Numerical Study on Thermal Performance Characteristics of Battery Pack Immersion Cooling Based on Cell Arrangements and Inlet/Outlet Configurations

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액침냉각이 적용된 배터리 팩의 셀 배열과 입출구 조건에 따른 열전달 특성에 관한 수치적 연구

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Abstract

Electric vehicles (EVs) with outstanding advantages of zero emissions and high efficiency are attracting attention due to fossil fuel depletion and global warming issues worldwide. Currently, Lithium-ion (Li-ion) batteries are a major source of energy in electric vehicles due to several benefits, including high energy density. However, the performance characteristics and safe operation of Li-ion batteries depend on their operating temperature, with the optimal operating temperature being between 25-40 ℃ and the temperature difference within the battery pack not exceeding 5 ℃. Therefore, developing an effective battery thermal management system is necessary to achieve high performance for electric vehicles. In the present study, the immersion cooling method with many outstanding advantages was considered for thermal management of 21700 cylindrical Li-ion battery packs. The thermal performance characteristics of the battery pack were comprehensively evaluated with varying battery arrangement configurations in the battery pack and different inlet/outlet configurations of the dielectric fluid. The comparison results demonstrate that the cross-battery arrangement configuration and configuration of one inlet on the left and two outlets in the middle and right can serve as potential candidates for an effective battery thermal management system using the immersion cooling method.

1. Introduction

Currently, the depletion of fossil fuel resources is a top concern worldwide. In addition, the problems of environmental pollution and the effects of global warming are increasing in many countries. According to many studies, Carbon dioxide (CO_2) is one of the most powerful greenhouse gases affecting global climate change. In particular, the transportation industry with vehicles using internal combustion engines is responsible for 14% of CO_2 emissions. Therefore, EVs (Electric Vehicles) with outstanding advantages of zero emissions and energy saving are the most potential solutions to the problems of environmental protection and energy security in the future. At present, LIBs (Lithium-ion batteries) are the best and most widely used power supply in EVs with outstanding advantages of high energy density, high power factor, low self-discharge rate, good stability, long cycle life, and no memory effect [1]. However, the performance characteristics and safe operation of LIBs depend on their operating temperature, with the optimal operating temperature being between 25-40 ℃ and the temperature difference within the battery pack not exceeding 5 ℃ [2]. Therefore, the research and development of a BTMS (Battery Thermal Management System) is essential to bring safety, reliability, and high performance to Lithium-ion battery applications in electric vehicles. In battery thermal management systems, immersion cooling is a potential method with many outstanding advantages, helping to enhance cooling efficiency and provide high performance to the battery pack. Therefore, in this study, the thermal performance characteristics of an immersion-cooled battery pack were considered based on the battery arrangement configurations in the battery pack and the dielectric fluid inlet/outlet configurations.

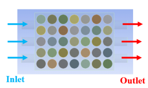
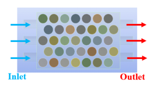
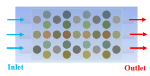
2. Numerical Method

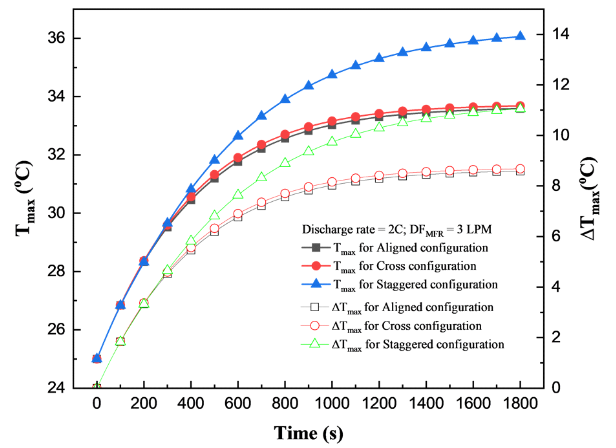
The numerical model was developed and analyzed using ANSYS Fluent software and the NTGK-MSMD model to study the thermal performance characteristics of the immersion-cooled battery pack under different discharge rates. A battery pack with a 5S7P configuration based on cylindrical 21700 battery cells is considered in this study. Mineral oil is used as a dielectric fluid for immersion cooling of battery pack. Experiments were conducted to extract U and Y parameters for the NTGK model to couple the battery heat generation process with ANSYS Fluent. The maximum temperature, temperature difference, and pressure drop of the battery module with an immersion cooling system are analyzed by considering different configurations of battery arrangement and inlet/outlet of the dielectric fluid.

3. Results and Conclusion

In the battery arrangement configurations, aligned-arranged battery cells provided effective cooling in terms of maximum temperature, temperature difference as well as relatively higher pressure drop compared to other configurations. The cross arrangement configuration shows superiority when considering the balance between thermal performance and pressure drop in the battery pack. The cooling configuration with one inlet on the left and two outlets in the middle and right combined with the cross battery arrangement configuration provided outstanding thermal performance for the dielectric fluid immersion cooled battery pack. Future work will continue to investigate the influence of flow rates and different dielectric fluid types on the thermal performance characteristics of immersion-cooled battery packs.

[Table 1] Comparison of Nusselt number and pressure drop for battery arrangement configurations

Comparison criteria	Aligned	Cross	Staggered
			
Nusselt number	296.02	275.56	152.22
Pressure Drop (Pa)	104.53	66.65	78.49



[Fig. 1] Maximum temperature and temperature difference for battery arrangement configurations.

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References

[1] Jiahao Liu, Hao Chen, Manjiang Yang, Silu Huang, Kan Wang, "Comparative study of natural ester oil and mineral oil on the applicability of the immersion cooling for a battery module", Renewable Energy 2024, 224, 120187.

[2] Qian Liu, Chen Sun, Jingshu Zhang, Qianlei Shi, Kaixuan Li, Boxu Yu, Chao Xu, Xing Ju, "The electro-thermal equalization behaviors of battery modules with immersion cooling", Applied Energy, 2023, 351, 121826.