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A Review of Microchannel Cooling in the Field of Battery Thermal Management

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Abstract

This paper introduces the application background of microchannel heat transfer technology, reviews the application and research progress of microchannel heat transfer in battery thermal management field at home and abroad, and summarizes the characteristics and existing problems of microchannel heat transfer. The analysis shows that the application of microchannel heat transfer technology in the field of battery thermal management in China has broad application prospects.

Keywords

Battery Thermal Management; Microchannel Flow; Heat Transfer; Heat Dissipation; Thermal Runaway.

1. Introduction

Under the guidance and promotion of national policies, the new energy industry is also booming. As the most popular representative of new energy vehicles, the core technology of electric vehicle mainly includes battery, battery management system, motor and control technology. Because the overall performance of the battery is greatly affected by the battery temperature, battery thermal management is an essential part of the battery management system. At present, the battery cooling methods mainly include air cooling[1, 2], phase change material cooling[3, 4], thermoelectric refrigeration[5, 6], microchannel cooling, etc. With the rapid development of the integration and high density of electric vehicle batteries, the heat production per unit volume also increases, and the conventional heat exchange methods and heat transfer media can no longer meet the conditions of electric vehicle battery use. At the same time, due to the space size limitation of the automotive battery, more concise and miniature battery management methods are in demand. Therefore, to solve the problem of high heat transfer and low space occupancy in battery thermal management, it is necessary to use microchannel heat dissipation technology with better heat transfer performance, smaller hydraulic diameter and lighter mass.

2. Microchannel Cooling Technology

With the reduction of the channel size, the importance of gas-liquid interface shear, surface tension and gravity for the effect of flow boiling heat transfer and pressure drop changes, and the law of flow boiling in microchannels has been significantly different from that of conventional channels. Due to its small structure size, the cooling working fluid can be in full contact with the thermal conductive material on the wall of the channel, which makes the working fluid temperature rise rapidly and can greatly improve the heat dissipation efficiency[7]. With the emergence and popularity of micro heat transfer devices, micro-scale heat transfer problems have become the focus of heat exchanger experiments and numerical simulation studies, which are considered to be one of the most promising technologies for high heat flux density heat dissipation due to the small size of microchannels, high heat transfer efficiency, and high-pressure resistance performance.

3. Microchannel Cooling in the Field of Battery Thermal Management Applications and Research Status

3.1 Application and Research Status in Foreign Countries

Microchannel heat transfer started from the cooling of high-density electronic devices in the 1980s and the heat transfer problem of microelectromechanical systems emerged in the 1990s. In the 1980s, Tuckerman and Pease[8] proposed the concept of microchannel heat transfer and conducted a single-phase heat transfer experiment using water as the workpiece to achieve a heat dissipation density of 790 W/cm2. In recent years, with the integration and miniaturization of automotive batteries, microchannel heat transfer has also become an important way for thermal management of electric vehicle batteries.

Shahabeddin K. Mohammadian[9] et al carried out two and three dimensional transient thermal analysis of a prismatic Li-ion to compare internal and external cooling methods for thermal management of Lithium Ion (Li-ion) battery packs. The results showed that at the same pumping power, using internal cooling not only decreases the bulk temperature inside the battery more than external cooling, but also decreases the standard deviation of the temperature field inside the battery significantly. Finally, using internal cooling decreases the intersection angle between the velocity vector and the temperature gradient which according to field synergy principle (FSP) causes to increase the convection heat transfer.

Mahesh Suresh Patil [10]et al performed the experiment and simulation on the thermal performance of water-cooled lithium-ion battery cell and pack used in electric vehicles at high discharge rate with a U-turn type microchannel cold plate and recommending an optimal cooling strategy by considering the effects of various parameters including different discharge rates, inlet coolant mass flow rates, inlet coolant temperatures, surface area coverage ratios via changing the number of cooling channels, channel hydraulic diameters via changing maximum width of cooling channels, and flow pattern layouts. The study demonstrated that optimized cooling parameters could maintain the maximum temperature and temperature non-uniformity of 50 V battery pack below 40 °C and 4 °C, respectively.

Krishnadash [11]et al. proposed a battery module thermal management method based on the integrated design of phase change materials and cooling plates in order to prevent thermal diffusion and thermal runaway in the battery module. It is shown that when the water flow rate is 3.9 L/min and counterflow is applied on two microchannel plates, the maximum temperature of the battery can be kept below 363 K, thus preventing thermal runaway of the battery module.

Monika[12] et al. designed and analyzed a multi-stage Tesla valve with forward and reverse flow structures in order to improve the temperature gradient problem inherent in conventional rectangular channels under turbulent flow conditions. The effects of parameters such as the number of channels, the distance between two consecutive valves, the coolant temperature and the density of heat flux applied to the cold plate on the Reynolds number variation were also investigated by means of numerical simulations. The results show that the backflow due to flow bifurcation and mixing mechanism in the multi-stage Tesla valve enhances the heat transfer at the cost of pressure drop.

Chakraborty[13] et al. proposed a microchannel cold plate cell cooling module sandwiched between consecutive cells. Numerical simulations were carried out by COMSOL. The effects of parameters such as number of channels, channel width, coolant flow rate, and ambient temperature were investigated in order to maintain the cell module temperature between 25°C and 40°C. The results show that the ideal operating condition of the cell module for simultaneous consideration of heat transfer and pressure drop requirements can be achieved with a coolant flow rate of 0.003 kg/s and a temperature of 25°C under the arrangement of five parallel microchannels with a width of 4 mm, and the longitudinal uniform heat transfer of the cold plate is the basis for the optimization of the cold plate design.

Jin[14] et al. designed an ultra-thin microchannel liquid-cooled plate to improve the conventional straight-through channel liquid-cooled plate design. In the conventional straight channel liquid-cooled plate design, the development of a hydrodynamic boundary layer leads to an increase in the maximum temperature and a significant increase in the temperature gradient. The ultra-thin channel liquid-cooled plate redivides the boundary layer. The discontinuity of the downstream airfoil leads to the redevelopment of the hydrodynamic boundary layer at the leading edge of the downstream section. The tilted liquid-cooled plate was able to maintain the cell surface temperature below 50°C and the flow rate less than 0.9 L/min at 1240 W. However, it is still some distance from the optimal operating temperature of the Li-ion cell.

Yiktan[15] et al. proposed a generalized finite element optimization method based on interface encryption under the condition of considering a multi-objective function for the optimization of a two-dimensional network of microchannels within a battery cooling plate. The effects of different operational constraints, such as the positioning of the heat source, the specified pump power and the applied flow rate, on the optimized design are investigated. The cross section of the microchannel is introduced as a design parameter to further improve the pressure drop of the design, and the effectiveness of the optimized design with variable cross section is verified experimentally.

3.2 Current Status of Domestic Research

The first domestic market to industrialize microchannel technology was the automotive air conditioning industry. Under the premise of lightweight and miniaturization of the structure, microchannel cooling device is an inevitable choice to meet pressure resistance, durability and system safety.

Fan[16] et al. designed a double-layered tree-like microchannel cooling plate based on the bionic structure theory and conducted an experimental study for three structural parameters of the channels (length ratio, aspect ratio, and channel volume fraction). The experimental results showed that the best maximum temperature and temperature uniformity were obtained when the channel length ratio was 0.7, the aspect ratio was close to 70/100, and the channel volume fraction was 0.06. The characteristic changes of the flow thermal characteristics parameters were also compared with those of the serpentine network for the same heat transfer area. The optimized cold plate maximum temperature and surface temperature standard deviation were reduced by 1.79% and 69.25%, respectively.

Liu[17] et al. proposed a new tree-shaped microchannel heat sink, which was used to numerically simulate and experimentally study the lithium-ion battery at 4C discharge rate. The effects of inlet width and inclined channel inclination on the maximum temperature and temperature difference during the discharge of Li-ion batteries were investigated. The results show that the tree-shaped microchannel has better heat transfer performance compared with the straight microchannel, and the optimized lithium-ion battery has a maximum temperature of 33.69°C, a temperature difference of 4.86°C, and a pressure drop loss of 17.99 Pa.

Yang[18] et al. proposed a new cellular battery thermal management system integrating a hexagonal cooling plate, bionic liquid microchannels, and phase change materials. The thermal performance of the cell module was investigated numerically using numerical simulations and a secondary equivalent circuit model. Based on the structural design of the cell module, a hexagonal single cooling plate with a fixed small channel width of 2.5 mm and a fixed number of tube joints of 2 was used. When the discharge current is 32.2 A, the inlet flow rate is 0.001 kg/s, and the ambient temperature is 298.15 K, the maximum temperature of the battery module with the internal flow scheme is 309.15 K, the temperature difference is 3.8 K, and the pressure drop is 11.95 Pa. And the BP neural network is used to estimate the suitable inlet flow rate according to the ambient temperature and working conditions. The maximum temperature and temperature difference of the battery module are stabilized at 312.0 K and 3.5 K after a period of fluctuation by the valuation of the BP model.

Deng[19] et al. established a U-tube serpentine channel cold plate and analyzed the effect of the number of cooling channels, channel layout, and coolant inlet temperature on the performance of the battery thermal management system by means of numerical simulations. The numerical simulation results show that a 5-channel arrangement in the length direction has the best cooling performance,

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and the design results in a maximum temperature reduction of 26°C compared to a 2-channel flow along the width direction. The maximum temperature of the cooling system increases as the coolant inlet temperature increases. There is an upper limit for the number of channels and inlet temperature under the condition of considering the safety and efficiency of the cooling system.

4. Conclusion

The low carbon transformation of the automotive industry is an important aspect of the carbon peak and neutrality goals, accelerating the low carbonization, energy saving and sustainable development of the automotive industry, and electric vehicles are important ways to achieve low carbon transformation. The battery thermal management of electric vehicles is an important link that restricts the development of electric vehicles. Microchannel cooling with high heat transfer and low space occupancy can better meet the demand of battery thermal management, and is also an important technology to promote the further development of battery thermal management. At present, the research on the application of microchannels in battery thermal management is mainly carried out through a combination of experiments and simulations. At the same time, the microchannel structure and microchannel layout are studied for different charging and discharging requirements. In order to achieve good heat transfer performance of battery modules, it is urgent to establish common design rules for microchannel heat exchangers for cooling batteries.

References

[1] D.K. Sharma, A. Prabhakar, A review on air cooled and air centric hybrid thermal management techniques for Li-ion battery packs in electric vehicles, Journal of Energy Storage, 41 (2021) 102885.

[2] M. Wang, S. Teng, H. Xi, Y. Li, Cooling performance optimization of air-cooled battery thermal management system, Applied Thermal Engineering, 195 (2021) 117242.

[3] J.T. Rajan, V.S. Jayapal, M.J. Krishna, K.A. Mohammed Firose, S. Vaisakh, A.K. John, A. Suryan, Analysis of Battery Thermal Management System for Electric Vehicles using 1-Tetradecanol Phase Change Material, Sustainable Energy Technologies and Assessments, 51 (2022) 101943.

[4] M. Zhi, R. Fan, X. Yang, L. Zheng, S. Yue, Q. Liu, Y. He, Recent research progress on phase change materials for thermal management of lithium-ion batteries, Journal of Energy Storage, 45 (2022) 103694.

[5] G. Liao, K. Jiang, F. Zhang, J. E, L. Liu, J. Chen, E. Leng, Thermal performance of battery thermal management system coupled with phase change material and thermoelectric elements, Journal of Energy Storage, 43 (2021) 103217.

[6] Y. Lyu, A.R.M. Siddique, S.H. Majid, M. Biglarbegian, S.A. Gadsden, S. Mahmud, Electric vehicle battery thermal management system with thermoelectric cooling, Energy Reports, 5 (2019) 822-827.

[7] Y. Pan, R. Zhao, Y. Nian, W. Cheng, Study on the flow and heat transfer characteristics of pin-fin manifold microchannel heat sink, International Journal of Heat and Mass Transfer, 183 (2022) 122052.

[8] D.B. Tuckerman, R.J.I.E.D.L. Pease, High-performance heat sinking for VLSI, 2 (1981) 126-129.

[9] S.K. Mohammadian, Y.-L. He, Y. Zhang, Internal cooling of a lithium-ion battery using electrolyte as coolant through microchannels embedded inside the electrodes, Journal of Power Sources, 293 (2015) 458-466.

[10] M.S. Patil, J.-H. Seo, S. Panchal, S.-W. Jee, M.-Y. Lee, Investigation on thermal performance of water-cooled Li-ion pouch cell and pack at high discharge rate with U-turn type microchannel cold plate, International Journal of Heat and Mass Transfer, 155 (2020) 119728.

[11] K.S. Kshetrimayum, Y.-G. Yoon, H.-R. Gye, C.-J. Lee, Preventing heat propagation and thermal runaway in electric vehicle battery modules using integrated PCM and micro-channel plate cooling system, Applied Thermal Engineering, 159 (2019) 113797.

[12] K. Monika, C. Chakraborty, S. Roy, R. Sujith, S.P. Datta, A numerical analysis on multi-stage Tesla valve based cold plate for cooling of pouch type Li-ion batteries, International Journal of Heat and Mass Transfer, 177 (2021) 121560.

[13] K. Monika, C. Chakraborty, S. Roy, S. Dinda, S.A. Singh, S.P. Datta, An improved mini-channel based liquid cooling strategy of prismatic LiFePO4 batteries for electric or hybrid vehicles, Journal of Energy Storage, 35 (2021) 102301.

[14] L.W. Jin, P.S. Lee, X.X. Kong, Y. Fan, S.K. Chou, Ultra-thin minichannel LCP for EV battery thermal management, Applied Energy, 113 (2014) 1786-1794.

[15] M.H.Y. Tan, A.R. Najafi, S.J. Pety, S.R. White, P.H. Geubelle, Multi-objective design of microvascular panels for battery cooling applications, Applied Thermal Engineering, 135 (2018) 145-157.

[16] Y. Fan, Z. Wang, T. Fu, H. Wu, Numerical investigation on lithium-ion battery thermal management utilizing a novel tree-like channel liquid cooling plate exchanger, International Journal of Heat and Mass Transfer, 183 (2022) 122143.

[17] H.-l. Liu, H.-b. Shi, H. Shen, G. Xie, The performance management of a Li-ion battery by using tree-like mini-channel heat sinks: Experimental and numerical optimization, Energy, 189 (2019) 116150.

[18] W. Yang, F. Zhou, Y. Liu, S. Xu, X. Chen, Thermal performance of honeycomb-like battery thermal management system with bionic liquid mini-channel and phase change materials for cylindrical lithium-ion battery, Applied Thermal Engineering, 188 (2021) 116649.

[19] T. Deng, G. Zhang, Y. Ran, Study on thermal management of rectangular Li-ion battery with serpentine-channel cold plate, International Journal of Heat and Mass Transfer, 125 (2018) 143-152.