Studi Eksperimental Immersion Cooling dengan Fluida Dielektrik untuk Manajemen Termal Battery Pack
Lithium-ion NMC Tipe 18650
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INTISARI

Peningkatan penggunaan kendaraan listrik (*Electric Vehicle* atau EV) mendorong kebutuhan akan sistem penyimpanan energi yang memiliki performa tinggi dan aman. Baterai lithium-ion tipe Nickel Manganese Cobalt (NMC) banyak digunakan karena memiliki densitas energi yang tinggi, namun performanya sangat dipengaruhi oleh temperatur operasi. Temperatur yang berlebih dapat mempercepat degradasi baterai dan meningkatkan risiko *thermal runaway*. Oleh karena itu, diperlukan sistem manajemen termal baterai (*Battery Thermal Management System* atau BTMS) yang efektif. Penelitian ini bertujuan untuk mengevaluasi performa *single-phase immersion cooling* menggunakan fluida dielektrik Shell S3X pada *battery pack* lithium-ion NMC tipe 18650.

Pengujian dilakukan pada *battery pack* Sony US18650VTC6 konfigurasi 4S1P (4 *Series* 1 *Parallel*) dengan variasi laju pengosongan 3C, 4C, dan 5C. Performa *natural cooling* (NC), *immersion cooling* statis (IC 0 LPM), dan *flow immersion cooling* (FIC) pada laju aliran 1 LPM dan 2 LPM dibandingkan berdasarkan temperatur baterai, distribusi temperatur, *absorbed heat*, dan *heat transfer coefficient*.

Hasil penelitian menunjukkan bahwa metode *immersion cooling* mampu memberikan performa pendinginan yang lebih baik dibandingkan *natural cooling*. Pada kondisi 5C, temperatur rata-rata *battery pack* menurun dari 50,30 °C pada NC menjadi 40,95 °C pada IC 0 LPM, 36,42 °C pada FIC 1 LPM, dan 33,90 °C pada FIC 2 LPM. Nilai *absorbed heat* dan *heat transfer coefficient* tertinggi diperoleh pada FIC 2 LPM, masing-masing sebesar 11,86 W dan 733,03 W/m²·K. Hasil tersebut menunjukkan bahwa peningkatan laju aliran fluida mampu meningkatkan kemampuan perpindahan panas dan keseragaman temperatur baterai. Berdasarkan parameter yang dianalisis, FIC 2 LPM memberikan performa pendinginan terbaik untuk manajemen termal *battery pack* lithium-ion NMC tipe 18650.

Kata Kunci: *Battery pack* lithium-ion NMC 18650, sistem manajemen termal *battery pack*, *immersion cooling*, fluida dielektrik Shell S3X, *heat transfer coefficient.*

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ABSTRACT

The increasing adoption of Electric Vehicles (EVs) has driven the demand for energy storage systems with high performance and operational safety. Nickel Manganese Cobalt (NMC) lithium-ion batteries are widely used due to their high energy density; however, their performance is highly dependent on operating temperature. Excessive temperatures can accelerate battery degradation and increase the risk of thermal runaway. Therefore, an effective Battery Thermal Management System (BTMS) is required. This study aims to evaluate the performance of a single-phase immersion cooling system using Shell S3X dielectric fluid for the thermal management of an NMC 18650 lithium-ion battery pack.

Experiments were conducted on a 4S1P (4 *Series* 1 *Parallel*) Sony US18650VTC6 battery pack under discharge rates of 3C, 4C, and 5C. The performance of natural cooling (NC), static immersion cooling (IC 0 LPM), and flow immersion cooling (FIC) at flow rates of 1 LPM and 2 LPM was evaluated based on battery temperature, temperature distribution, absorbed heat, and heat transfer coefficient.

The results show that immersion cooling provides better cooling performance than natural cooling. At a discharge rate of 5C, the average battery pack temperature decreased from 50.30 °C under NC to 40.95 °C under IC 0 LPM, 36.42 °C under FIC 1 LPM, and 33.90 °C under FIC 2 LPM. The highest absorbed heat and heat transfer coefficient were obtained under FIC 2 LPM, reaching 11.86 W and 733.03 W/m²·K, respectively. These results indicate that increasing the fluid flow rate improves heat transfer performance and temperature uniformity. Based on the evaluated parameters, FIC 2 LPM provided the best cooling performance for the thermal management of NMC 18650 lithium-ion battery packs.

Keywords: NMC 18650 lithium-ion battery pack, battery pack thermal management system, immersion cooling, Shell S3X dielectric fluid, heat transfer coefficient.