), yaitu Baterai A (1800 mAh) dan Baterai B (3000 mAh). Pengujian kinerja dilakukan dengan memvariasikan laju pengosongan daya (*C-rate*) sebesar 3C, 4C, dan 5C hingga baterai mencapai batas *Depth of Discharge* (DoD) 80%. Kinerja termal baterai kemudian dievaluasi secara komparatif melalui tiga metode pendinginan, yaitu konveksi alami (*Natural Convection/NC*), *Static Immersion Cooling* (IC 0 LPM), serta *Flow Immersion Cooling* (FIC) dengan variasi laju aliran volume fluida sebesar 1 LPM dan 2 LPM.

Hasil penelitian menunjukkan bahwa peningkatan *C-rate* menaikkan temperatur operasional secara signifikan, namun metode FIC 2 LPM tampil sebagai strategi paling superior dalam mengendalikan suhu baterai. Pada beban pengosongan ekstrem 5C, metode FIC 2 LPM berhasil menurunkan temperatur rata-rata akhir Baterai A hingga 29,55% (menjadi 37,90°C) dan Baterai B hingga 32,60% (menjadi 33,90°C) apabila dibandingkan dengan metode konveksi alami. Selain itu, distribusi keseragaman temperatur permukaan (ΔT) juga membaik secara drastis, mengecil dari 4,40°C menjadi 1,60°C pada Baterai A, dan dari 22,40°C menjadi 8,00°C pada Baterai B. Sebagai kesimpulan, sistem *single-phase flow immersion cooling* terbukti menjadi solusi manajemen termal alternatif yang sangat efisien, merata, dan aman. Kontribusi dari penelitian ini memberikan landasan operasional yang sangat relevan untuk diaplikasikan pada sistem kelistrikan berdaya tinggi guna memaksimalkan kinerja baterai dan mencegah malfungsi termal di masa depan.

Kata Kunci: *lithium-ion battery, immersion cooling, dielectric fluid, Shell S3 X, heat transfer coefficient, battery thermal management system.*

ABSTRACT

Lithium-ion (Li-ion) batteries play a vital role in electric vehicles and energy storage systems; however, they are highly susceptible to performance degradation and the risk of thermal runaway due to excessive heat generation during high-rate discharging processes. Conventional cooling systems, such as air cooling, are considered ineffective in managing these high thermal loads. Therefore, this study aims to experimentally investigate the performance of a single-phase immersion cooling system utilizing a hydrocarbon-based dielectric working fluid (Shell S3 X) in regulating temperature and enhancing the reliability of Li-ion batteries.

This experimental research was conducted using a Battery Immersion Cooling Test facility on two types of Li-ion battery packs configured in a 4S series: Battery A (1800 mAh) and Battery B (3000 mAh). Performance testing was carried out by varying the discharge rates (C-rates) at 3C, 4C, and 5C until the batteries reached an 80% Depth of Discharge (DoD) limit. The thermal performance of the batteries was then comparatively evaluated using three cooling methodologies: Natural Convection (NC), Static Immersion Cooling (IC 0 LPM), and Flow Immersion Cooling (FIC) with varied fluid volume flow rates of 1 LPM and 2 LPM.

The experimental results demonstrated that an increase in the C-rate significantly elevated the operational temperature, yet the FIC 2 LPM method emerged as the most superior strategy for mitigating the battery temperature rise. Under extreme discharging loads of 5C, the FIC 2 LPM method successfully reduced the final average temperature of Battery A by 29.55% (down to 37.90°C) and Battery B by 32.60% (down to 33.90°C) when compared to the natural convection method. Furthermore, the surface temperature uniformity (ΔT) improved drastically, narrowing from 4.40°C to 1.60°C for Battery A, and from 22.40°C to 8.00°C for Battery B. In conclusion, the single-phase flow immersion cooling system is proven to be a highly efficient, uniform, and safe alternative thermal management solution. The contribution of this research provides a highly relevant operational foundation for high-power electrical system applications to maximize battery performance and prevent future thermal malfunctions.

Keywords: lithium-ion battery, immersion cooling, dielectric fluid, Shell S3 X, heat transfer coefficient, battery thermal management system.